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RECENT HUMAN IMPACT AND LAND USE CHANGE IN BRITAIN AND IRELAND: A POLLEN ANALYTICAL AND GEOCHEMICAL STUDY

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ABSTRACT

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RECENT HUMAN IMPACT AND LAND USE CHANGE IN BRITAIN AND IRELAND: A POLLEN ANALYTICAL AND GEOCHEMICAL STUDY

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With the exception of a few researchers, the study of the historic period to the present day has largely been neglected by palaeoecologists and existing studies often lack multiple methods of reconstruction, sufficient chronologies or detailed correlation with the documentary record. Consequently, this research seeks to investigate what effect human activity has had on the environment over the recent past by using a multi-proxy approach, trying to establish more rigorous chronological control over profiles and comparing sequences with local historical evidence.

A number of analytical techniques have been applied to four peat profiles from three ombrotrophic mires: Abbeyknockmoy (Co. Galway, Ireland), Shaw Moss (southwest Cumbria) and Tregaron (Southeast and West Bogs, Ceredigion, Wales); and three profiles from two lake deposits: Lake Gormire (Yorkshire) and Talkin Tarn (north Cumbria). Pollen analysis is used as the principal method of vegetation reconstruction at all sites, while Silicon and Titanium analyses were also undertaken at Abbeyknockmoy, Shaw Moss and Tregaron Southeast Bog. These geochemical profiles provide additional proxy records for the intensity and timing of anthropogenic activity. The chronology of each site is based on *Pinus* pollen data and AMS radiocarbon dates, with the exception of Lake Gormire where ^{210}Pb dating is used. The presence of an historic tephra isochrone at Abbeyknockmoy allows direct comparison with the documentary record and can be used to constrain the radiocarbon chronology of this profile.

The original aim of the project was to reconstruct the land use history around each of the study sites for the last 1,000 years, with special reference to monastic influences. The results indicate, however, that some profiles date from either the prehistoric or Roman periods. While this was originally beyond the scope of this research, such profiles offer insights into the debates concerning the extent of Iron Age activity prior to the Roman invasion and the fate of agricultural activity after Roman withdrawal in c. 400 AD.

The results indicate varying degrees of Iron Age farming activity at Tregaron Southeast Bog, Shaw Moss and Talkin Tarn. Agriculture increased around the Southeast Bog during the period of Roman occupation, although the centuries immediately following Roman withdrawal are characterised by a phase of woodland regeneration and declining activity at the Southeast and West Bogs. Evidence from Talkin Tarn, however, suggests the continuation of farming after the end of Roman rule. The records from Abbeyknockmoy and the Southeast and West Bogs indicate that the establishment of local Cistercian monasteries in the 12th century AD had a significant impact on the landscape, while evidence from Abbeyknockmoy and Lake Gormire suggest that the Dissolution of the monasteries in the 16th century AD did not result in widespread land abandonment and woodland regeneration. The geochemical profiles correlate well with the pollen record for human impact and both proxies demonstrate a close relationship with the documentary evidence.

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Chapter 1 – Introduction

1.0 Background and rationale

It is widely accepted that human activity has been the dominant force behind landscape change during the historic period (Behre, 1986). The majority of previous research into anthropogenic impact on the environment has tended to focus on the prehistoric period, whilst the study of rural landscapes in the historic period to the present day has largely been neglected by palaeoecologists and environmental archaeologists. Existing studies, however, often lack multiple methods of reconstruction, sufficient chronologies or detailed correlation with the documentary record. Consequently, this research seeks to investigate landscape and land use change in the historic period by using a multi-proxy approach, establishing tighter chronological controls over profiles by having more than one or two radiocarbon determinations from the recent past and comparing sequences with local historical and archaeological evidence. The aims of the project are to reconstruct land use histories for selected parts of the areas surrounding the sampling sites and thus to elucidate what effect human activity has had on the environment over the recent past. The intensity and nature of human impact is also examined. (The original time frame for this research was to be the last 1,000 years, however as is explained later in the text, some profiles actually date from the prehistoric period and first millennium AD.)

To do this, a number of analytical techniques have been applied to several ombrotrophic peat bogs and lakes in different areas of the British Isles and Ireland, therefore allowing regional comparisons of variations in landscape history to be made. The principal technique of vegetation reconstruction over time used in this study is pollen analysis. "Pollen grains from lake and mire deposits provide a continuous record of the surrounding vegetation, reflecting periods of change in land use through fluctuations in inputs of pollen of trees and herbaceous plants, including the pollen of crops" (Bell and Dark, 1998 p181). Many previous pollen diagrams from the historic period have sampling intervals of approximately 100 years (Bell and Dark, 1998) which mean that short-term episodes of human activity are unlikely to be detected. As a result, high-resolution pollen analysis with sampling intervals of between 0.5 - 4 cm have been employed in this research. This is supplemented by geochemical (silicon and titanium) analyses, which provide additional proxy records relating to the intensity and timing of anthropogenic activity (Hölzer and Hölzer, 1998).

The establishment of sufficiently detailed and reliable chronologies for profiles dating from the last 1,000 years has been identified by Oldfield *et al.* (1997) and Edwards (1998) as an area requiring further work. For example many early studies lack any form of independent dating and instead rely on inferred palynological/historical correlations (e.g. Mitchell, 1965; Moore, 1968; Moore and Chater, 1969; Oldfield, 1969) and even those profiles with radiocarbon chronologies often only have one or two dates spanning the last 1,000 years (e.g. Roberts *et al.*, 1973; Tinsley, 1976; Jelicic and O'Connell, 1992). Indeed Edwards (1999) quotes a survey carried out by Lowe and Tipping (1994) in Scotland where more than 328 pollen diagrams span the post-5,000 BP period, but only one third have dates, and many of these sites have only a single ^{14}C date in the last five millennia. Similarly, results from a survey undertaken by Moffat (1986) indicate that at this time there were 217 sites covering the last 2,500 years in Great Britain, but only 15 profiles had radiocarbon determinations for the historical period.

AMS radiocarbon chronologies have been obtained for the peat and one lake site, while limestone in the catchment of the other lake under investigation meant that ^{210}Pb dating was used in this instance. Where applicable, tephrochronologies have been used to constrain the radiometric determinations.

A major advantage of studying the historic period is that independent sources, such as historical documentation and cartographic data, can be used to calibrate and validate the palaeoenvironmental evidence (Astill, 1998). The difficulties of comparing the environmental record based on radiocarbon chronologies with historical evidence recorded in calendar years are recognised and discussed later in the text.

One problem that has become evident from this project is the fact that there are far fewer intact deposits covering the last millennium than there are sites recording environmental change during prehistory. Furthermore, suitable sites are becoming increasingly rare as peatlands are drained, cut and burned and lakes are drained and dredged. Radiocarbon chronologies for three profiles from two different mires and one lake indicate that the palaeoecological record pre-dates the original time frame under investigation by approximately 1,000 to 2,000 years. Since the results are very interesting, they are discussed in this thesis, although the Iron Age/Roman period was beyond the original scope of the project.

Two hypotheses have been established for this research:

1. The establishment of Cistercian monasteries in the 12th century AD in Britain and Ireland began a major phase of land use and landscape change in the local area.
2. The Roman invasion of Britain in the first century AD resulted in considerable land use and landscape change in the local area.

The issue of "continuity and change" (Bell and Dark, 1998) is discussed with relation to both the establishment and Dissolution of the monasteries in the 16th century AD and the Roman invasion in the 1st century AD and their subsequent withdrawal in the 5th century AD. Regional comparisons between the sites for the same historical contexts are examined. A series of questions, adapted from those of Astill (1998), are considered:

1. How sensitive is pollen analysis to relatively short phases of land use?
2. Can the deficiencies of the pollen sequences be offset by a multi-proxy approach?
3. Can the results be compared with, or refined by, documentary evidence?

1.1 Thesis structure

The literature review in Chapter 2 provides the context for this research and is divided into three sections. The first deals with the current understanding of, and recent advances in, pollen analytical theory, while the second part discusses interpretation of human impact from pollen data, and the third section reviews previous palynological investigations into human impact on the environment and land use change over the last 1,000 years. The review concentrates on England, Wales and Ireland. Scotland has been omitted because the present study has no sampling sites in this region, but surveys of both the historic and prehistoric periods can be found by a number of authors including Walker (1984), Tipping (1994) and Lowe and Tipping (1994). As mentioned earlier, the unexpected radiocarbon results mean that specific reviews of the relevant regional prehistoric and Roman palynological literature are made for the appropriate sites in Chapter 7.

Chapter 3 introduces the sites selected for investigation and details the field and laboratory methods employed in this research. The chronology of each site is examined in Chapter 4 and this covers the three techniques of AMS radiocarbon dating, tephrochronology and

^{210}Pb. The pollen analytical results are summarised in Chapter 5 and Chapter 6 details the geochemical findings for the three principal peat sites and the charcoal results from the lake deposits. Chapter 7 consists of the interpretation of results for both proxies of human impact and integrates them with the documentary record. This is followed by the discussion which features observations on intra- and inter-site comparisons, pollen diagram replicability, the comparison of the pollen analytical record with the geochemical signal and the degree of correlation between these two proxies for reconstructing past human activity with historical documentation. The final chapter details the conclusions reached from this study and indicates directions for future research. The appendices contain full pollen diagrams and additional plates.

Chapter 2 - Literature Review

2.0 Introduction

The first section of this chapter deals with the concept of pollen analysis. The aim is to introduce developments in palynological theory over time and to present the current understanding of palynological processes and models for fossil pollen reconstructions from lakes and bogs. The second section reviews the ways in which fossil pollen evidence for human impact on the environment and land use change have been interpreted from pollen diagrams, while the final section provides a synthesis of previous research into past anthropogenic activity and land use change in England, Wales and Ireland over the last millennium. Specific reviews of the relevant regional prehistoric and Roman palynological literature are presented in Chapter 7 for those sites with radiocarbon chronologies pre-dating the last 1,000 years.

2.1 Pollen analysis

Pollen analysis from stratified sequences of sediment is a well-established technique for reconstructing anthropogenic impact on the vegetation over time (West, 1971; Moore and Webb, 1978; Behre, 1981, 1986; Prentice, 1988). The theory of pollen analysis, however, requires an understanding of the modern processes involved in pollen production, dispersal, deposition and preservation in order to delimit contemporary pollen source areas and thus assess the degree of representativity of the modern pollen spectra at a particular site (Birks and Birks, 1980). Only then can pollen analysis be used as a tool for reconstructing past vegetation changes from fossil pollen assemblages (Gaillard, Hicks and Ritchie, 1994). Furthermore, the size and nature of deposits, be they lakes, mires, forest hollows etc., must be considered since the transportation, recruitment, movement and preservation of pollen grains and spores varies according to the nature of the site (Moore, Webb and Collinson, 1991). Despite the advances made in the knowledge of these processes, which will be reviewed in this chapter, precise quantification of pollen data in order to reconstruct absolute areas covered by different vegetation and land use types continues to remain elusive (Gaillard and Berglund, 1998). As a result, research is currently being undertaken using a range of techniques in an attempt to solve this problem.

2.1.1 Pollen production

Andersen (1970) defines absolute pollen productivity of trees as the number of pollen grains produced per unit crown area per time unit. Pollen production varies between species and is related to the mode of pollination and ecological conditions (West, 1971; Birks and Birks, 1980; Fægri and Iversen, 1989). Generally, wind-pollinated taxa such as the major tree species, produce more pollen than insect-pollinated taxa (Prentice, 1988).

The productivity of individual species was originally estimated by Pohl (1937) and Rempe (1937) (in Andersen, 1970), although later work by Andersen (1967, 1970, 1973) using the modern pollen content from moss polsters suggests different figures for a forested region. Andersen's (1973) results from Denmark indicate a high relative pollen productivity for *Quercus*, *Betula*, *Pinus* and *Alnus*; intermediate for *Carpinus* and *Ulmus*; and low values for *Tilia* and *Fraxinus*, using *Fagus sylvatica* as a reference species. Berglund's (1973) research adapts the figures slightly for southeastern Sweden, whilst Bradshaw (1981) found a similar pattern from moss polsters in woods in southern England, although he noted much lower pollen productivity values for *Quercus*. Tinsley and Smith (1974) also recorded a moderate level of pollen production for this species in Yorkshire.

Variations in pollen production within species may result from a number of environmental factors, including changes in temperature and rainfall (Bonny, 1980), the density of forest stands, changes in the amount of light reaching understorey shrubs and herbs, different soil types etc. (Fægri and Iversen, 1989). As a result, "pollen productivity of a particular species in relation to the vegetation as a whole is extremely complex and difficult to analyse" (West, 1971 p15).

2.1.1.1 Correction factors

These variations in productivity, which also affect transportation and deposition and thus representation in the pollen record, have long been recognised as a problem by pollen analysts. Consequently, attempts have been made to try and compensate for the over- and under-representation of certain species in pollen diagrams in comparison with their distribution in the vegetation.

Fægri and Iversen (1964) discuss a number of studies by researchers who tried to establish a ratio between a species represented in the vegetation and in a pollen diagram. Correction factors were then put forward as a means of quantifying over- or under-representation. Iversen (1947) (in Fægri and Iversen 1964,1989) suggested dividing the pollen types of northern Europe into three groups dependent upon their pollen productivity. The percentage representation of the highest producers were divided by a factor of 4, while the lowest producers were multiplied by a factor of 4. The final group includes pollen types so scarce that their inclusion or exclusion makes no difference to the pollen sum, although their presence or absence is important as an indicator species (see Figure 2.1). Criticisms of this method have been that the figures are only applicable to forest trees in Denmark and the categorisation of species into groups should also take into account "the effectivity of dispersal of pollen (i.e. *Tilia*, *Abies*), the periodicity of flowering, the ratio between male and female flowers etc." (Fægri and Iversen, 1989 p126).

Andersen (1967, 1970, 1973) established another set of correction factors based on his pollen productivity results from within forested areas. These factors are similar to those of Iversen's, although he suggested that *Quercus* production is higher and therefore should also be divided by a factor of 4, while *Fraxinus* is a lower producer resulting in a multiplication by a factor of 2. Corrected pollen diagrams give greater importance to the low pollen producing species, such as *Tilia* (see for example Eldrup Forest; Andersen, 1973 and Epping Forest; Baker, Moxey and Oxford, 1978). Oldfield (1970) and Moore, Webb and Collinson (1991) have criticised this approach for only being applicable to sites with a similar situation, i.e. a moss polster under a forest canopy with a known, small pollen source radius of approximately 20 – 30m.

2.1.1.2 Pollen production and representation models

Attempts to quantify correction factors more precisely lead to the R-value model of Davis (1963) which was derived from the ratio of pollen in a surface assemblage to the abundance of that taxon in the surrounding vegetation:

$$R = \frac{\text{Percentage of pollen of taxon in surface sample}}{\text{Percentage of taxon in surrounding vegetation}}$$

Figure 2.1 Comparison between selected correction factors and R rel-values (adapted from West, 1971)

Pohl's relative pollen production figures (Fagus : 1) (1937)		Andersen's pollen productivity sequence (1967;1970)		Bradshaw's relative pollen representation (1981)	Iversen's pollen production groups (1947)		R rel-values (Andersen, 1970)	
Alnus	17.7	Pinus, Betula, Quercus, Alnus	1:4	Betula	A. High: Pinus	divide by 4	Quercus	4.6
Pinus sylvestris	15.8	Carpinus	1:3	Pinus	Betula		Betula	4.8
Tilia cordata	13.7	Ulmus, Picea	1:2	Taxus	Alnus		Alnus	3.6
Corylus	13.7	Fagus, Abies	1:1	Alnus	Corylus		Carpinus	2.5
Betula	13.6	Tilia, Fraxinus, Acer	1*2	Quercus			Ulmus	1.7
Carpinus	7.7			Fagus	B. Moderate: Picea		Fagus	1.0
Quercus	1.6			Salix	Quercus		Tilia	0.6
Fagus	1.0	↓ Decreasing Productivity		Fraxinus	Fagus		Fraxinus	0.4
				↓ Decreasing Productivity	B2. Low: Tilia	multiply by 4		
					Hedera			
					C. Scarce: e.g. Ilex			
					Viscum			
					Vitis			

High R-values are obtained when the taxon is over-represented in the pollen spectra. Davis demonstrated with a hypothetical model that although the R-value for individual species is not constant, due to variations in species combination, it should produce the same ratios of abundance for those species (called R_{rel}-values). Davis also used these R-values to calculate fossil ratios and pollen diagrams can be corrected by multiplying the pollen curves by their R-values. This approach does, however, suffer from some limitations. The correction is based on the present day relationship between pollen rain and frequency of the species in question in the surrounding vegetation and therefore "assumes that the observed R-values can be extrapolated back in time even though the frequency and distribution of the genera concerned may have changed very substantially" (West, 1971 p12). The R-value obtained depends upon the pollen catchment area and is thus really only applicable to studies using moss polsters and small hollows within tree canopies with catchments of around 20m in radius. The R-values will also depend upon the vegetation structure and local topography which influence pollen release and transport and are therefore not comparable from site to site (Moore, Webb and Collinson, 1991). This method also fails to take account of the long distance component of pollen assemblages (Prentice, 1986).

Andersen (1970, 1973) also attempted to model productivity and representation by introducing P-values; a more comprehensive approach that used absolute pollen influx data from pollen traps and incorporated the background pollen into the estimates. This approach proposed that pollen deposition in forested areas (p) was mainly derived from trees within 20-30m of the sampling site, and that deposition was proportional to the total tree crown area (a), assuming a constant production (P). Therefore giving the equation:

1. $p = a * P$

However, if some pollen is derived from outside the sampling area, a regression term is added, where po is extra-local pollen:

1 $p = a * P + po$

Andersen then calculated P_{rel}-values from the P-values by comparing them to *Fagus*. This form of correction is applied to the pollen counts prior to being calculated into percentages (in Birks and Birks, 1980). This method can only be applied, however, to moss polsters from woodland areas that are surrounded by an open landscape (Prentice, 1986). Both of these approaches, although modified, were used by Bradshaw (1981) in forested areas, although Chen (1988) found various correction factors unsatisfactory for a forest hollow in Michigan. Hjelle (1998) estimated $R\text{-}_{rel}$ values for various herbaceous taxa from Norway, but found that the reliability of the value was compromised by low pollen productivity in certain species, the "patchiness" of distribution for some taxon and variations in the input of background pollen. Furthermore, Jackson and Wong (1994) found that 25-90% of the arboreal pollen in moss polsters from closed canopy heterogeneous forest were derived from distances greater than the 20-30m suggested by Andersen (1970; 1973). This has implications for the study of fine-scale ecological processes and forest stand dynamics. They did note, however, that moss polster assemblages may be sensitive to annual variations in pollen production and that the results may have been influenced by the high *Pinus* pollen production values recorded in that particular sampling year.

Therefore, "detailed studies of pollen productivity and representation are useful for solving particular problems of ecological interpretation associated with pollen diagrams form the same area" (Tinsley and Smith, 1974 p564) whereas the wider application of these results should be used with some caution. The limitations of these approaches have resulted in the development of more sophisticated models of pollen representation, source area delimitation and quantification, which will briefly be reviewed later in the text.

2.1.2 Pollen dispersal

Originally, pollen analysts assumed that pollen grains and spores were transported to deposition sites by thermal convection currents which carried the grains to high altitudes, spread them over wide areas and then they fell back to the Earth's surface via a largely vertical descent. This idea was termed the "pollen rain" by Von Post in as early as 1916 (Manten, 1967). This approach, however, was criticised by Tauber (1965), who emphasised the composite nature of deposition, suggesting three main components for aerial pollen transfer into lakes and bogs within closed deciduous forests. These different mechanisms were thought to have had different origins and therefore different pollen compositions.

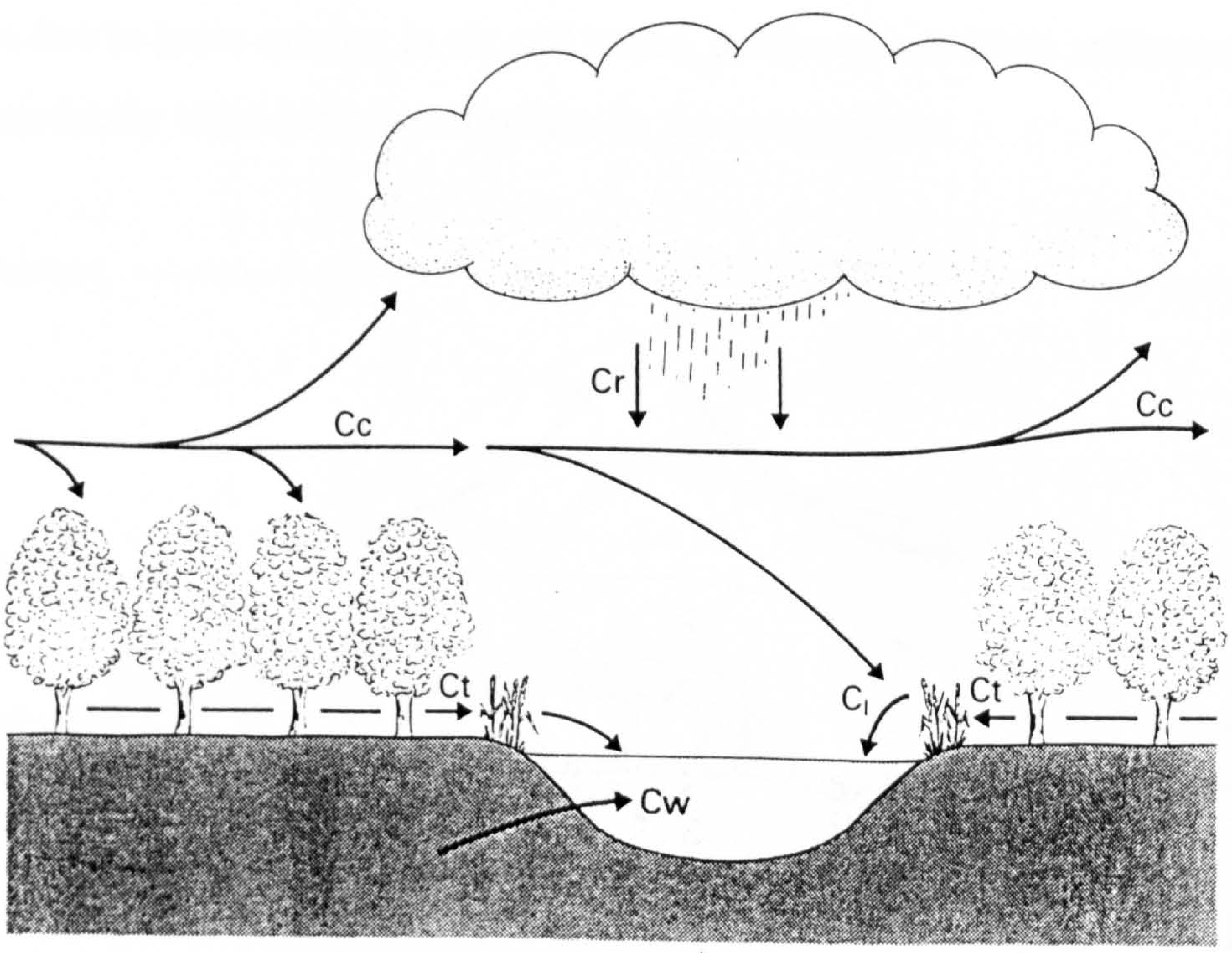
These three major components consist of: (1) the trunk space component (Ct) which contains pollen grains fallen from the tree canopy or produced by shrubs and herbs under the canopy which are carried through the trunk space laterally by air masses and largely deposited on the forest floor. When a forest borders a deposition site, this component is transported out over the surface of the lake or bog. (2) the canopy component (Cc) which is carried above the canopy of the forest and deposited on sites which are "large enough to create adequate aerodynamic interruptions in the canopy to provide downward movements in the air currents" (Moore, Webb and Collinson, 1991 p13); and (3) the rainout component (Cr) brought down by more or less vertically falling raindrops.

Moore, Webb and Collinson (1991) suggest adding two more components to Tauber's model: (4) the local or gravity component (Cl) which comprises of species growing on the surface of a bog or aquatic plants growing in lakes, and also the contribution of pollen from local overhanging trees; and (5) the secondary or inwashed component (Cw) as surface drainage water from a surrounding catchment is likely to bring in pollen that has been deposited elsewhere. This may increase the non-local pollen in the deposit and may also introduce reworked, older pollen to the contemporary assemblage causing problems of interpretation due to age mixing in the same horizon (see Figure 2.2). Tauber's model (1965) is complicated, however, by the strong filtration of pollen in the vegetation and a considerable amount of reflotation of local pollen, especially in the late Autumn (Tauber, 1967). Smaller reflotation proportions have been noted by Berglund (1973) and Bonny (1980).

To interpret pollen diagrams, it is important to know the respective share of each of the components, although this will vary with vegetational, topographic and climatic conditions, wind velocities, basin size and individual species, depending on pollen grain size and the time of year of emission (Tauber, 1965). The model predicts that the contribution of each component will vary with the size of the deposition site, for example for a small bog 100-200m in diameter, the expected percentages are 80% Ct, 10% Cc and 10% Cr, whereas for a large bog (1 km or more in diameter) the percentages become 10% Ct, 70% Cc and 20% Cr (in Birks and Birks, 1980). (These figures are based on input through aerial transport only and lakes will be discussed specifically in a following section). Further experiments were undertaken by Tauber (1977) to test the predictions and quantify the ratios. Results from a small lake in a forest on Zealand, Denmark, demonstrated approximately 60% Ct, around 35% Cc and only roughly 5% Cr for aerial deposition.

Fægri and Iversen (1989) have contested Tauber's conclusions on the trunk space component since studies have shown (such as Andersen, 1967) that there is an almost perfect correlation between the composition of pollen deposited on the forest floor and pollen produced in the canopy directly above, which would not be the case if there was a significant horizontal pollen transfer through the forest. They also bring attention to the much lower values obtained for the trunk space component than predicted in the model. Possible explanations include the fall of tree pollen immediately below the parent tree, either as individual grains or in detached catkins and anthers (Andersen, 1974) which are not moved laterally; or the trapping and filtration of pollen as suggested by Tauber (1965).

Figure 2.2 Pollen dispersal mechanisms (after Tauber, 1965; from Moore, Webb and Collinson, 1991 p12) Cc = canopy component; Cl = local component; Cr = rainout component; Ct = trunk space component; Cw = secondary component, transported by water



Fægri and Iversen (1989) suggested alternative components consisting of: (1) the gravity component, which corresponds to the Ct but is not transported horizontally because a dense undergrowth will impede lateral air movement and increase scavenging. A large part of this gravity component is redeposited, such as those pollen grains stuck to leaves and branches in the canopy or understorey that are washed down by rain; (2) the local pollen, consisting of grains which form a diffusion cloud running approximately parallel with the ground, increasing in diameter and being scavenged by the ground cover. In this instance their definition of ground cover means the upper surface of the vegetation which may range from *Sphagnum* mats to tree crowns; (3) the regional component, which is wholly airborne as pollen is caught by updraughts and carried to greater altitudes above the canopy (see Figure 2.3). The model is complicated by various aerodynamic theories, which are reviewed in Fægri and Iversen (1989).

Due to the fact that tree pollen is emitted in greater quantities than shrub and herb pollen, and that low wind velocities in the trunk space reduce the effectiveness of dispersal for pollen released near the ground, the non-arboreal pollen (NAP) is often under-represented in diagrams from forested areas. NAP does become significant, however, in areas where forests have been cleared (Tinsley and Smith, 1974), although diagrams from such open areas often have important amounts of long-distance arboreal pollen which is usually biased towards grains such as *Pinus*, rather than heavier types like *Picea* (Prentice, 1988). Despite the criticisms and problems of these models of pollen dispersal, Watts (1973) indicates that due to grain mixing in air and water, pollen counts from sediments are generally statistically valid samples of pollen in the atmosphere.

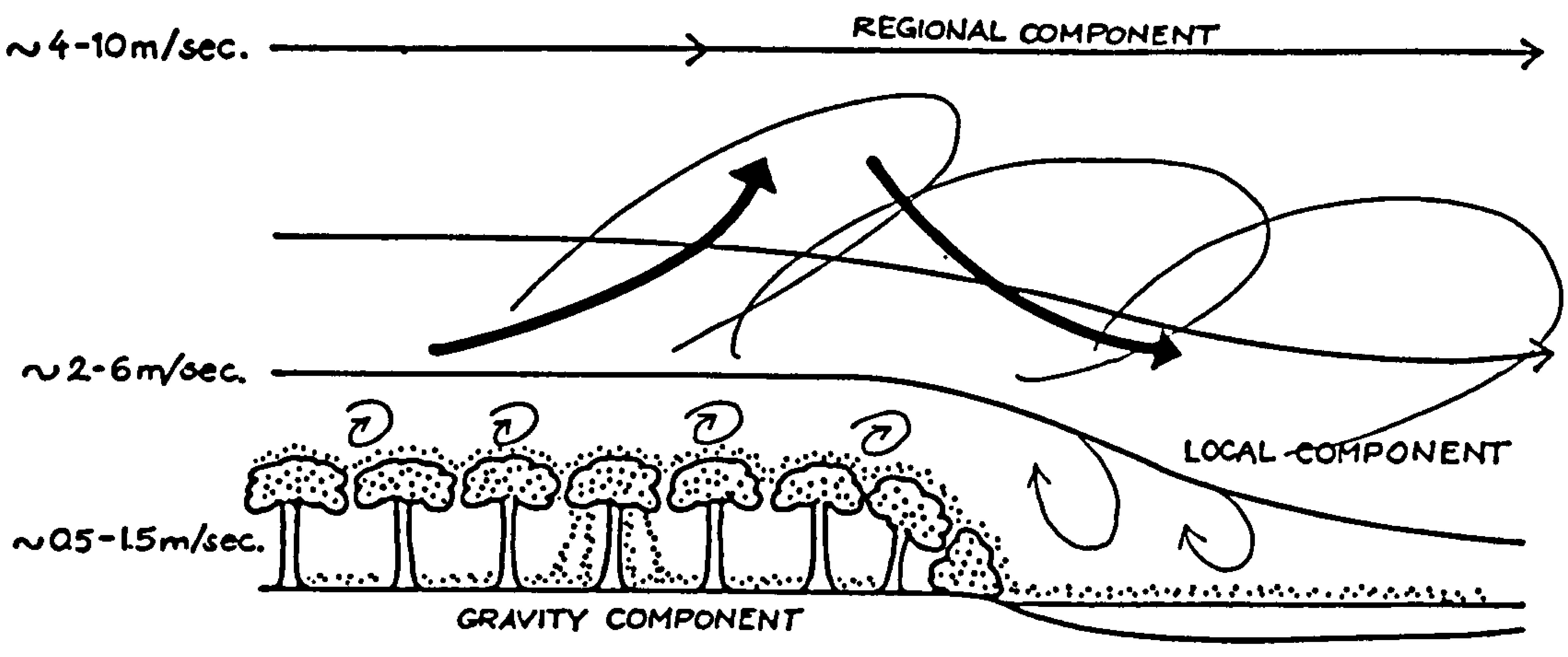


Figure 2.3 Normal wind conditions (lines) and pollen dispersal (dots) in a forest and a lake. Thin lines: horizontal wind and turbulence; heavy lines: resultant updraft (after Tauber, 1965; from Fægri and Iversen, 1989 p24)

2.1.3 Pollen deposition

Deposition in natural situations is complicated by a number of issues, such as the fact that sources involve vegetation of varying height, variations in meteorological conditions between source and sample points and filtration by the surrounding vegetation. Consequently, pollen deposition cannot be related directly to pollen production (Birks and Birks, 1980), although various statistical techniques have shown that there are some characteristic pollen assemblages which are highly correlated with particular vegetation communities (Caseldine and Gordon, 1978). Thus surface pollen studies can aid pollen diagram interpretation by determining the composition of known modern vegetation communities which can then be identified in fossil pollen records, although Bunting *et al.* (1998) found that wetland vegetation diversity was more difficult to detect from the palynological record than upland dryland taxa.

Janssen (1973) identified four scales of pollen deposition as a result of dispersal which can be used in the interpretation of fossil pollen assemblages and are summarised in Table 2.1. Examples of studies using pollen deposition at a regional and extraregional scale include Prentice's (1983) pollen maps of south and central Sweden, and Webb and McAndrews' (1976) patterns of pollen and vegetation in central North America.

For the smaller local and extralocal scales, the various modes of pollen production and transport usually result in characteristic curves of pollen deposition from individual species. These curves often decline exponentially from very high values at the source to a background value usually reached at a distance of a few hundred metres (Janssen, 1966, 1981; Edwards, 1982). "Beyond this distance the contribution of an individual tree cannot be traced in the general pollen rain" (Fægri and Iversen, 1989 p28). Surface sample studies have confirmed that the distance of deposition from a local source is short (Andersen, 1970; Janssen, 1973; Tinsley and Smith, 1974; Cundill, 1979; Behre and Kucan, 1986).

For example, Turner (1964a) demonstrated that *Pinus* pollen from a plantation at Cameron's Moss, Ayrshire, had high local values near the source, falling exponentially until relatively low regional values were obtained at a distance of around 300-500m, although the "winged" nature of *Pinus* may allow increased travel from its source than other pollen types. In terms of interpreting pollen diagrams, therefore, it may be possible to detect a small forest clearance within approximately 100m of the original forest edge, although Edwards (1982) would narrow this down to 30m (see also Caseldine, 1981; Hicks, 1998). Waller (1998) has found that in terms of fen peat, the representation of dryland taxa varies in relation to distance from the dryland edge. This poses difficulties for the reconstruction of dryland vegetation histories because poorly dispersed dryland taxa may not be registered with increasing distance into the wetland area.

Table 2.1 Categories of pollen deposition (after Janssen, 1973)

Pollen Deposition Type	Characteristics
Local deposition	High pollen values, often irregular; many species represented in assemblage; recognition of minor vegetation types.
Extralocal deposition	Pollen values slightly higher than the regional values over a few 100m from the local source; only present for a few types in specific locations.
Regional deposition	The deposition of pollen in specific proportions in an area of formation; only large vegetation types recognised.
Extraregional deposition	Deposition from outside the area of formation for the sample collection.

Tinsley and Smith (1974) calculated, with respect to pollen diagram interpretation, that tree pollen percentages greater than 50% are most likely to be an indicator of woodland within 100m of the sampling site, while percentages between 25% and 50% may be interpreted as either from a site within 100m of a woodland edge or from a site surrounded by dispersed trees. Hicks (1992 p35) concluded that "there is no direct relationship between distance and percentage presence of indicator species... because more significant is the openness of the vegetation between the activity and the pollen sampling site, i.e. easy dispersal routes". Evidence from a forest environment in Finland suggests that frequencies of indicator species >5% with an influx of >1000 grains $cm^{-2}year^{-1}$ would indicate that the activity had been practised within 200m of the sampling site (Hicks, 1992).

2.1.4 Pollen recruitment and deposition in lakes

Interpretation of fossil pollen assemblages from lakes must take into account a number of complex additional factors affecting pollen recruitment and deposition (Oldfield, 1970). Unlike raised bogs, which receive the majority of their pollen through aerial inputs, lakes receive pollen through the differential movement of grains by air and water. Whereas pollen is incorporated into peat accumulations with negligible downward mixing according to West (1971) or movements of approximately 1.5 cm in the unsaturated layer of surface peat according to the laboratory experiments of Clymo and Mackay (1987), pollen recruited to lakes is subjected to a number of limnological processes before being incorporated into the sediment (Bonny, 1978; 1980). The size, nature and morphology of both the lake and the drainage basin will also influence the efficiency of these processes.

It is therefore necessary to evaluate the relative importance of the airborne and waterborne pollen components in open lakes using pollen influx studies (West, 1973). These studies differ from percentage pollen frequencies by collecting absolute pollen frequencies in order to calculate pollen influx (defined as the numbers of grains deposited per unit area in unit time). This is because influx allows "consideration of pollen curves as independent variables rather than as interdependent percentages or proportions" (Bonny, 1972 p393), especially where changes in abundance of one or more of the high pollen producers introduce complications to the interpretation of percentage curves (Pennington, 1973), see for example Davis *et al.* (1973), Pennington (1973).

Peck (1973) calculated the pollen budget for two reservoirs in Yorkshire and found that aerial deposition accounted for 9% and 3% respectively of total pollen influx, thus meaning that the streamborne component was extremely large (91% and 97%). Consequently, interpretations from such lakes must be aware of the geography and vegetation of the catchment. Peck (1973) suggested that waterborne pollen grains have three major sources: (1) direct fall from species growing on the bankside; (2) bank erosion and (3) overland runoff. Peck's study also demonstrated the importance of floods for transporting very large quantities of pollen. Bonny (1976) found slightly smaller proportions of streamborne pollen for two lakes in the Lake District, 89% and 70%

respectively. Similarly Pennington (1979), showed that the annual influx of pollen is lower in enclosed basins than open ones, and that the streamborne component accounted for less than 50% of total pollen influx at Blelham Tarn during the forested period, whereas after forest clearance by human activity it increased to over 80%, a similar figure to that found by Bonny. The increase was attributed to deforestation, ploughing and the development of acid organic soils (mor) which kept the grains in a better state of preservation and provided a "reservoir" of pollen for the catchment streams (see also Davis *et al.*, 1984). Tauber (1977) attributed approximately 50% of pollen deposition in a lake in Denmark to the waterborne component, thus reducing the importance of the trunk space, canopy and rainout inputs.

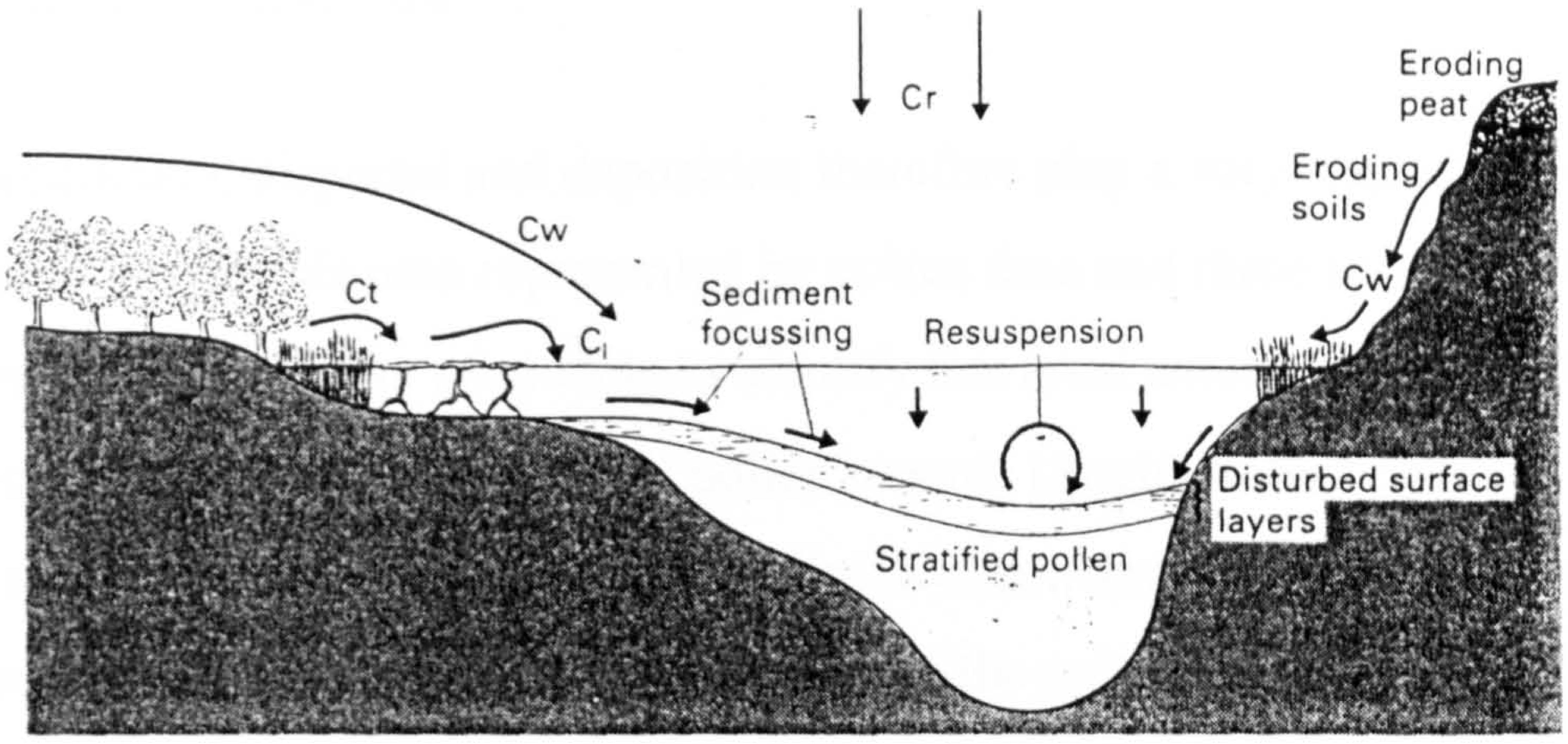
The importance of stream inputs varies considerably depending on factors such as rate of flow, the size of the watershed etc. (Jacobson and Bradshaw, 1981). In terms of understanding pollen diagrams, streams can increase the percentages of taxa which are poorly dispersed in air and can also introduce elements of extralocal pollen which are originally deposited elsewhere in the catchment and regional pollen from even greater distances (Bonny, 1978). However, it must be remembered that pollen is also lost from a lake's basin by the throughput of water (Pennington, 1973; Bonny, 1976).

Tauber (1965), Pennington (1973) and Bonny (1976) suggest that lake size may be one of the factors determining rates of pollen deposition, since decreases in deposition rates correlated with increasing size of basin. This may be a result of the exponential decrease in intensity of deposition away from a source, which in large lakes may mean that part of the water surface could lie outside the range of the local pollen trajectory and thus greater amounts of regional pollen would be expected with increasing distance from the shore (Bonny, 1976). Results from Crose Mere, near Shrewsbury, (Bonny and Allen, 1984) demonstrated that whilst most local pollen was deposited within 50m offshore, the "background" pollen was relatively uniform along the transect.

Several studies, such as Davis (1968; 1973, *et al.*, 1984) and Bonny and Allen (1984) demonstrate that there is considerable circulation of pollen within the water column before sedimentation occurs. For example, for one sampling year in Frains Lake, Michigan, 80% of pollen was redeposited and only 20% was fresh input during the flowering season (Davis, 1973). The intensity of resuspension appears generally to diminish with increasing water depth. This results in "a net transfer of sediment from shallow to deep water, since particles are likely to be transported gradually, with the assistance of gravity, from the littoral zone of persistent resuspension to the deep-water zone where settled material largely escapes further disturbances" (Bonny, 1978 p414). This is known as sediment focusing (Davis, 1973; Lehman, 1975). This process results in the uneven distribution of sediment, and thus pollen, over the basin floor (Davis, 1973) by increasing the rate and volume of annual sediment accumulation in the deepest part of the lake which will have implications for the interpretation of fossil pollen influx profiles (Davis, 1968; Davis *et al.*, 1984; Bonny and Allen, 1984). For example, variations in the rate of sedimentation across a basin may vary the rate of pollen influx by a factor of up to x3 (Davis *et al.*, 1973). Although Davis (1973) found that the resuspension process occurs without sorting the pollen within the sediment matrix. The morphology of basins can also affect sediment focusing and thus accumulation rates (Lehman, 1975). This process does appear to homogenise pollen percentages over the mud surface (Bonny and Allen, 1984).

Research by Davis and Brubaker (1973) suggests that variations in pollen settling rates in water may lead to differential deposition. Slowly sinking small or less dense pollen grains are driven by the wind and currents towards the lee side of the lake and are deposited in littoral areas, while heavier or larger grains may penetrate directly into the hypolimnion resulting in even deposition across the sediment surface. Redeposition may also cause annual stirring, which involved the uppermost 6-12 mm in the littoral zone at Frains Lake, and the top millimetre in the deeper part of the basin (Davis, 1973). The fossil pollen sample is therefore a "running average of several years' pollen deposition" (Davis, 1968 p79) which may reduce the resolution of vegetation reconstruction studies. Nichols (1967) discusses the disturbance of sediments by bioturbation as lake-bottom organisms ingest and burrow into the mud (see Figure 2.4).

Figure 2.4 The sources of pollen at a lake site and its subsequent behaviour (from Moore, Webb and Collinson, 1991 p19)



2.1.5 Pollen preservation

Pollen corrosion is caused by a number of complicated processes, involving the effect of external mechanisms, such as microbial attack, oxidation, mechanical forces and high temperatures, as well as inherent mechanisms dependent upon the individual taxa's sporopollenin content and chemical and physical composition of its wall (Havinga, 1967). It is the differential destruction of pollen grains due to corrosion that is important because it could change the composition of the fossil pollen spectra, thus biasing pollen analytical counts towards the more resistant species (Andersen, 1970).

Havinga (1967) investigated the susceptibility of different pollen types to corrosion in various sediments and found a distinct relationship between susceptibility and sporopollenin content. Species with high sporopollenin contents, such as *Lycopodium*, were more resistant to corrosion than those with lower contents, such as *Acer* and *Ulmus*. In general, preservation is a greater problem in soils than in anoxic and waterlogged peat and lake sediments (Havinga, 1967; Jacobson and Bradshaw, 1981) although Wilkinson and Huntley (1987) found large variations in the rate and concentration of pollen destruction from different cores within a small topogenous mire. Tipping (1987) noted a possible increase in pollen deterioration from "clumping" of sediments causing mechanical corrosion after the addition of *Lycopodium* tablets.

2.1.6 Pollen source areas

Pollen production, dispersal and deposition therefore play a very important role in defining the geographic area represented by pollen data and these processes have been incorporated into a variety of models to identify this areal extent. An evaluation of this area is essential for interpreting fossil pollen records (Sugita, 1993). This is known as the "pollen source area" and has been defined by Jacobson and Bradshaw (1981 p80) as "the area from which a fixed percentage (e.g. 70%) of the pollen sampled at a site is derived". Estimations of pollen source area will be influenced by the size and nature of the deposit and the individual pollen types, since the source area will vary for each taxon according to its pollen production and dispersal abilities. Taxa with heavier grains will have smaller pollen source areas (Tauber, 1965; Jackson, 1990). Fossil pollen assemblages therefore reflect the composite nature of pollen source areas. It is the ability of airborne pollen grains to travel long distances that is recognised as a critical problem in reconstructing pollen source areas and thus in interpreting fossil pollen assemblages (Jackson and Dunwiddie, 1992). Furthermore, the source area may have changed over time (Hicks, 1971; Edwards, 1979; Berglund, 1985) and if this is the result of human activity, then the scale and degree of modification also needs to be known (Oldfield, 1970), since "more distant land use activities may appear as local entities after local deforestation has occurred" (Brown, 1999 p586).

Attempts have been made to disaggregate the composite signal recorded in fossil pollen assemblages by trying to identify the relative contributions of different pollen sources at varying distances from the deposition site. These involve studies of modern pollen transport and deposition of the local, extralocal, regional and extraregional components within isolated pollen sources, for example from forested plateaux (Jackson and Smith, 1994) and offshore islands (Jackson and Dunwiddie, 1992).

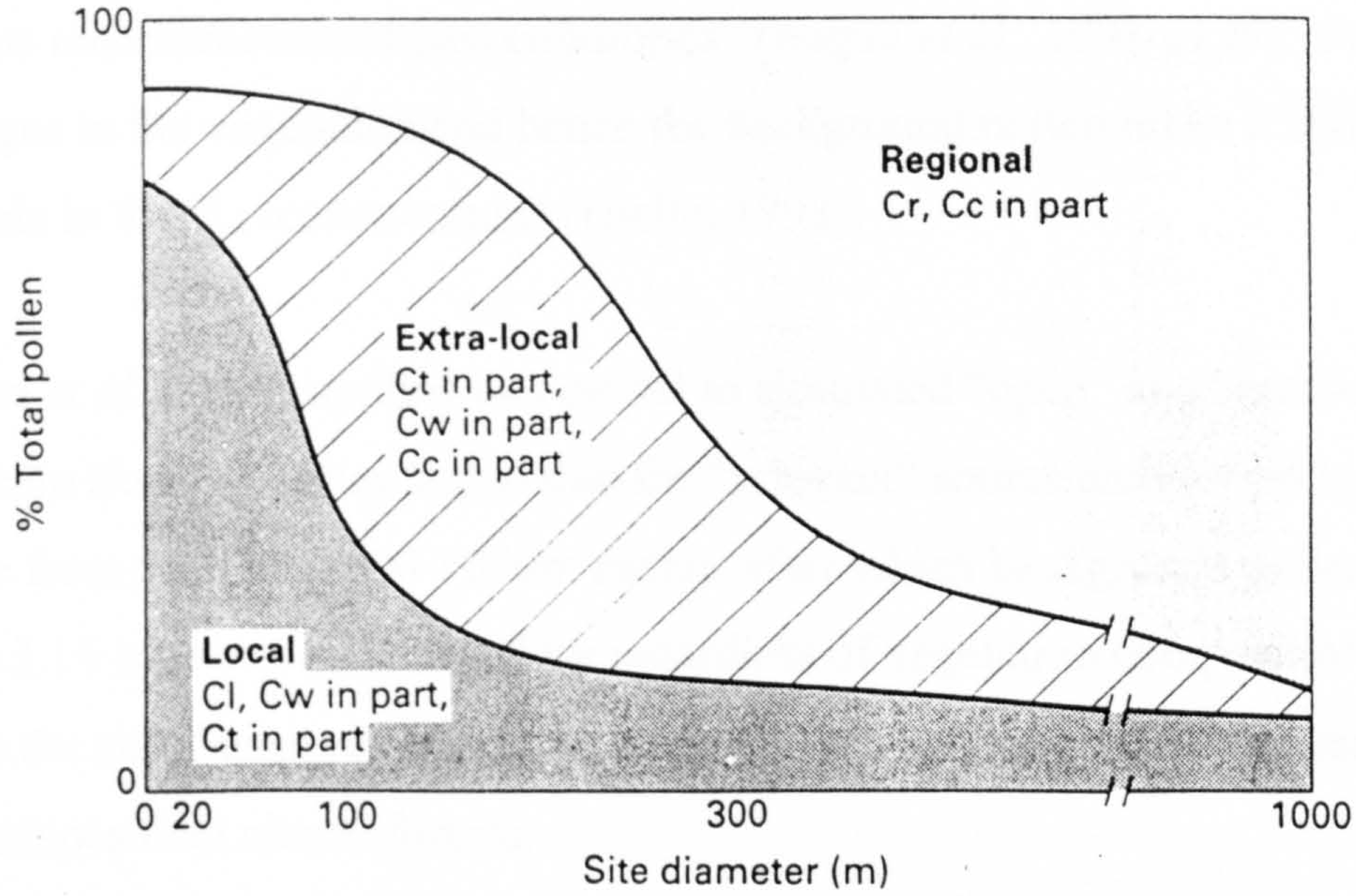
The most basic of these pollen source area models is related to the size of the deposit. Jacobson and Bradshaw (1981) constructed a model that estimates pollen source area for closed lake basins (see Figure 2.5). In this concept, local pollen is defined as originating from within 20m of the edge of the sampling basin, extralocal pollen from between 20m and several 100m and regional pollen as coming from greater distances. As the size of the deposit increases, there will be a greater proportion of extralocal and regional pollen input. Consequently, small sites are best suited to reconstructing extralocal human activity, whilst large sites demonstrate regional vegetation dynamics.

This differs from Tauber's (1965) predictions which suggest that in forested areas, the majority of pollen grains carried through the Ct will originate from within some hundred metres, pollen carried above the canopy will reflect the vegetation from several kilometres while the Cr will be even more regional. Prentice (1988 p22) argues, however, that the Ct component is probably not important in determining pollen source areas "(a) because there is a continual exchange of particles across the canopy and much of the pollen content of the trunk space is therefore derived from above and (b) there is evidence that the airstream above the canopy rapidly reaches ground level in openings in the forest, so the "overshoot" predicted by Tauber (1965) does not occur". Jackson (1990) showed that in the case of very small lakes (0.1-2.5 ha) regional pollen contributions from the canopy component were greatly underestimated by Tauber (1965) and Jacobson and Bradshaw (1981).

Parsons and Prentice (1981) considerably modified the original R-value concept by various statistical methods to produce the extended R-value (ERV) model which calculates a representation coefficient and a background pollen coefficient for long distance pollen input for each taxon. Prentice *et al.* (1987) concluded from this model that small to medium sized lakes in Sweden have source areas of 30-50 km in radius and Jackson and Kearsley (1998) applied the model to moss polsters in forested areas.

A fundamental development was Prentice's (1985; 1988) quantitative theory to numerically evaluate pollen source areas, which was used in northern midwestern North America (Prentice, 1985). This model adapts Sutton's equation for atmospheric diffusion of pollen grains to predict pollen source areas from the size of the basin, a set of depositional parameters and a set of atmospheric parameters (Jackson and Lyford, 1999). Jackson and Lyford (1999) argue that while this model is largely adequate for estimation of pollen source areas for medium to large size basins for subregional and regional vegetation reconstructions, it is more doubtful when applied to small basins and closed-canopy depositional situations. As the model assumes the deposition of pollen from a point in the centre of a deposit, Sugita (1994) argued that it is more suited to predict source areas for bogs and fens, because in these situations the horizontal movement of pollen after deposition is negligible. A selection of these models has been reviewed by Prentice (1988).

Figure 2.5 The relationship between the size of site and various sources of pollen entering it (after Jacobson and Bradshaw, 1981; from Moore, Webb and Collinson, 1991 p14)



Sugita (1993) adapted Prentice's (1985; 1988) model to predict the pollen source area for an entire closed lake surface and to take into account the limnological processes that redeposit sediment over the mud surface. His results indicate that the source area for an entire lake surface is 10-30% smaller than the source area of pollen deposited at a single point in the centre of a basin, thus suggesting that "the pollen record from a lake may provide different spatial resolution than the record from a bog of a similar radius" (Sugita, 1993). Both the Prentice and Sugita models are, however, based on regions of homogeneous vegetation which rarely occurs in natural situations (Sugita, 1998).

Consequently, Sugita (1994) combines and extends these two concepts to give the Prentice-Sugita model which provides computer simulated data of source areas from different sized closed lakes in heterogeneous forest vegetation. This model suggests that much shorter radii would be sufficient to detect local vegetation composition. For example, for a small lake with a radius of 50m, the "relevant" source area for pollen has a radius of 300-400m, and only 30-45% of pollen needs to come from within this distance, providing a constant background pollen, to adequately reflect the local vegetation situation. Sugita (1994) suggests that nothing more can be gained from increasing the radius to beyond this distance. Calcote (1995) obtained similar results for the "relevant" pollen source area from small forest hollows in North America. Sugita (1994) attributes this difference of an order of magnitude between results to variations in sampling resolution and the omission of distance-weighting to evaluate the plant abundance surrounding the study site. It must be noted, however, that "simulations cannot provide a unique reconstruction of past conditions" (Sugita *et al.*, 1998 p129). Furthermore, changes in the vegetation and hence the background pollen make it difficult to use such models in fossil reconstructions (Hjelle, 1998).

Sugita *et al.* (1999) applied this model to simulated "open" and "semi-open" landscapes in southern Sweden. They found that the "relevant" source area for pollen was predicted to come from within an 800-1000m radius, after which background pollen became constant, for a 3.14 ha lake or small hollow regardless of vegetation composition and patchiness. Thus the simulation results show larger pollen source areas for open and semi-open landscapes than closed forests.

Sugita (1998) does use this model to detect humanly induced disturbances on simulated landscapes, which may give an insight into the interpretation of fossil pollen signatures for clearance. The model predicts that for large lakes, the area of the disturbance has to be at least 10 times larger than the lake, and the disturbance must occur at, or very near, the lake margin. Alternatively, nearby clearances from small sites with restricted source areas will be strongly registered. These models are based, however, on very simple assumptions, such as equal wind directions, no topographic features and circular vegetation patches, which are not found under "real" conditions. There are also many problems with incorporating non-arboreal pollen into these models since pollen productivity of these species is generally poorly known (Sugita *et al.*, 1998).

Most pollen source area models, including those of Prentice and Sugita, assume pollen dispersal takes place under neutral atmospheric conditions, whereas Jackson and Lyford (1999) argue that the majority of pollen dispersal actually takes place under unstable atmospheric conditions, which are characterised by high turbulence, gusting and frequent changes in wind speed and direction. They suggest appropriate values for unstable atmospheric condition parameters, which cause model simulations to predict "more widespread pollen dispersal from a source than under neutral conditions" (Jackson and Lyford, 1999 p40), therefore increasing the pollen source area of a basin of given size predicted by previous models. They also suggest that more work is needed on pollen dispersal and deposition in order to more accurately model and delimit pollen source areas. This includes calibration in non-forest situations, which has received little research to date, partly because of the difficulty in quantifying the abundance of shrubs, dwarf shrubs and herbs (Prentice, 1986), using model simulations to take account of differences in source height of pollen between trees and herbs, and differences in surface roughness between forested and open landscapes (Sugita *et al.*, 1999).

2.1.7 Pollen quantification

"Quantifying the area of open land from pollen records is complex" (Sugita *et al.*, 1999 p418). A very crude measure of the relative magnitude of landscape openness and thus human impact can be obtained from the ratio of arboreal pollen (AP) to non-arboreal pollen (NAP) (Birks, 1990; Aaby, 1994). Alternatively, Birks *et al.* (1988) used correspondence analysis on fossil pollen assemblages to estimate quantitatively the varying intensities of human impact on the environment. Major developments involve preliminary attempts to precisely quantify the relationship between modern pollen values and actual areas of open land in the present day landscape, with the aim of applying this to fossil pollen sequences. Approaches include the regression of a training-set of modern pollen spectra and related landscape data in order to develop partial least square (PLS) regression models which may be able to predict landscape units such as open cultivated land and forested land within specific types of regional landscapes (Gaillard *et al.*, 1998; Broström *et al.*, 1998); and sub-recent (1800 AD) pollen data combined with historical map and soil map data which are then subjected to various multivariate statistical techniques (Odgaard and Rasmussen, 1998). There is still much scope for further research in this field of pollen analysis (Gaillard and Berglund, 1998), with reliable estimates of pollen productivity and fall speed in air of plant taxa needed for successfully modelling the percentage cover of open land from pollen values (Sugita *et al.*, 1999).

2.1.8 Pollen replicability

There is debate in the literature as to the representativity of pollen data provided by a single core (Edwards, 1983). The majority of palynological investigations rely on individual profiles from sampling sites because of the laboratory time involved in pollen analysis (Whittington *et al.*, 1991) and the financial implications of dating multiple cores, not to mention the difficulties associated with matching chronologies. Indeed, instead of replicating results, further research often involves expanding the number of sites under investigation or increasing the temporal resolution (Dumayne-Peaty and Barber, 1998).

Vegetation reconstructions from single core profiles have been justified, for example by Turner *et al.* (1989) from blanket peat in the North York Moors, Tolonen (1984) from a lake in Finland and David and Roberts (1990) from a lake in Leicestershire, all of whom found minor intra-site variability in relative pollen frequencies. On the other hand, Turner (1975), Vorren (1986) and Whittington *et al.* (1991) found that some palaeoecological data can be lost unless results are synthesised from a number of cores across the same site. In terms of inter-site variability, Barber and Twigger (1987 p241) argue that " a single pollen profile cannot be satisfactorily representative in respect of the probable spatial variation in the foci of human activity at a time of cultural and economic change". Dumayne-Peaty and Barber (1998) statistically demonstrated that broad sequences of vegetation change can be replicated, although distinct differences in pollen frequencies occurred at certain levels.

In summary, a single core may be adequate for reconstructing vegetation change over time, although some caution is needed in interpretation (Edwards, 1983), but to obtain more spatially "precise" data and to detect small scale local differences in human impact (i.e. within a few hundred metres of the site), a multiple core approach is recommended (Dumayne-Peaty and Barber, 1998).

2.2 Interpretation of human impact from pollen diagrams

During the historic period, human impact has been the most important factor influencing vegetation change (Behre, 1986). Pollen analytical investigations of recent deposits will therefore reconstruct the vegetation history of the cultural landscape. Fægri and Iversen (1989 p179) define this as "a mosaic of plant communities directly or indirectly influenced by the activities of man". Anthropogenic activity modifies the vegetation directly through plant cultivation, indirectly through animal husbandry and also through technical utilisation of resources, such as the felling of trees for timber. Each of these activities has a characteristic vegetational signal that can be identified from the palynological record (Behre, 1981; Fægri and Iversen, 1989). Increased human impact may result from the intensification of cultivation within the same area or the extension of agricultural activity to new areas, or from a combination of both these processes (Berglund, 1985).

Complications arise when several activities occur simultaneously in the same area, thus giving a composite pollen curve of impact rather than reflecting one activity clearly (Hicks, 1988). Historical documentation may then be necessary to unravel these situations (which will be discussed in a later chapter). Furthermore, small scale clearances that were abandoned and left to regenerate after only a few years or decades may not be registered in pollen diagrams due to smoothing by sediment mixing in lakes or may be missed with insufficient sampling resolutions (Jackson, 1997). Maguire (1983) identified three approaches for the interpretation of human impact on the environment from fossil pollen spectra. These approaches, with their respective advantages and limitations, will be discussed here.

2.2.1 The indicator species approach

The use of indicator species has been the most common method of interpretation of pollen diagrams in terms of identifying past land uses and changes in their intensities over time (Iversen, 1941) (in Fægri and Iversen, 1989). This approach involves the extension back in time of known present day sociological and ecological preferences of individual taxa (Birks and Birks, 1980). It therefore relies on the "principle of uniformitarianism assuming that the preferences of the taxa in question and their response to competition have not changed through time" (Maguire, 1983 p11).

Indicator species consist of cultivated plants and crops, as well as weeds and ruderals that occur in specific contexts or are highly correlated with a certain type of human activity. Interpretation needs an awareness of farming histories because weed communities are affected by cultivation practices and agricultural implements. For example in early mixed agricultural economies with long-term rotational systems, perennial weeds are favoured, whereas annual species are better suited to the later methods of continuous short-term cultivation (Fægri and Iversen, 1989). Parallel to this, technological improvements in farming tools, such as the mouldboard plough which was in general use by the Middle Ages, largely destroyed the perennial plants which were again replaced by annual species (Behre, 1981).

Behre (1981) devised a table of anthropogenic indicators often found in pollen diagrams (see Figure 2.6) but there is much overlap between some of the species. From this Veski, (1998) constructed five land use categories with their representative pollen indicator species (see Table 2.2). Despite the fact that much work has been done on pollen indicator species from a variety of countries (see for example Vuorela, 1970, 1986 and Hicks, 1988 for Finland; Kaland, 1986 and Vorren, 1986 for Norway; Rybnícková and Rybnícek, 1986 for the former Czechoslovakia; Behre and Kucan, 1986 for Germany; and Veski, 1998 for West Estonia), there is still some debate over certain pollen taxa and their corresponding land use types. Indeed, some of the most common herb species in pollen diagrams are categorised in different ways depending on the individual researcher. For example *Plantago lanceolata* is classified as a pastoral indicator by Turner (1964b), Godwin (1967a), Behre (1981), Rybníckovά and Rybnícek (1986), Scaife (1991) and Gaillard *et al.* (1994), but as an arable indicator in prehistoric times by Vorren (1986) and Groenman-van Waateringe (1986). Behre (1981) indicates that while this species is thought to represent pasture land, modern pollen analysis suggests that it is also indicative of the recolonization of fallow land in early rotational systems. Furthermore Hall (1989) found this species growing as a component of the weed understorey in fields of crops as well as in pastoral situations in a reconstructed 19th century farm in Ireland. Therefore although it is an important indicator of pastoral farming, in certain circumstances it may indirectly reflect arable agriculture as it invades previously cultivated land. Indicator species must therefore be interpreted in the light of agricultural history as well as ecological conditions for sites under investigation. Similarly, *Rumex* species also seem to be difficult to categorise (Godwin, 1967a; Pals and van Geel, 1976; Behre, 1981; Vorren, 1986; Peglar, 1993b; Makohonienko *et al.*, 1998).

Figure 2.6 Anthropogenic indicators in pollen diagrams (from Behre, 1981 p233)

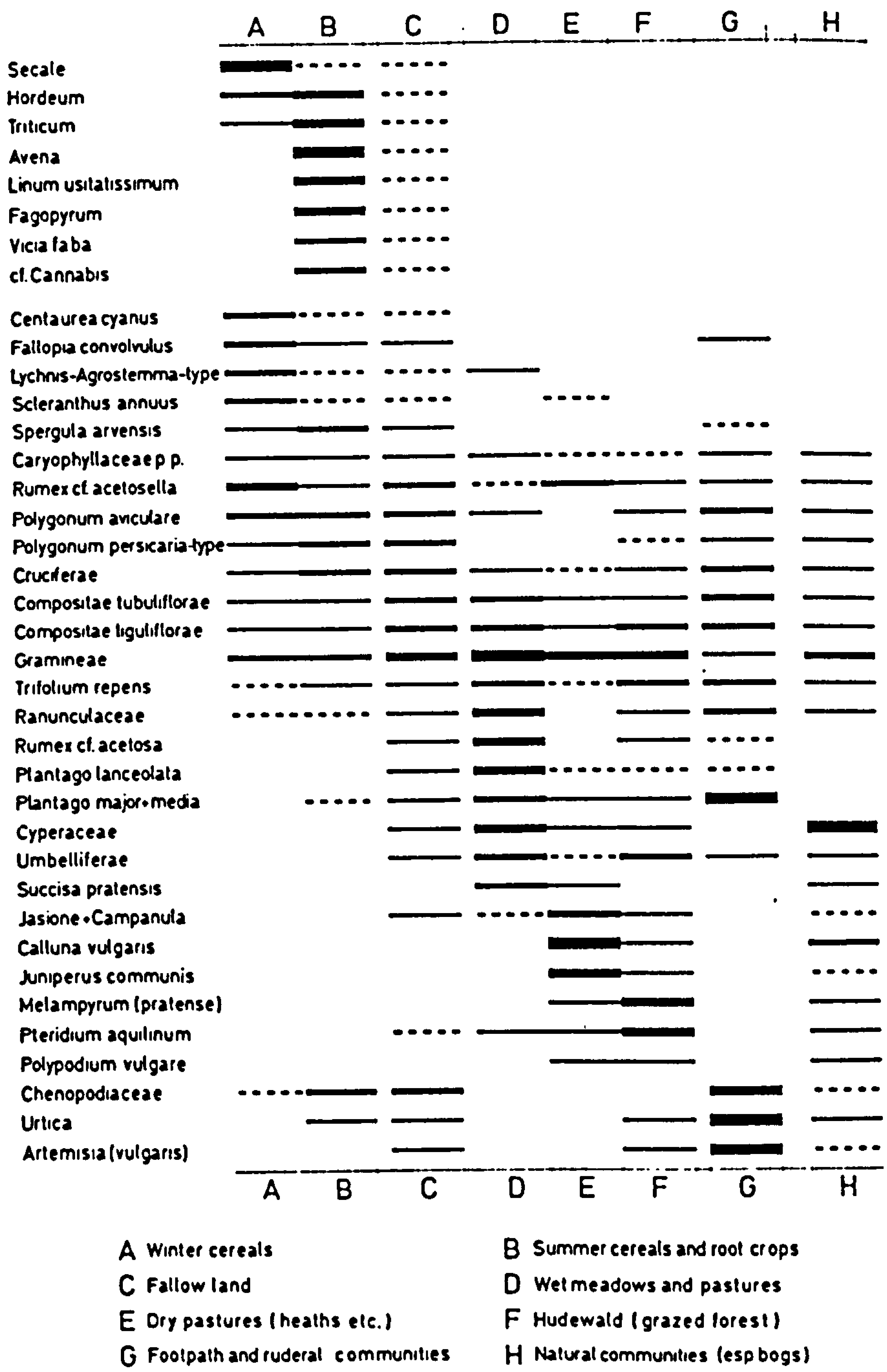


Table 2.2 Land use categories and pollen taxa (from Veski, 1998)

Land use Category	Pollen Taxa
Cultivated land	*Centaurea cyanus*, *Avena* type, *Hordeum* type, *Triticum* type, *Triticum spelta* type, *Secale cereale*, Cerealia, *Cannabis* type, *Polygonum convolvulus*
Ruderal communities	*Artemisia*, *Centaurea* spp., Chenopodiaceae, *Chamaenerion*, Cruciferae, *Plantago lanceolata*, *Plantago major/media*, *Polygonum aviculare*, *Polygonum persicaria*, *Rumex acetosa/acetosella* type, *Urtica*
Fresh meadows	*Achillea* type, *Centaurea scabiosa*, *Centaurea jacea*, *Cirsium* type, Fabaceae, *Hypericum*, *Linum catharticum*, *Potentilla* type, *Plantago maritima*, Ranunculaceae, *Ranunculus actris* type, *Ranunculus flammula* type, *Rhinanthus* type, *Succisa*, *Trifolium* type, *Valeriana*, *Vicia*
Dry pastures	*Campanula*, *Cerastium* type, *Juniperus*
Grazed forest	*Melampyrum*, *Pteridium*, *Anemone* type

Behre (1981) summarises that in terms of arable indicators, the cultivated plants themselves, such as *Secale*, *Hordeum*, *Fagopyrum* and *Cannabis*, as well as species such as *Centaurea cyanus* and *Spergula arvensis* (Godwin, 1967a, 1968; Pals and van Geel, 1976; Vorren, 1986; Scaife, 1991) are relatively reliable. Indeed, *Centaurea cyanus* is often associated with *Secale* cereal cultivation (Turner, 1986; Greig, 1991) although Pals and van Geel (1976) demonstrated that the absence of this species does not necessarily exclude the growing of rye. *Polygonum* species (Roberts *et al.*, 1973; Pals and van Geel, 1976; Turner, 1986; Vorren, 1986; Andrieu-Ponel *et al.*, 2000) and Cruciferea (Godwin, 1967a) are not quite so reliable as indicators of arable cultivation. *Urtica* (Godwin, 1967a) and Chenopodiaceae (Roberts *et al.*, 1973; Turner, 1986; Fenton-Thomas, 1992; Odgaard and Rasmussen, 1998) have also been assigned to arable indicators, but Behre (1981) and Scaife (1991) caution their use because of the complications caused by the prevalence of certain species in natural communities, especially by the coast. Thus these species, plus *Artemisia*, are broad indicators according to Behre (1981) because they may represent cultivated and fallow land and nitrogen-rich cattle pastures (Andrieu-Ponel *et al.*, 2000).

Pastoral situations may be suggested from high values of *Plantago lanceolata* (Moore, 1968; Godwin, 1975; Buckland and Edwards, 1984; Gaillard and Berglund, 1988; Hall, 1990b; Andrieu-Ponel *et al.*, 2000), *Plantago major*, *Rumex acetosa*, *Gramineae*, *Ranunculus* (Behre, 1981; Hall, 1990b) and *Pteridium* (Oldfield, 1963). Recent work by Groenman-van Waateringe (1993) demonstrates, however, that after a clearance episode or in open habitats, there is an increase of flowering in grass species, but as grazing and trampling continue and intensify, Poaceae pollen production actually falls, which may be represented by increasing AP values and declining grass frequencies in a pollen diagram. Reductions in grazing pressure are then followed by increases in grass flowering and pollen production.

The most obvious limitation of this approach is that few plants have very narrow ecological preferences or tolerances, thus causing some confusion in terms of their indicative ability (c.f. Peglar, 1993b). Classification into representatives of single land use types therefore becomes difficult. Secondly, those species which do have restricted ecological niches, such as the cereals, tend to have poor pollen production and dispersal causing difficulties in interpretation (Maguire, 1983; Sergerström. 1991). For example, Hall (1994) found that modern pollen samples collected from beneath the crop itself registered only 9-22% cereal pollen, and values decreased with distance from the cultivated field so that 15m away from the crop edge, approximately 5 cereal grains were counted in a pollen sum of 500. Whilst *Secale* has high productivity and good dispersal ability making it one of the most reliable cultivation indicators, *Triticum*, *Hordeum* and *Avena* pollen is often trapped in the hulls and hence poorly dispersed (Behre, 1981). Although Vuorela (1973) found that *Hordeum* and *Avena* dispersal increased dramatically during the harvesting and thrashing period. Furthermore, Hall (1988) found that harvesting processes where cereals are hulled on site, such as by combine harvester, contribute greatly to pollen dispersal and concentration. This has implications for interpreting arable agriculture over the last 200 years when harvesting techniques were becoming mechanised (Hall, 1988).

Another problem arises from the fact that the pollen of many good anthropogenic indicators cannot be identified to species level and thus cannot be distinguished from species within the same family that are not associated with human activity (Jones, 1988). For example, some cereals, crucifers and legumes are not easily differentiated (Behre, 1981). There has been much work, however, on the identification of *Cannabis* (cultivated for hemp) as distinct from *Humulus* (grown for hops and occurs naturally in the vegetation) because of their implications for elucidating agricultural and economic histories (Whittington and Gordon, 1987; Whittington and Edwards, 1989). Sergerström (1991) suggests that when large amounts of *Cannabis* type pollen (including *C. sativa* and *H. lupulus*) are found in association with other agricultural indicator pollen, it is most likely that hemp was cultivated. Conversely, when *Cannabis* type pollen occurs without any other human activity indicators, it is most likely to represent wild hop.

In addition, complications stem from the knowledge that many of these agricultural indicators were present during previous glacial and inter-glacial episodes (Godwin, 1975) before farming reached this country, rather than being introduced contemporaneously with new types of land use (Fægri and Iversen, 1989). Reliance upon the uniformitarianism principle is another limitation since the niche of a particular species may have changed over time and space (Birks, 1990). Finally, it is difficult to estimate the area of land under different usages from this approach (Birks and Birks, 1980; Gaillard *et al.*, 1992). Despite the limitations of anthropogenic indicator species "it does offer a relatively simple solution to a complex problem" (Maguire, 1983 p12).

2.2.2 The comparative approach

This approach involves the "characterisation of a range of modern vegetation types by means of contemporary pollen spectra (usually from surface samples), and then the comparison of these spectra with fossil pollen spectra" (Birks and Birks, 1980 p237). If the two assemblages are similar, then it can be concluded that they were produced by similar vegetation. Again this approach relies on the uniformitarianism principle (Maguire, 1983). However, very few attempts have been made at reconstructing past vegetation communities from modern pollen spectra for humanly induced landscape units such as arable land, pasture land, grazed forests, meadows etc. in northwest Europe (Gaillard *et al.*, 1992). This has largely been due to the lack of modern analogues for past agrarian systems and their resulting cultural landscapes (Aaby, 1994).

Berglund *et al.* (1986) suggested establishing modern local pollen/vegetation/land use relationships and then using multivariate statistical techniques to compare them to fossil assemblages for the different aspects of the cultural landscape. This work was undertaken in southern Sweden where traditional management practices for some areas can be traced back to the 18^{th} century, the Medieval period and even the Middle Ages. The study was then extended by Gaillard *et al.* (1992) by increasing the number of sampling sites and including more land use categories. Further research from this ongoing project includes datasets from meadows and cultivated land (Gaillard *et al.*, 1994). Their results suggest that woodland, grazing, mowing and cultivation produce statistically significant distinctive pollen assemblages, although separating grazing and mowing can prove difficult. Most of the pollen taxa strongly associated with mowing, grazing and cultivation (such as *Plantago lanceolata, Rhinanthus, Filipendula, Gramineae, Betula, Corylus* and Cerealia) are not strongly associated with soil variables and are therefore good land use indicators. Those taxa strongly associated with certain soil characteristics should be used cautiously as land use indicators (such as *Juniperus* and *Cirsium*). Subsequent numerical analysis by Broström *et al.* (1998) indicates that Gramineae, Cerealia, *Filipendula* and *Salix* are positively correlated to the landscape unit "cultivated" in data-sets from southern Sweden. They explain that *Salix*, as a light demanding species occurs in borders between forested land and fields, and that *Salix* and *Filipendula* are also common in the ditches between cultivated land.

A comparison between reconstructions based on the indicator species and comparative approaches demonstrates that although there is a general agreement, the comparative method offers additional and more precise information about the predominant land use types and also gives details on soil conditions. Although small lakes and bogs recording extra-local pollen were used, the most reliable comparative reconstructions are still based on the smallest deposits registering local pollen (Gaillard *et al.*, 1994). This approach was found to be unsuitable, however, for Neolithic or Bronze Age periods and for contemporary farming from 1850AD onwards because of the lack of modern analogues.

Subsequent studies have added further datasets from Poland which complement the results from southern Sweden, although there are differences from the mowed sites (Makohonienko *et al.*, 1998). Both suggest that *Plantago lanceolata* is an indication of mowing rather than grazing. A similar approach has been undertaken for boreal regions in Finland (Hicks, 1988; Hicks and Birks, 1996), although human impact here is on a much smaller scale. This analysis had difficulties in separating taxa of tracks and farmyards, and to a lesser extent certain fields and farmyards. Hicks (1985) also used this approach to establish a key for interpreting pollen communities indicative of human interference, although it is only applicable to spruce-dominated forest regions. Hall (1989) studied the modern pollen rain from a reconstructed 19^{th} century farm in Northern Ireland. Samples were collected from 3 transects across the farm which incorporated all the major crop and hedge types. She suggested that, in a pollen sum of 500 grains, frequencies of 1 to 10% of Cerealia, *Linum*, and weeds such as *Spergula*, *Bidens* type, *Plantago*, *Rumex*, *Urtica* and *Ranunculus*, along with the hedge species of *Crateagus*, *Prunus spinosa* and *Fraxinus* in a fossil deposit, would be indicative of a mixed enclosed 19th century agricultural system.

In spite of the encouraging results from this method, there are some limitations. For example "when comparing fossil and present day spectra the, not always tenable, assumption is made that the pollen source area of the collecting sites is similar" (Maguire, 1983 p12). Complications also occur when modern samples are taken from moss cushions and surface litters, but fossil profiles are recovered from lakes or bogs (Gaillard *et al.*, 1994). Modern samples may also miss some vegetation types that are no longer as prominent today (Fægri and Iversen, 1989). Furthermore, different vegetation types in varying relative proportions within the pollen source area of sampling sites might, at the extra-local level, produce similar pollen assemblages (Gaillard *et al.*, 1994). The fossil pollen reconstructions are also only applicable in the same geographical area as the modern pollen dataset, or to areas with a very similar agricultural history.

Finally, it may be very difficult to find modern analogues of "traditional" vegetation types because of the agricultural and environmental changes that have occurred during the 20th century which have dramatically altered the majority of the cultural landscape of Europe (Emanuelsson *et al.*, 1998). Factors such as the mechanisation of farming and the use of fertilisers, pesticides and herbicides have altered, perhaps selectively, the productivity, abundance and composition of various plant and weed assemblages (Maguire, 1983). This will also affect the indicator species approach. Despite these criticisms, according to Birks and Birks (1980) "the comparative approach is probably the soundest method currently available for the reconstruction of past communities".

Fægri and Iversen (1989) have noted that the distance between the two methods is narrowing. The indicator species approach is evolving to recognise groups of indicators rather than specific species (c.f. Peglar (1993a; 1993b) who used a discriminant function analysis to characterise "recurrent groups" of distinctive vegetation types over time) and at the same time the comparative approach is pinpointing those pollen types which are more indicative of a certain type of human activity (c.f. Birks (1991) and the pollen-indicator values derived by weighted averaging). Consequently, researchers should perhaps be aiming to utilise a combination of these approaches, which would be even more effective if combined with a multiproxy or multidisciplinary approach (Núnéz and Vuorela, 1978; Edwards, 1979; Maguire, 1983; Berglund, 1985).

2.2.3 The statistical approach

This approach is an extension of the comparative concept (Maguire, 1983) which attempts to quantify the extent and relationship of arable and pastoral activities within a farming economy. It is based on the ratio of arable to pastoral pollen indicators. One of the first and most simple attempts was that of Steckhan (1961) (in Behre, 1981) who used the ratio of Cerealia to *Plantago lanceolata*. A more sophisticated concept was the arable/pastoral index of Turner (1964b) which expressed the number of *Plantago* grains as a percentage of the total number of *Plantago*, Compositae, cereal, Cruciferea, *Artemisia* and Chenopodiaceae grains. Her results suggest that values below 15% indicate arable regions and above 50% pastoral regions, with the values in between representing mixed agriculture. This index was modified by Turner (in Roberts *et al.*, 1973) by calculating the sum of the pollen frequencies of taxa which were most likely to have grown in pastoral situations as a percentage of these pastoral taxa plus those most probably associated with crop cultivation. The pastoral category included *Plantago lanceolata*, *Artemisia* and Ranunculaceae; whilst the arable indicators consisted of *Triticum*, Compositae, Chenopodiaceae, Cruciferea, *Vicia*, *Polygonum*, *Centaurea cyanus*, *Knautia*, *Trifolium* and Centaurium. This calculation was used by Donaldson and Turner (1977) and is comparable with the arable/pastoral index used by Godwin (1968) at Old Buckenham Mere. Alternatively, Riezebos and Slotboom (1978) suggested a ratio using Cerealia, *Fagopyrum*, *Rumex*, *Centaurea*, *Artemisia* and *Linum* as arable indicators and *Gramineae*, *Plantago lanceolata* and Papilionaceae as pastoral indicators. Maguire *et al.* (1983) calculated several of these different ratios on the same pollen diagram and although the results were broadly in agreement, there were some significant contrasts. It was noticed that the ratios are likely to be unreliable if the indicator species used in the calculation are not present, or are only present in very low frequencies in the fossil pollen profile.

The difficulty of establishing such an index, however, is demonstrated by the use of *Rumex*. For example, Roberts *et al.* (1973) use this species as a pastoral indicator whereas Riezebos and Slotboom (1978) use it as an arable indicator. Again this demonstrates the confusion and uncertainty which exists between researchers and calls into question the validity of such ratios. Therefore there is a need for more modern empirical research into this area (Greig, 1998). Since these ratios are also created and calibrated using modern pollen data, the problems associated with the comparison of contemporary and fossil pollen spectra will apply. "Empirical pollen analytical data are not, therefore, translatable into exact numerical quantities" (Behre, 1981 p239). Furthermore, such rigid indices are not comparable between different regions, since the frequency of the significant indicator species will also vary with the geographical location.

Identifying human impact from pollen diagrams is therefore possible, but establishing more precise details of the type, intensity and duration of the various activities is more complicated and requires a knowledge of ecological preferences and tolerances of individual species and whole assemblages, as well as local soil conditions and agricultural histories. Thus projects such as the one in southern Sweden (Berglund *et al.*, 1986; Gaillard *et al.*, 1992, 1994) are very important for this, although more research is needed to link various land use types with their characteristic vegetation and pollen assemblages.

2.3 Previous research into human impact over the last millennium

A number of reviews demonstrate the vast range of literature concerning human impact during the Holocene in Britain, Ireland and indeed worldwide (e.g. Turner, 1970; Edwards, 1985; Edwards and MacDonald, 1991; Behre and Jacomet, 1991). It is beyond the original aims of this study, however, to comment on anthropogenic activity in prehistoric times and thus the present review concentrates on the historic period. Since the original objective of this research was to reconstruct human activity over the last millennium, particular reference is made to detailed palynological investigations correlated to the documentary record dating from the Norman Conquest of 1066 to the present day.

Discussions of pollen analytical evidence for human impact in the Roman and Anglo-Saxon periods can be found in the works of a number of authors (e.g. Hicks, 1971; Tinsley, 1976, Turner, 1979; Barber, 1981; Peglar, Fritz and Birks, 1989; Dumayne, 1992; Barber, Dumayne and Stoneman, 1993; Whittington and Edwards, 1993, Dumayne and Barber, 1994; Mackay and Tallis, 1994; Tipping, 1995; McCarthy, 1995; Dark and Dark, 1997; Manning, Birley and Tipping, 1997; Dumayne-Peaty, 1998a,1998b; Dark, 2000). In the light of the radiocarbon dates from the Tregaron raised mire complex, Shaw Moss and Talkin Tarn (TAL2), which pre-date the original time frame of the last millennium (see

Chapter 4), a more detailed discussion of prehistoric and Roman impact will be presented for these individual regions in Chapter 7.

This section focuses on work undertaken in England, Wales and Ireland, since the current research is also based in these countries. This commentary is not exhaustive but aims to introduce the significant historical events and agricultural processes, coupled with their resulting pollen analytical signatures, which have formed the cultural landscape of today. This review highlights the diversity of pollen records in terms of geographical location and local histories, and identifies areas of conflict within the literature.

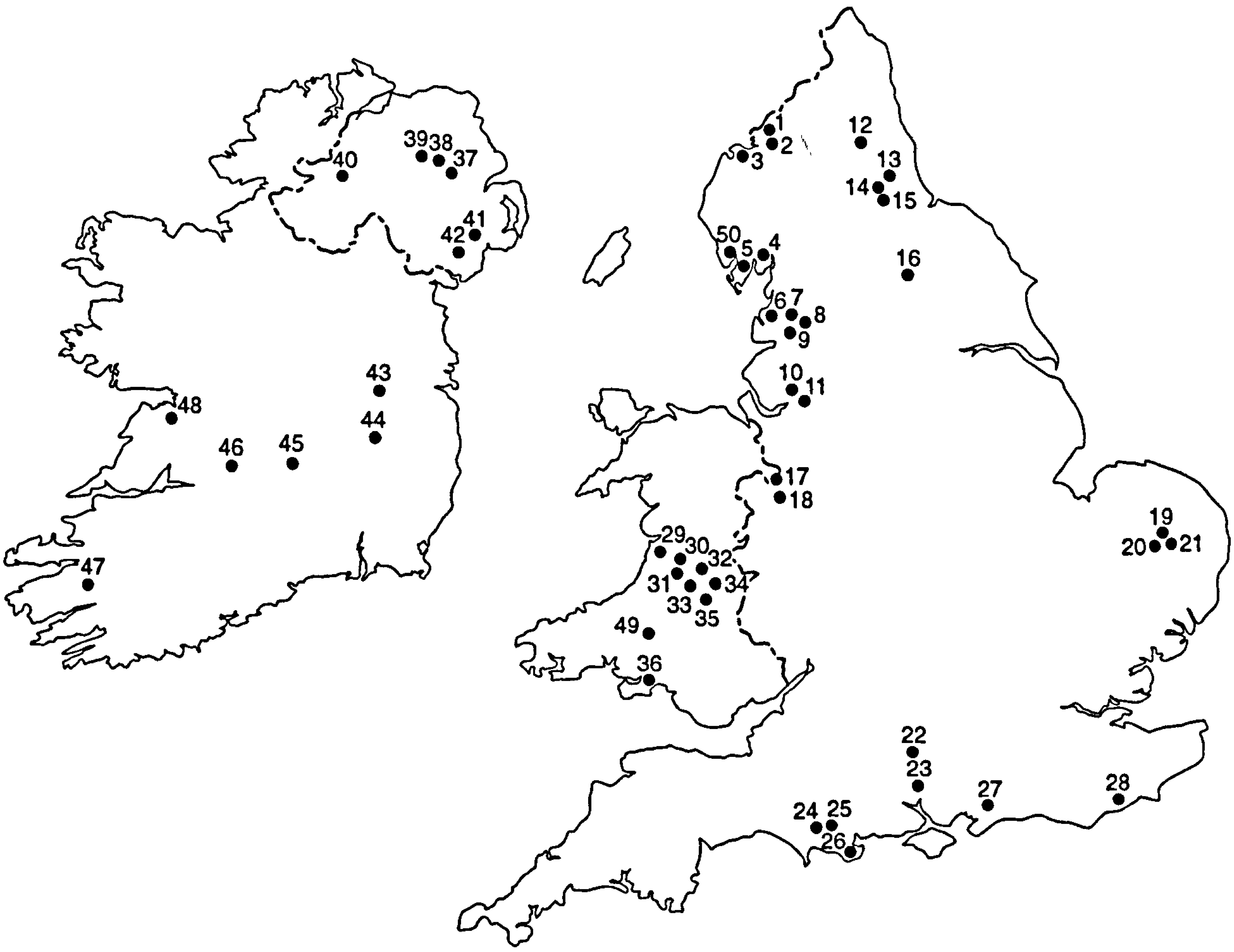
2.3.1 Northwest England

A number of sites suggest a brief period of forest regeneration at the end of the 11th century as many areas were laid waste, such as Ellerside Moss and Urswick Tarn in the southeastern Lake District (Oldfield, 1963; 1969), White Moss in the Duddon Estuary in south Cumbria (Wimble, 1986; Wimble *et al.*, 2000) and Holcroft and Lindow Mosses in southern Lancashire and Cheshire respectively (Birks, 1965). (See Figure 2.7 for location of sites mentioned in the text). This increase in arboreal pollen has often been attributed to the "Harrying of the north", although Wells, Huckerby and Hall (1997 p164) argue that "the extent and nature of this historical episode is a source of controversy and it seems unlikely to have had as disastrous an effect on population as to produce woodland regeneration signals in pollen spectra". Pollen diagrams from Bolton Fell Moss in northern Cumbria (Barber, 1981; Dumayne-Peaty and Barber, 1998) would appear to support this view as there is evidence for the survival of agriculture during this period. It may, however, result from the fact that Cumberland was not under Norman rule at this time. Similarly, cereal pollen is also registered at Extwistle Moor in the Pennines around 980-1350 AD (Bartley and Chambers, 1992). The pollen analytical data for this event therefore needs to be investigated in more detail in northern England.

The establishment of Furness Abbey in 1127 AD in the Lake District led to a period of clearance and mainly pastoral farming at Ellerside Moss, Urswick Tarn and White Moss, which peaked in the 14th and 15th centuries under the Cistercian influence. Although higher values and a greater diversity of arable indicators were also recorded at White Moss around this period. This record differs from the nearby sequence of Deer Dyke Moss (Oldfield, 1963; 1969), which demonstrates little monastic activity at this time, possibly as a result of its isolated situation. Holcroft and Lindow Mosses also record clearance phases concurrent with the establishment of Abbeys, although monastic activity here was predominantly arable in nature.

Despite monastic activity in the area of Bolton Fell Moss and neighbouring Walton Moss (Dumayne, 1992; Dumayne-Peaty and Barber, 1998), such as Holm Cultram and Lanercost Priory, the period between 1190-1380AD records a small amount of pastoral activity and extensive woodland regeneration. This was probably because "the general character of the period was one of war, pestilence and famine, particularly during the 1300's" (Barber, 1981 p116) with Border raids by the Scots and the Black Death in 1348-50 AD. Similarly, the pollen records from the Forest of Bowland in the central Pennines (Mackay and Tallis, 1994) and Extwistle Moor show woodland regeneration with increasing AP values during the 14th century, again attributed to falling population levels due to crop failures, poor harvests, cattle murrain and the plague. Alternatively, Glasson Moss in the Solway Plain (Dumayne, 1992) experienced clearance between 1220-1445 AD because it was not subject to the Border raids until 1445-1630 AD when forest regeneration occurred. A more general landscape history of the Central Rossendale area in Lancashire demonstrates that the woodland was gradually cleared between the 13th and the beginning of the 16th centuries and was replaced by a predominantly pastoral agricultural system by 1507 AD (Tallis and McGuire, 1972).

Agricultural activity, involving the beginning of hemp cultivation, and resumed forest clearance occurred at Bolton Fell Moss between 1380-1640 AD, although the Border raids continued. Improved pasture gradually increased on Extwistle Moor between 1420-1650 AD. The Dissolution of the Monasteries in the 1530's AD produced a phase of extended clearance and a decline in tree pollen frequencies in the southeastern Lake District and south Cumbria as woodland and waste were reclaimed for agricultural purposes and common land was gradually enclosed. Here, mixed farming continued until approximately 1700 AD and hemp cultivation is recorded at Deer Dyke Moss during this period. Similarly, increased arable activity and the cultivation of hemp are also registered at Holcroft and Lindow Mosses and Extwistle Moor during the Tudor period. Evidence from Fenton Cottage in Over Wyre, Lancashire, indicates a predominance of arable farming from 1280-1700 AD (Wells, Huckerby and Hall, 1997).



1 Bolton Fell Moss
2 Walton Moss
3 Glasson Moss
4 Ellerside Moss and Deer Dyke Moss
5 Urswick Tarn
6 Fenton Cottage
7 Forest of Bowland
8 Central Rossendale
9 Extwistle Moor
10 Holcroft Moss
11 Lindow Moss
12 Fozy Moss
13 Hallowell Moss
14 Steward Shield Moss
15 Bollihope
16 North Gill Wood
17 Crose Mere
18 Berth Pool
19 Old Buckenham Mere
20 Quidenham Mere
21 Diss Mere
22 Snelsmore
23 Winchester
24 Okers
25 Rimsmoor
26 Kingswood
27 Amberley
28 Battle Abbey Estates
29 Borth Bog
30 Plynlimmon
31 Blaen yr Esgair
32 Elan Valley
33 Tregaron Bog
34 Llyn Gynon
35 Towy Valley
36 Crymlyn Bog
37 Sluggan Bog
38 Ballyscullion East
39 Fallahogy Bog
40 Lough Catherine
41 Lough Henney
42 Long Lough
43 Carbury Bog
44 Leigh
45 Littleton Bog
46 Shower
47 Derrycunihy Wood
48 Lios Lairthín Mór
49 Talley Lakes
50 White Moss

Figure 2.7 Location of pollen analytical sites mentioned in the text

Agricultural indicators demonstrate an increase in mixed farming from 1640-1785 AD and further declines in forest cover at Bolton Fell Moss, which is comparable to the intensification of clearance at Glasson Moss from 1630 AD, although Walton Moss records another regeneration episode at this time. The Forest of Bowland pollen sequence indicates an additional peak in AP during the climatic deterioration of the "Little Ice Age", c.1550-1730 AD, as failing harvests, famine and plague again decimated the population in this area.

Clearance generally continues during the 18th century. The end of this century and the beginning of the 19th century are often characterised by a sharp peak in agricultural indicators in pollen diagrams. This is generally attributed to the plough-up campaigns of the Napoleonic Wars which resulted in the intensification of farming, even in marginal areas. This phase is registered in pollen sequences from Bolton Fell Moss, Walton Moss, Deer Dyke Moss, Urswick Tarn, the Forest of Bowland and Extwistle Moor. The 19th century is also noted for the decline in *Artemisia* pollen, such as at Deer Dyke Moss, Urswick Tarn, Bolton Fell Moss, Holcroft Moss and Lindow Moss. This feature has been attributed to the introduction of better farming techniques, such as deep ploughing (Oldfield, 1969). Deer Dyke Moss, Bolton Fell Moss, Holcroft Moss and Lindow Moss demonstrate the disappearance of *Cannabis* pollen from the record due to cheaper imports from abroad (Barber, 1981). A decline in alder around this time is also common, such as at the Forest of Bowland, Deer Dyke Moss, Holcroft Moss, Lindow Moss, Fenton Cottage and White Moss, and is probably the result of drainage in order to reclaim waterlogged land for agriculture. This is, however, much later than the alder decline at Bolton Fell Moss which is dated to c.1350 AD (Dumayne-Peaty and Barber, 1998).

The late 18th and 19th centuries are often characterised by a rise in pine pollen due to the planting of this species on estates, parklands and plantations. The Forest of Bowland and Fenton Cottage profiles demonstrate the agricultural depression of the 19th century by increasing AP values and declines in Cereal and *Plantago* pollen.

2.3.2 Northeast England

Documentary and pollen evidence from the Nidderdale region of the east-central Pennines in North Yorkshire suggests that this area did suffer heavily during the "harrying of the north" in the 11th century with the regeneration of scrubby woodland (Tinsley, 1976).

According to the pollen data from North Gill Wood, this was followed by renewed forest clearance and the growth of mixed farming due to monastic activity from the Cistercian Abbeys of Byland and Fountains in the 12th and 13th centuries. Similarly, Hallowell Moss, outside of Durham city, was given to the monks in the mid-13th to mid-15th centuries and the pollen record suggests managed woodland with some mixed farming (Donaldson and Turner, 1977).

The records from Fozy Moss (Dumayne, 1992) and Steward Shield Meadows and Bollihope in Weardale, west of Durham (Roberts, Turner and Ward, 1973) register regeneration of forest in the 14th century and agricultural depression due to famine, plague and Scottish attack. The North Gill Wood pollen diagram records a later phase of woodland reafforestation at c.1420 AD, which Tinsley (1976) argues to be the result of the same factors.

All diagrams from this region record increases in mainly pastoral activity in an almost treeless landscape during the 15th, 16th and 17th centuries, with some hemp cultivation at North Gill Wood. Alder regeneration is registered at Bollihope during the 18th century, although documentary evidence suggests that this species was encouraged for timber. The agricultural impact of the Napoleonic Wars can be seen at Steward Shield Meadows, Bollihope and Hallowell Moss, although it does not appear to be registered at Fozy Moss. It must be noted, however, that the chronologies for Steward Shield Meadow and Bollihope are dependent on only 1 date and 3 dates respectively for the last 2000 years, and these suggest suspect rates of varying peat accumulation throughout the sequence.

The agricultural depression during the mid-19th century is registered at Steward Shield Meadows, Bollihope, Hallowell Moss, Fozy Moss and possibly at North Gill Wood, although Tinsley (1976) suggests that instead of natural regeneration, high oak values may be the result of planting. The pine rise in the 18th and 19th centuries is common to these deposits and mixed farming is recorded during the 20th century at Hallowell Moss and pastoral agriculture at Fozy Moss.

2.3.3 Midlands

The pollen diagrams from Berth Pool (Barber and Twigger, 1987) and Crose Mere (Beales, 1980) in Shropshire indicate a period of arable activity dating from around

Anglo-Saxon/early medieval times, with increases in cereal pollen, occurrences of *Fagopyrum* and a peak in *Cannabis* frequencies. Cereal pollen and other arable indicators remain very low, however, from the 13th century onwards, as both records reflect the predominance of pastoral farming. This apparent lack of arable activity differs from most of the previous sites discussed, and the records register no response to the Napoleonic Wars, although the sampling interval of 10 cm for both sites may be too coarse to identify such events.

2.3.4 Eastern England

Pollen analytical evidence from Diss Mere (Peglar *et al.*, 1989; Peglar, 1993b) and Old Buckenham Mere (Godwin, 1968) in Norfolk indicates that arable agriculture, with high frequencies of Cereals and *Cannabis*, was already dominant in a largely treeless environment during the Anglo-Saxon/Norman period. This is much earlier than the corresponding northern records. Indeed, by 1066 AD East Anglia was the most densely populated area in England. Arable farming continued to dominate the local and regional landscape, although indications of water meadows and fallow land suggest that a complicated crop rotation system was being practised. From the 14th to mid-19th century *Cannabis* was one of the most important crop plants of East Anglia. The diagram from Diss Mere records frequencies of up to 20% for *Cannabis*, although this is most likely to have been the result of retting in the lake.

An anomaly for this region is the land use history from Quidenham Mere (Peglar, 1993a), only 10 km away from Diss. Here, extensive forest clearance is only recorded at the much later date of the Anglo-Saxon period, and pastures and meadows appear to be the dominant land use instead of arable at this time. There is evidence for some *Cannabis* cultivation, although a peak in hemp is most likely the result of retting. The medieval era sees the deforestation of the remaining woodland and the concurrent expansion of pasture and arable farming.

The 19th and 20th centuries register the planting of pine and other exotics in the town of Diss and in the surrounding parklands of Quidenham Hall. Both diagrams record the cessation of hemp cultivation in the 19th century. A cereal decline at the Diss sequence would suggest the conversion of some arable land to pasture although the Quidenham profile records an increase in arable farming, fen woodland and the maturation of the parkland trees. The occurrence of hedgerow pollen taxa at Diss Mere has been linked to the enclosure movement, although there is no evidence for this at Quidenham.

2.3.5 South Central England

Pollen evidence from Rimsmoor, Amberley and Okers in southern England (Waton, 1982; Waton and Barber, 1987) indicates a steady increase in agriculture, especially arable cultivation, and declines in tree frequencies around the period of the Norman Conquest to the 14th century. At Rimsmoor this culminates with a peak in cereal and hemp pollen at c. 1340 ± 60 AD, which coincides with the "high tide" of agriculture before the Black Death. The Rimsmoor pollen diagram then records a sharp decline in agricultural indicators due to the later 14th century recession, with the expansion of heath and grassland over formerly arable areas. Some arable activity survived since hemp was still cultivated during this period as a response to legal enforcement. The Kingswood sequence indicates woodland reafforestation after the Medieval period, largely at the expense of heathland. The pollen diagrams from Amberley and Okers record a decline in agricultural intensity after 1400 AD and the expansion of heathland. The existence and intensification of agriculture predates the establishment of Cistercian monasteries in this area, such as Bindon Abbey, and Waton (1982) suggests that there was little monastic influence on the landscape in this region, which contrasts significantly with documentary evidence and some of the northern histories.

The expansion of pine and exotics is recorded for the 18th and 19th centuries in diagrams from Winchester, Snelsmore, Rimsmoor and Kingswood, although no clear response is obtained from the impact of the Napoleonic Wars. The pollen sequence from Kingswood does, however, indicate a peak in agricultural activity at the later date of c.1850 AD, and therefore differs from those records that register post-war agricultural depression and reforestation.

Pollen diagrams from alluvial marshlands in the Pevensey Levels on a former manor 3-5 km from the Battle Abbey Estate in East Sussex (Moffat, 1986) offer a very different reconstruction of land use history. Here, the local area is predominantly wooded with a minor open ground element before 1400 AD. After this date, the open ground and wasteland indicators expand in conjunction with the growth of secondary woodland. The author, however, found no corresponding explanation for this clearance phase in the documentary record. He argues "… nor the local laying waste around the time of the conquest, nor local abandonment following the Black Death, nor other such 'events' register in these pollen records, and had any direct and sustained influence on the vegetation" (Moffat, 1986 p81). This poses interesting challenges for this study, however, in terms of achieving a suitable palynological resolution to identify historical events and processes. The lack of sensitivity in the Battle Abbey pollen record may be a function of the size and nature of the deposit used, coupled with a sampling interval of 5 cm.

2.3.6 Wales

Moore (1968) and Moore and Chater (1969) produced a composite picture of landscape change in west-central Wales from a number of bogs, including Borth, Towy Valley, Elan Valley, Plynlimmon, Llyn Gynon and Blaen yr Esgair. Turner (1964b) constructed a palynological record for this area from Tregaron Bog near Strata Florida Abbey in Cardiganshire and Butler (1984) produced pollen diagrams from the Talley Lakes, next to Talley Abbey in Dyfed. The evidence from Moore (1968) and Moore and Chater (1969) suggests that little agricultural activity took place in the Dark Ages prior to the Monastic period due to tribal warfare. Turner (1964) records, however, an extensive pastoral phase which has been radiocarbon dated to c.400BC – c.473 AD, placing it in the Iron Age/Roman period. The composite record from the 6 bogs then registers increases in agricultural indicators, especially for grazing, which in the absence of radiocarbon dates is believed to have resulted from the establishment of Strata Florida Abbey in 1164 AD. At Tregaron, the date of 1182 AD is postulated to mark the start of an arable record resulting from Cistercian activity, although no cereal curve is present on the pollen diagram. Furthermore, the Tregaron record shows very low levels of pastoral agriculture for the Monastic period, indeed Cistercian influence appears to be much less significant than that of the Iron Age/Roman people. Butler (1984) demonstrates a similar period of woodland clearance, with an associated increase in pastoral indicators and without a radiocarbon chronology has postulated that this is a response to the establishment of Talley Abbey in the last decades of the 12th century AD.

A different history of landscape usage has been recorded from Crymlyn Bog (Dumayne-Peaty, 1998c) in south Wales. An increase in clearance and the extension of small-scale pastoral and arable activity has been attributed to the establishment of Neath Abbey in 1130 AD and Margam Abbey in 1147 AD. Despite some forest regeneration caused by

Welsh uprisings, famine, cattle murrain and Black Death in the 14th century, agricultural indicators do survive this period. Clearance continued into the 15th century with increased pastoral activity, although some woodland regeneration was experienced in the later 15th and 16th centuries. Further woodland decline and expanding pastoral indicators are demonstrated from the Talley Lakes, which has been attributed to the economic recovery of the late 15th and 16th centuries.

The period between 1740 – 1902 AD is characterised by high percentages of arboreal pollen and a decline in agricultural taxa, with little evidence for agricultural intensification during the Napoleonic Wars at Crymlyn Bog. The pollen record shows some discrepancies with documentary evidence at this point because historical sources note that an increased demand for charcoal for smelting caused severe forest decline. It has been suggested that the local marginal scrubby woodland obscured the regional pollen input. The decline in cultivation indicators during the 19th century has been attributed to the increased demand for industrial land and contamination from sulphurous fumes.

The composite cereal curve from the deposits in west-central Wales peaks during the Napoleonic Wars, although peace is followed by depression, emigration, abandonment and depopulation, allowing the recovery of woodland in the 19th century. The Talley Lakes palynological record indicates increases in *Ranunculus*, *Rumex* and *Plantago* pollen frequencies which might be a response to the intensification of farming after the agrarian and industrial revolutions. Both south and west-central Wales demonstrate pine rises in the 20th century although the sharp increase in NAP at Crymlyn may be the result of further clearance for industrial expansion.

2.3.7 Ireland

Evidence from Fallahogy, Sluggan Bog and Ballyscullion East in northeast Ireland (Hall, Pilcher and McCormac, 1993) suggests that an early period of cultivation, including that of flax, which is generally believed to be an 18th century phenomenon in Ireland, was followed by woodland regeneration in 1100 AD. The record from Long Lough, also in northeast Ireland, (Hall, 1990) indicates some forest clearance with pastoral activity dominant up to c.1600 AD.

In contrast, Lios Lairthín Mór in the northwest Burren (Jelicic and O'Connell, 1992) demonstrates substantial increases in farming activity during the 11th – 13th centuries, which may have been the result of the establishment of a Cistercian monastery at Corcomroe in 1194-1195 AD. This is followed by continuous farming until around 1350 AD when a minor regression is attributed to warfare, famine and the Black Death. Arable farming peaks towards the mid-17th century.

The record from Littleton Bog in Tipperary, south central Ireland (Mitchell, 1965) suggests that clearance and expansion of grasslands around 1000 AD resulted from a monastery founded in the 7th century. Small-scale agriculture survived despite forest regeneration, which is linked to repeated Viking invasions. Between 1160-1300 AD more extensive clearance is indicated, with cereal cultivation becoming important, perhaps as a result of the influence of English invaders and the establishment of a Cistercian Abbey at Kilcooly in 1183 AD. After 1300 AD there is some regression in agricultural activity due to less settled political conditions. The pollen sequence from Carbury Bog, Co. Kildare (van Geel and Middeldorp, 1988) also indicates relatively large AP values for the period 1130-1450 AD with low levels of agriculture, followed by deforestation between 1450-1530 AD and some regeneration in the 16th century.

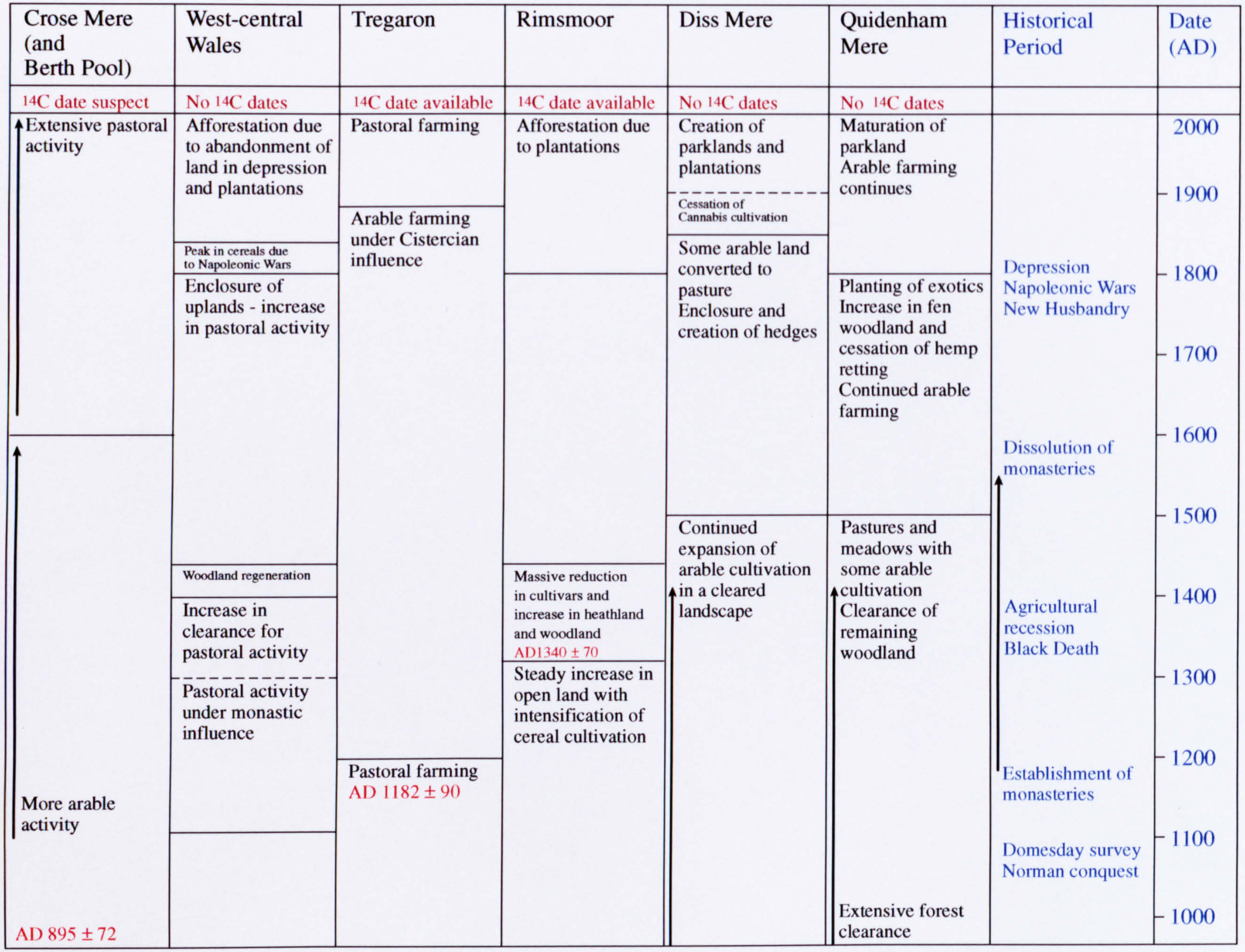
The well-documented extensive woodland clearance phase of the mid-16th and 17th centuries does not appear in all pollen records (Hall,1990). For example, Carbury, Derrycunihy Wood in southwest Ireland (Mitchell, 1988), Littleton Bog, Shower and Leigh in Tipperary (Mitchell, 1956) all record considerable declines in AP as a result of commercial demands for wood for leather tanning, barrel-stave making, charcoal and shipbuilding. Deforestation on such an extensive scale is not registered at Lios Lairthín Mór, Lough Henney and Sluggan Bog (Hall, 1994) and Long Lough. Agricultural indicators generally suggest mixed farming at these sites after this period. The late 17th and 18th centuries are characterised by the planting of pine, beech and other exotics, which is also demonstrated at Lough Catherine in Northern Ireland (Thompson and Edwards, 1982). Increases in *Crateagus* and *Prunus* pollen at this time have been correlated with the creation of hedges to enclose new agricultural land (Hall, 1990; 1994). The shift from arable to mainly pastoral farming at Lios Lairthín Mór has been tentatively attributed to the potato famine of 1846-47 AD.

2.3.8 Summary of previous research

This review demonstrates the complex nature of reconstructing land use change and human impact over time and space. As would be expected, there are distinct differences in landscape histories between regions. These studies reflect the sensitivity of the pollen record to more localised historical events and agricultural processes. A general summary of the main land use changes discussed is provided in Table 2.3 (the depth/age scales have been standardised to allow direct comparison of historical and agricultural episodes), although a major problem inherent in a comparison such as this is the quality of dating. Many sites lack any form of independent dating, instead chronologies are based on inferred palynological/historical correlations. Furthermore, sites with radiocarbon chronologies often have only one or two dates spanning the last 1,000 years. Problems with radiocarbon dating recent sediments are acknowledged but are considered in detail in a later chapter. Thus there is scope to explore the last 1,000 years in greater pollen analytical detail, within a more temporally precise framework, which will allow specific correlation to the historical record and the identification of particular agricultural practices in their relevant historical contexts. For example, Oldfield (1969 p311) states with reference to his work in the southeastern Lake District "....the scheme is very tentative and will need to be confirmed and extended in detail by further work at this and other sites".

Lindow Moss and Holcroft Moss	Ellerside Moss and Urswick Tarn	Bolton Fell Moss	Forest of Bowland	Extwistle Moor	North Gill Wood	Steward Shield Meadow and Bollihope	Historical Period	Date (AD)
No 14C dates	No 14C dates	14C dates available	14C dates available	14C dates available	14C dates available	14C dates available		
	Improved farming techniques adopted, increase in cereal cultivation and creation of plantations and parklands	Decrease in pine Agricultural depression between Wars	Pine plantations Regeneration and subdued farming activity due to depression after the Napoleonic Wars		Oakwoods planted or natural regeneration?	Plantations		2000
Afforestation from plantations and parklands		Agricultural improvements and plantations						1900
Drainage of peatlands due to reclamation attempts	Dissolution of Abbey resulted in enclosure and extension of cleared land for arable and pastoral farming	Intensification of farming due to Napoleonic Wars; Further clearance and increase in mixed farming	Cereal peak during Napoleonic Wars; Increase in NAP			Intensification of agriculture due to Napoleonic Wars; Clearance resumed with increases in pastoral activity AD 1780 ± 80 AD 1700 ± 80	Depression Napoleonic Wars New Husbandry	1800
		Revival in agricultural activity	Forest regeneration due to famine, plague and death	Increase in arable cultivation cal. AD1645-1953				1700
Progressive deforestation and extension of farmland	Extensive pastoral activity under Cistercian influence			Expansion of grassland	Renewed clearance and increasing agricultural indicators	Scrub woodland regeneration caused by agricultural depression due to famine, plague and war	Dissolution of monasteries	1600
			Reclamation and enclosure of land for mixed farming	Partial recovery of woodland followed by extension of heathlands				1500
Domestic agriculture		cal. AD1301-1428	Woodland regeneration due to falling population levels cal.AD1399-1433		Regeneration AD 1470 ± 80; AD 1420 ± 80 Clearance followed by increasing mixed farming due to local Cistercian influences		Agricultural recession Black Death	1400
Common pasture	Establishment of Furness Abbey in 1127 lead to clearance and subdued pastoral activity	Regeneration due to war, pestilence and famine. Subdued agricultural activity cal. AD1258-1394	Increase in heathland Subdued agricultural activity; Peak in AP due to forest laws	cal. AD1279-1387; cal. AD1261-1284				1300
Expansion of farmland with local establishment of Abbeys		Clearance followed by regeneration Agriculture survived due to independent rule and monastic influences cal. AD980-1260	Gradual clearance and small increases in agriculture cal. AD1188-1261 cal. AD1164-1261	Increasing cereal cultivation and spread of hazel scrub cal. AD1023-1214			Establishment of monasteries	1200
Brief forest regeneration as extensive areas laid waste	Brief forest regeneration as large areas laid waste				Forest regeneration due to land laid waste	AD 1110 ± 100	Domesday survey Norman conquest	1100
								1000

Table 2.3 Summary of land use histories from selected sites


Crose Mere (and Berth Pool)
14C date suspect
Extensive pastoral activity
More arable activity
AD 895 ± 72
West-central Wales
No 14C dates
Afforestation due to abandonment of land in depression and plantations
Peak in cereals due to Napoleonic Wars
Enclosure of uplands - increase in pastoral activity
Woodland regeneration
Increase in clearance for pastoral activity
Pastoral activity under monastic influence
Tregaron
14C date available
Pastoral farming
Arable farming under Cistercian influence
Pastoral farming
AD 1182 ± 90
Rimsmoor
14C date available
Afforestation due to plantations
Massive reduction in cultivars and increase in heathland and woodland
AD1340 ± 70
Steady increase in open land with intensification of cereal cultivation
Diss Mere
No 14C dates
Creation of parklands and plantations
Cessation of Cannabis cultivation
Some arable land converted to pasture
Enclosure and creation of hedges
Continued expansion of arable cultivation in a cleared landscape
Quidenham Mere
No 14C dates
Maturation of parkland
Arable farming continues
Planting of exotics
Increase in fen woodland and cessation of hemp retting
Continued arable farming
Pastures and meadows with some arable cultivation
Clearance of remaining woodland
Extensive forest clearance
Historical Period
Depression
Napoleonic Wars
New Husbandry
Dissolution of monasteries
Agricultural recession
Black Death
Establishment of monasteries
Domesday survey
Norman conquest
Date (AD)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000

Long Lough	Littleton Bog	Lios Lairthín Mór	Historical Period	Date (AD)
^{14}C dates available	No ^{14}C dates	^{14}C dates available		
Planting of exotics Beginning of hedged enclosure	Afforestation due to plantations and parklands	Regeneration of scrub Decline in arable agriculture		2000
		Increasingly open environment High grazing pressure and decline in arable activity		1900 1800
Further scrub clearance Extension of arable and pastoral activity Reintroduction of pine		Woodland fluctuates Meadows become more important than permanent pasture		1700
	Extensive clearance of woodlands for leather tanning, shipbuilding, barrel-staves and charcoal	Increase in AP values Grazing pressure reduced	Well-documented woodland clearance Military campaigns complete English Conquest	1600
Continuation of gradual woodland clearance for damp pastures with patches of cereal cultivation	Increase in agricultural activity			1500
		Agricultural recession due to plague and famine		1400
	Decline in agriculture and expansion of scrub due to war			
	Renewed clearance Cereal cultivation becomes important due to establishment of Cistercian Abbey and English Manorial system	Importance of arable farming due to Cistercian influence cal. AD 1269 - 1438	Irish resurgence	1300
		Increase in mixed farming		1200
cal. AD 1160 - 1254	Woodland regeneration and subdued agriculture possibly due to Viking raids		English invasion Cistercian Monasteries established	1100
cal. AD 1048 - 1235		cal. AD 978 - 1216	Viking raids Monastic influence began c.500AD	1000

Chapter 3 – Methodology

3.0 Introduction

This chapter explains the rationale behind site selection and introduces those sites considered suitable for palaeoecological investigation, and describes the coring strategies implemented for both bog and lake deposits. The methods employed for the reconstruction of past human impact on the environment and land use change over time are presented. These consist of pollen analysis, geochemical analyses involving the determination of silicon and titanium concentrations from the peat sites and charcoal counts where applicable. Where available, tephra isochrones have been used as "pinning points" within the AMS radiocarbon chronology (Barber *et al.*, 1999). This is followed by a brief description of ^{210}Pb dating, which was undertaken at Lake Gormire since this site was not suitable for radiocarbon assay. The types of historical documentation used for correlation with the palaeoecological record are then outlined. The final section discusses techniques that were considered but ultimately not included in the present research.

3.1 Site selection

In order to meet the objectives, test the hypotheses and attempt to answer the questions set out in Chapter 1, site selection was based on a number of criteria. These criteria were: (i) the existence of stratigraphically intact sediments; (ii) proximity to historic monastic centres; and (iii) areas with good documentary records. Due to the general lack of undisturbed mires in zones of human settlement and activity, a combined approach of utilising both peat sites and lake deposits was adopted. A total number of eight sites were considered, although three had to be rejected (see Table 3.1). Ireland was included in this research because of the potential to compare a different monastic history to that of Britain and due to the fact that "little interest has been shown in pollen analytical studies of deposits (in Ireland) which have developed over the last two millennia" (Hall, 1990 p377). Ultimately three raised bog sites and two lakes, distributed across northern England, Wales and Ireland (see Figure 3.1), were selected for palaeoecological investigation.

In response to the AMS radiocarbon results received from the Southeast Bog at Tregaron, which indicate that the sequence dates from around the first millennium AD to c. cal. 12th

and 13th centuries AD and is then overlain by modern peats (discussed in Chapter 4), a second profile was investigated from the West Bog in order to try and obtain a more detailed record for the last 1,000 years. Unfortunately this record dates from approximately the same period and also experiences a rapid decline in peat accumulation rates between the c. cal. 12th century AD and the 19th to 20th century surface peats. The age/depth profiles of these two records and the possible causes of this apparently synchronous event are considered in Chapter 4. Due to the fact that the initial core from Talkin Tarn (TAL1) dates from the Lateglacial, a second core was also taken from this site (TAL2).

Table 3.1 Sites considered for palaeoenvironmental investigation

Site	Grid reference	Comments	Status
Abbeyknockmoy Bog, County Galway, Ireland	M 490 437	Previous research indicates sections of the bog to be intact (Barber *et al.*, 1994, in prep.; Hughes, pers. comm.). Proximity to Cistercian abbey of Abbeyknockmoy.	Accepted
Tregaron Bog, Ceredigion, Wales	SN 682 621	Stratigraphic and photographic evidence, surface vegetation and published information (Godwin and Mitchell, 1938; Turner, 1964) implied that the central regions of the surviving bogs in the mire complex are intact. Proximity to Cistercian abbey of Strata Florida.	Accepted
Shaw Moss, southwest Cumbria	SD 190 852	Stratigraphic evidence and surface vegetation implied the bog was intact. Proximity to Cistercian abbey at Furness.	Accepted
Lake Gormire, Yorkshire	SE 503 832	Previous research (Blackham *et al.*, 1981; Oldfield and Wake, pers. comm.) indicates that the deposit is intact. Proximity of Cistercian abbeys of Byland and Rievaulx and at a greater distance Fountains and Jervaulx.	Accepted
Talkin Tarn, Cumbria	NY 545 585	Thought to be intact (Barber, pers. comm.). Proximity to Lanercost Priory.	Accepted
Ardkill Bog, County Kildare, Ireland	N 706 353	Stratigraphy was very dry which raised queries over pollen preservation. Burning episodes are known to have occurred. Proximity to castle and monastic lands.	Rejected
Mongan Bog, County Offaly, Ireland	N 004 302	Pollen record and tephra already under investigation (Hall, pers. comm.). Proximity to abbey at Clonmacnoise.	Rejected
Sowley Pond, New Forest, Hampshire	SZ 376 966	Historical records indicate lake was drained, which is likely to have disturbed the basal sediments. Proximity to Cistercian abbey at Beaulieu.	Rejected

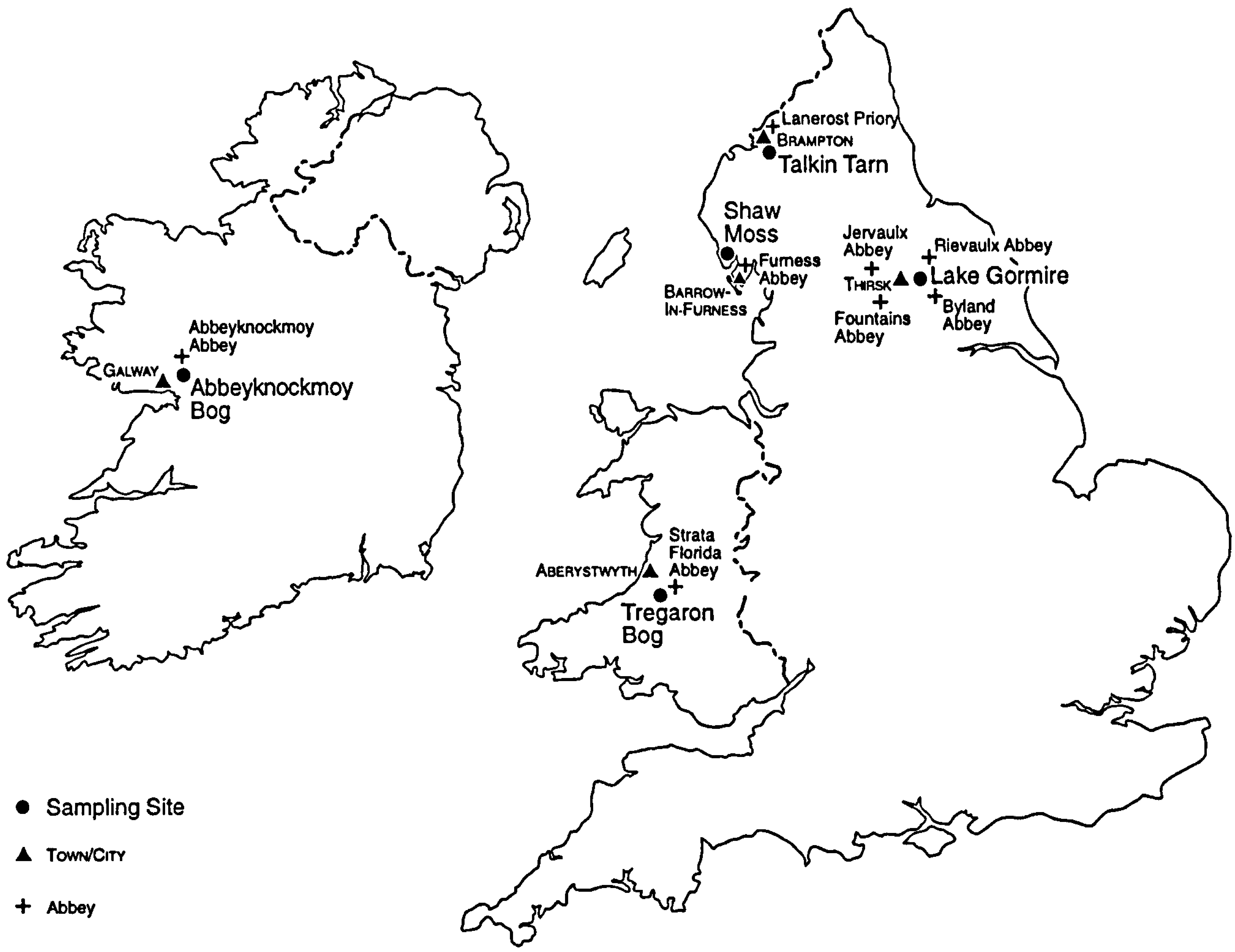


Figure 3.1 Sites selected for palaeoenvironmental investigation

3.2 Site descriptions

3.2.1 Abbeyknockmoy Bog (AKM'99)

Abbeyknockmoy Bog lies approximately 25 km northeast of Galway, in County Galway, Ireland, adjacent to the Cistercian abbey of Abbeyknockmoy. This roughly circular site has a diameter of around 2.5 km. Cutting on the eastern side of the bog has created a peat face of around 2m in height, exposing the stratigraphy of peat accumulation (see Plate 3.1). The local geology consists of Carboniferous limestone overlain by glacial deposits, while the mire itself occupies a former calcareous lake (Hughes, 1997). The bog is surrounded by farmland, with a coniferous plantation to the northeast and mixed woodland to the east. The mire is classified as NVC M18 (Rodwell, 1991). The centre of the bog is intact and the surface vegetation consists of "*Sphagnum magellanicum* and *Sphagnum papillosum* amongst other Sphagna, brown moss carpets and a full range of raised mire vascular plants" (Hughes, 1997 p68). The core AKM'99 was taken from a *Sphagnum* lawn in the centre of the mire, in order to avoid the disturbance obvious at the peat margins (see Figures 3.2 and 3.3).

Previous palaeoecological research at this site consists of palaeoclimate reconstructions by Barber *et al.* (1994 NERC Special Topic Grant GST/02/539) and Barber *et al.* (in prep.), and Hughes' (1997) study of the fen/bog transition. This project is believed to be the first palynological and geochemical investigation of Abbeyknockmoy Bog.

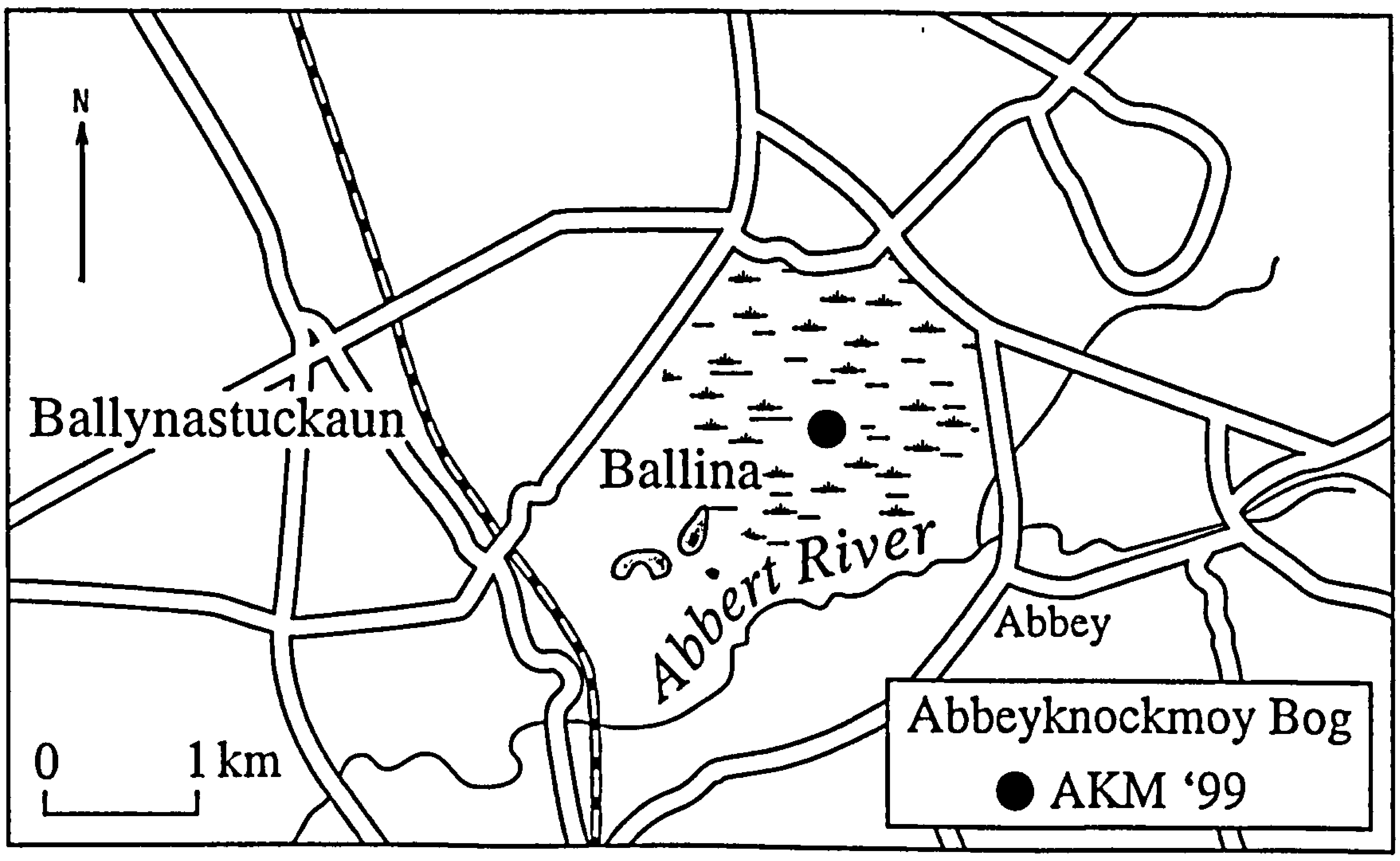


Figure 3.2 Location of core AKM'99

Plate 3.1 **Peat face exposing the stratigraphy at Abbeyknockmoy Bog, Co. Galway**

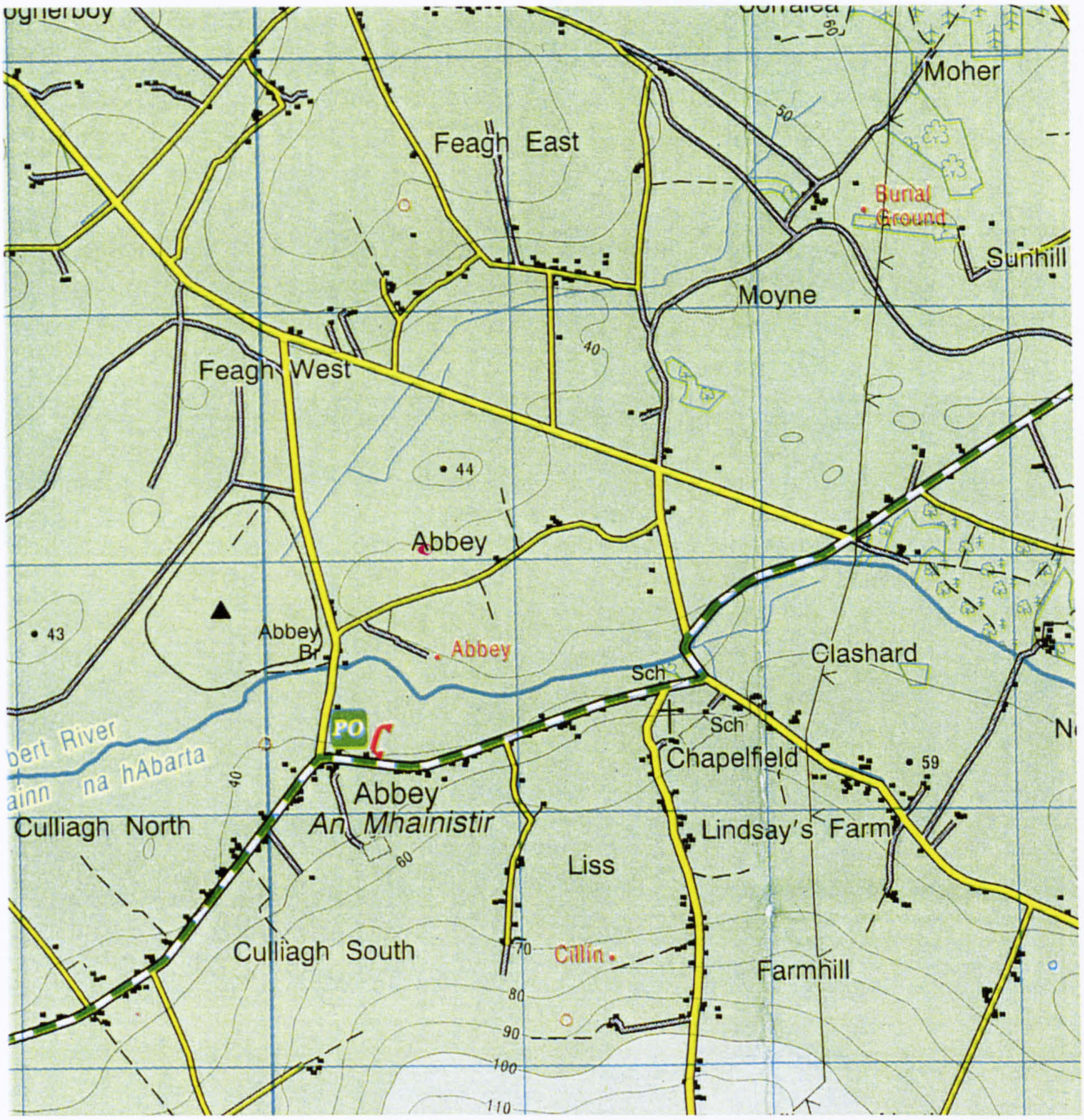


Figure 3.3 **Map of Abbeyknockmoy Bog (Source: Ordnance Survey of Ireland, Discovery Series No. 46, 1:50,000)**

3.2.2 Tregaron Bog

Tregaron Bog, or Cors Caron, is situated a short distance north of the village of Tregaron, 15 km southeast of Aberystwyth. The Cistercian Abbey of Strata Florida lies 8.5 km to the northeast of the village. This huge peat complex occupies a 6 km stretch of the Teifi valley and covers 872 hectares (see Figure 3.4). At the end of the Devensian a series of recessional moraines blocked the valley resulting in the formation of a large shallow lake. Subsequent sediment inwash and invasion by reeds and other fen species lowered the lake levels and initiated peat development to ultimately produce this raised bog complex (CCW, 1995). Despite some marginal cutting, three bogs survive today (the Southeast, Northwest and West mires), although evidence suggests that three more bogs originally existed but were probably destroyed through peat extraction for fuel (CCW, 1994). Tregaron holds National Nature Reserve, SSSI and Ramsar status (CCW, 1995) and is classified as NVC M18 (Rodwell, 1991).

3.2.2.1 Southeast Bog (TRE'98)

The original core for this study (TRE'98) was taken from the centre of the Southeast Bog (see Plate 3.2 and Figure 3.5), which is bordered by the River Teifi and the West Bog to the west and northwest, a disused railway and hilly ground to the east and agricultural land or woodland to the south and northeast. It is approximately 1200m in length and 800m wide. The surface vegetation is dominated by *Sphagnum magellanicum*, *Sphagnum papillosum* and *Rhynchospora alba*, with some *Eriophorum vaginatum*, *Eriophorum angustifolium*, *Erica tetralix*, *Andromdeda polifolia*, *Vaccinium oxycoccos*, *Drosera* and *Calluna vulgaris*. The eastern margins of the Southeast bog have been colonised by birch and willow.

3.2.2.2 West Bog (TRWA 2000)

The second core from this raised mire complex (TRWA 2000) was taken from a wet area in the centre of the West Bog (see Plate 3.2 and Figure 3.5), which is bordered by the River Teifi and more peat to the east, peatland to the south, agricultural land to the north and willow swamp to the northwest. It is approximately 2.5 km in length and just under 1.5 km in width. The vegetation around the coring site includes various *Sphagnum* species, such as *S. pulcrum*, *S. magellanicum*, *S. papillosum* and *S. capillifolium var*

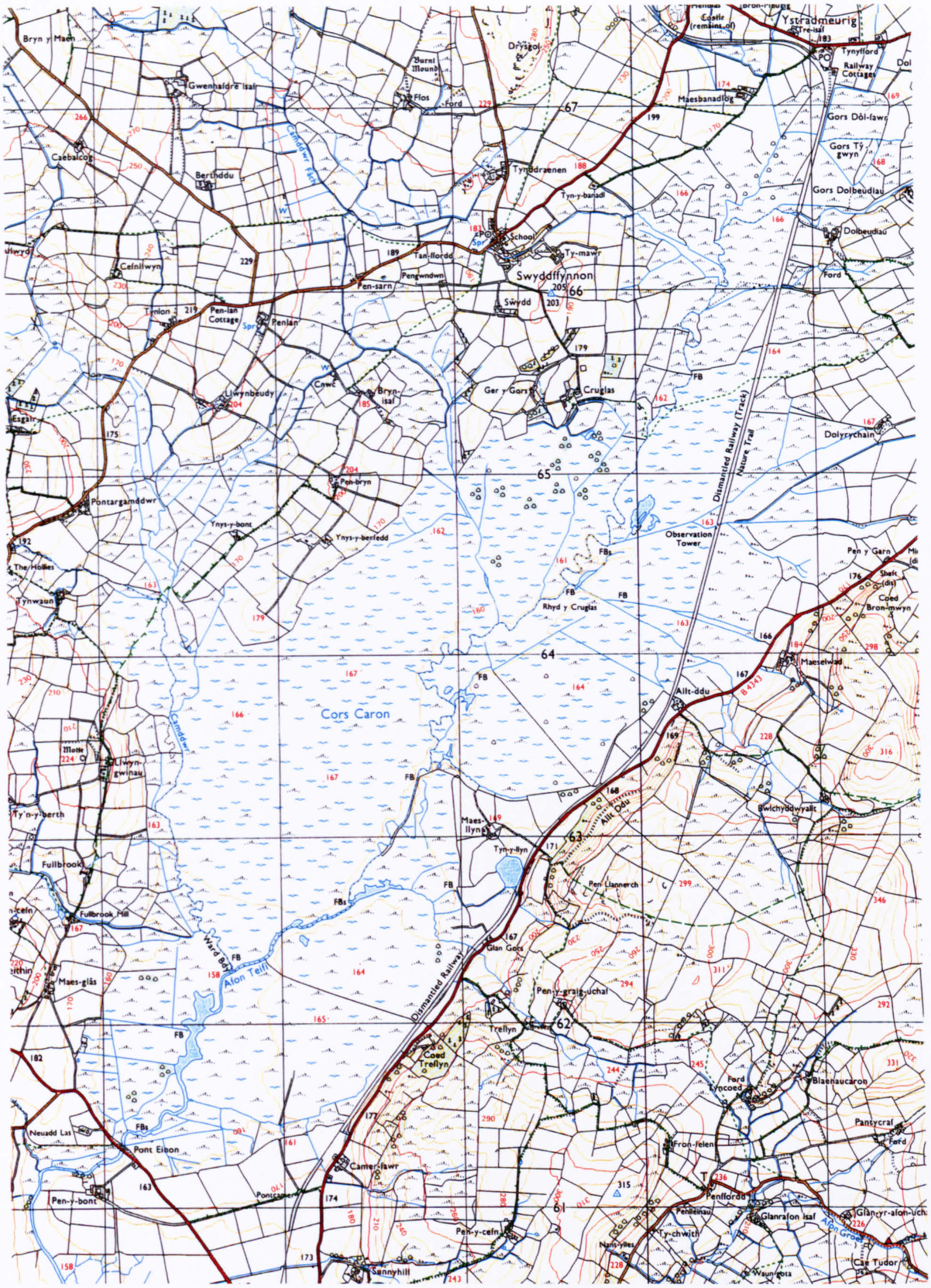


Figure 3.4 **Map of Tregaron raised mire complex (Source: Ordnance Survey, Pathfinder Series, Sheet SN 66/76, 1:25,000)**

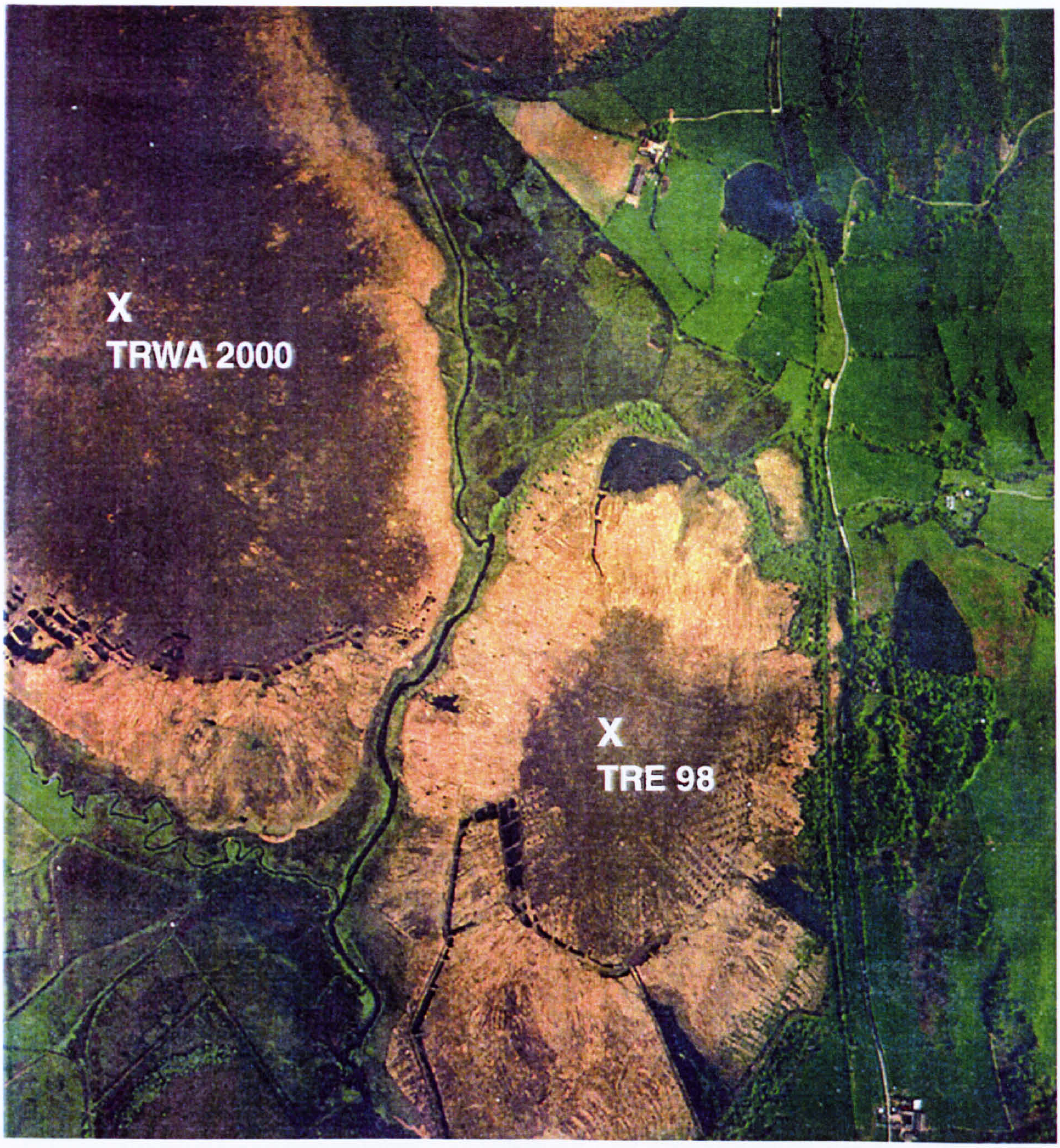


Plate 3.2 **Location of cores TRE'98 (Southeast Bog, Tregaron) and TRWA 2000 (West Bog, Tregaron) (Source: CCW)**

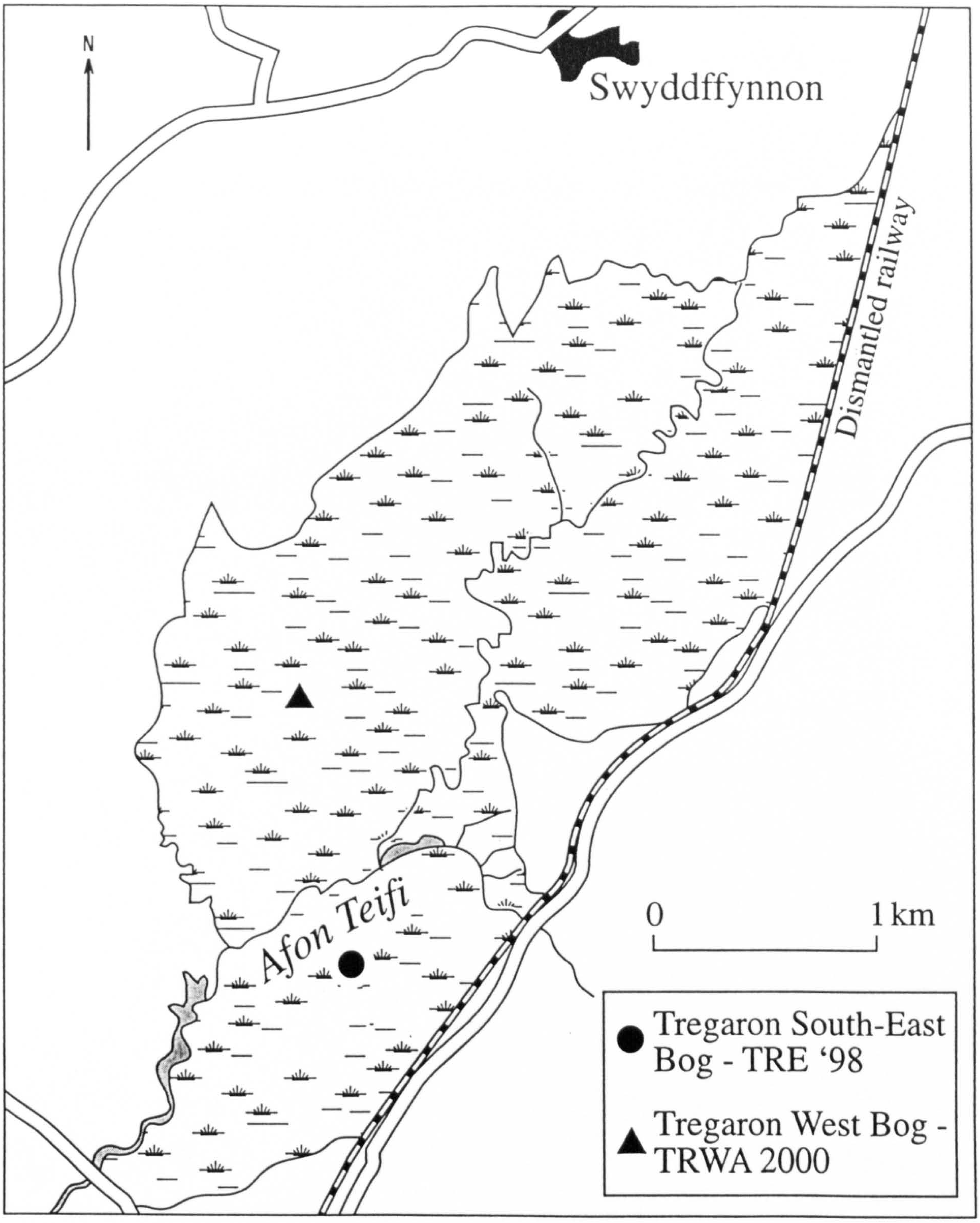


Figure 3.5 Location of cores TRE'98 and TRWA 2000

rubellum, together with *Narthecium ossifragum*, *Andromeda polifolia*, *Rhynchospora alba*, *Calluna* and patches of *Mollinia*. Scattered birch trees are growing on the mire surface and pine trees have started to colonise the edge of the rand.

Previous palaeoecological research on Tregaron has been undertaken by Erdtman (1928) who produced a single stratigraphic profile from one of the eastern bogs and Godwin and Mitchell (1938) who published stratigraphic transects from the Southeast and West Bogs in conjunction with pollen diagrams for arboreal species. Turner (1964; 1965) produced more detailed pollen diagrams from the upper levels of the Southeast Bog indicating the anthropogenic impact on the local vegetation history. Hibbert and Switsur (1976) published a Holocene pollen sequence, also from the Southeast Bog, with a suite of 18 radiocarbon dates covering the profile from 10,200±220 BP to 2,920±50 BP. Additional radiocarbon dates were reported by Godwin (1960). Haslam (1987) used peat stratigraphy and macrofossil analysis from both the Southeast and West Bogs to reconstruct late Holocene climate change and Hughes (1997) studied the fen/bog transition during the early- to mid-Holocene from the Southeast mire. The modern ecology and distribution of mire species on the West Bog were surveyed by Godwin and Conway (1939).

3.2.3 Shaw Moss (SAW2)

Shaw Moss lies 15 km north of Barrow-in-Furness in southwest Cumbria and 12 km northeast of Furness Abbey. This small raised bog is approximately 300m by 500m and forms part of the Duddon Mosses, a fragmented estuarine raised mire complex underlain by marine sediments and alluvium (Newson, pers. comm.). The head of the Duddon Estuary is bordered on both sides by saltmarsh flats, areas of raised mires and farmland (Wimble, 1986), with sheep and cattle grazing being the most widespread agricultural uses (Bayliss, 1994). Shaw Moss is classified as NVC M18 (Rodwell, 1991) and is a designated SSSI, although a section at the eastern margin of the bog was lost to agricultural reclamation between 1840 and 1974 AD and the West Cumbrian Railway dissects the eastern side of the peat deposit (see Figure 3.6). The Moss is surrounded by mixed woodland and pastureland and the mire surface vegetation is dominated by *Calluna vulgaris*, *Erica tetralix*, *Narthecium ossifragum* and various *Sphagnum* species in lawns and hollows. The core SAW2 was taken from the centre of the bog in order to minimise any human interference that could have affected the palaeoecological archive (see Figure 3.7).

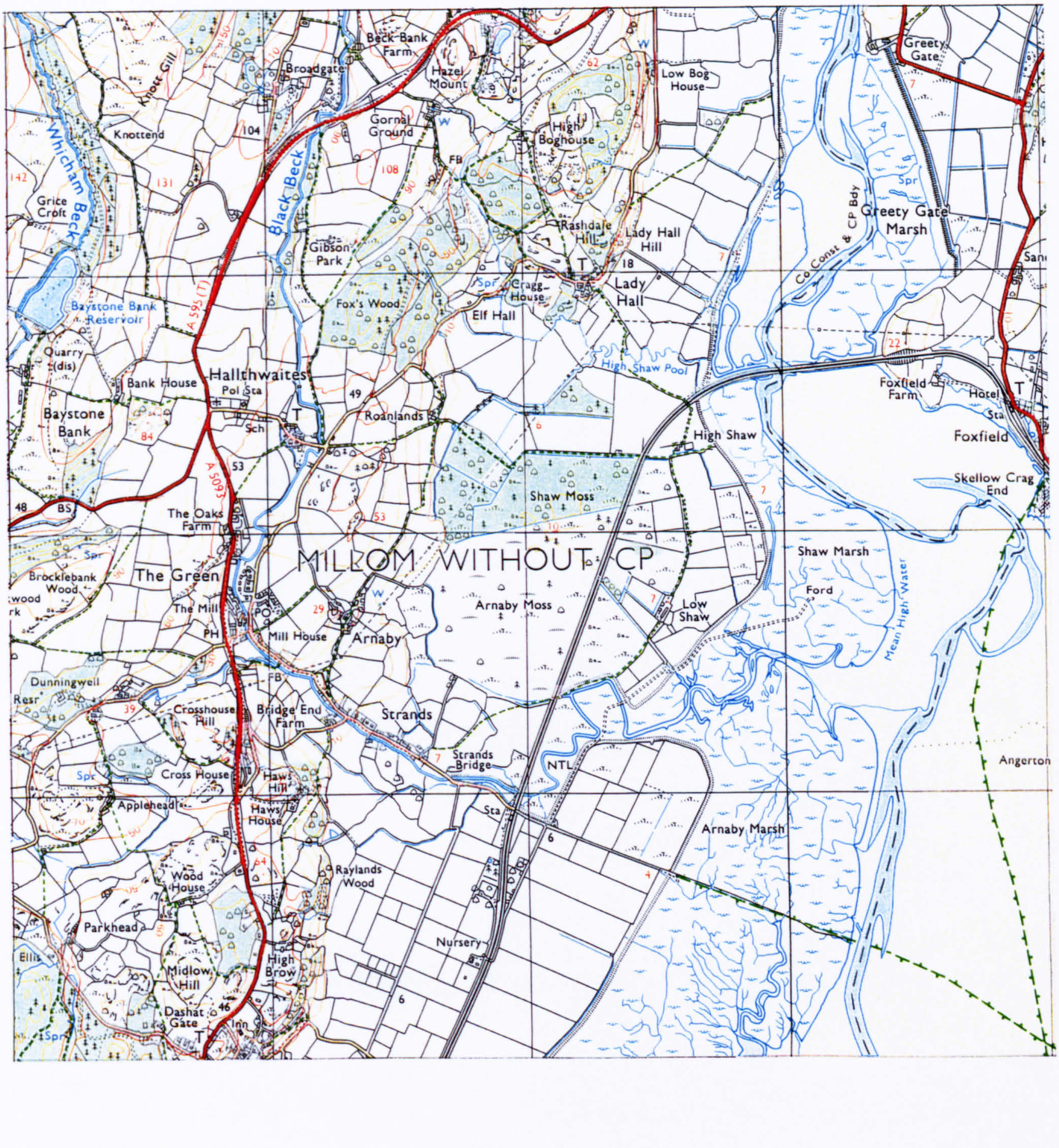


Figure 3.6 **Map of Shaw Moss (Source: Ordnance Survey, Pathfinder Series, Sheet SD 08/18, 1:25,000)**

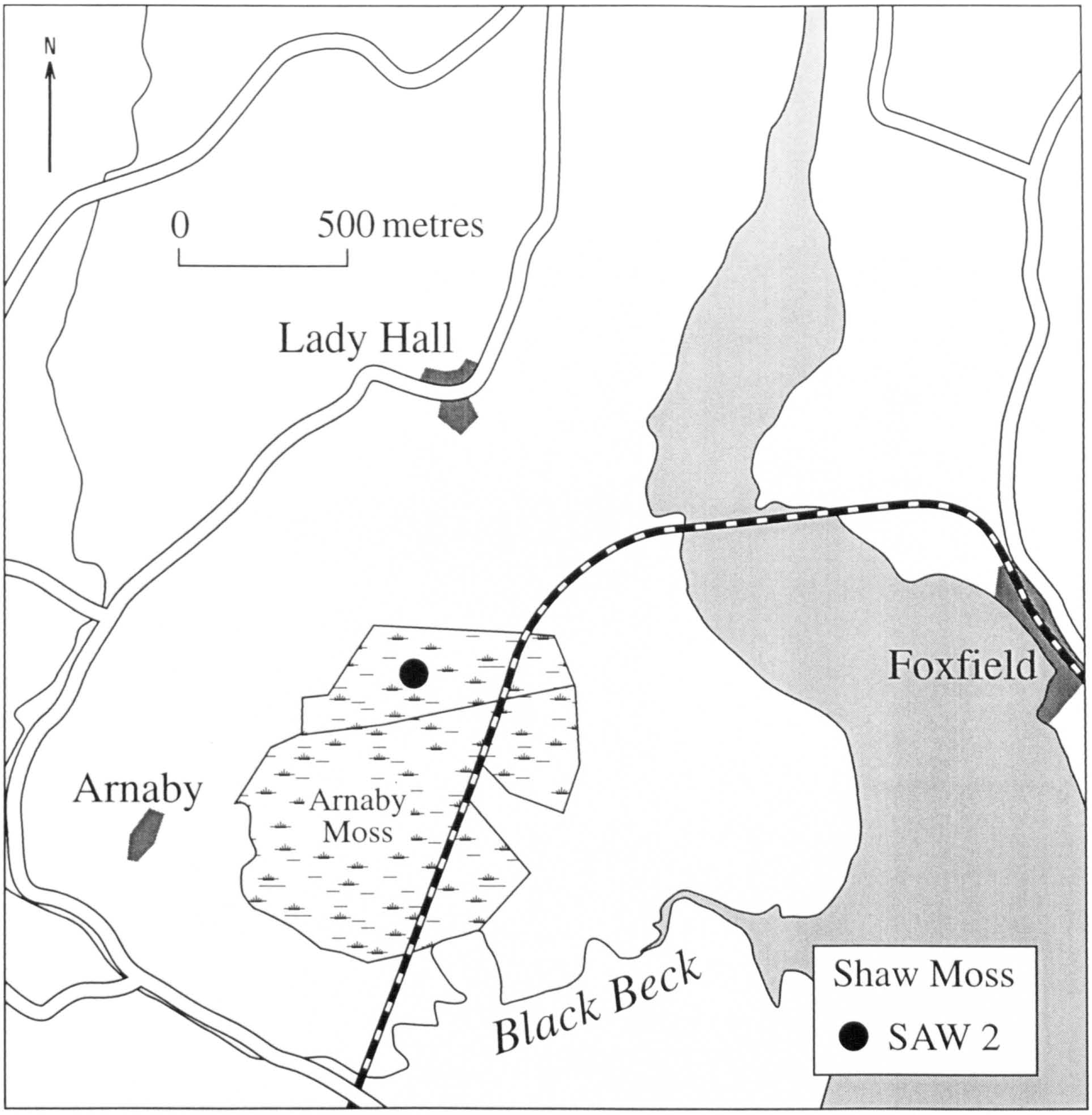


Figure 3.7 Location of core SAW2

It is believed to be the first palaeoecological investigation of this site, although previous research has been undertaken on other mosses from the Duddon complex by McMullen (2000) and Wimble (1986).

3.2.4 Lake Gormire (GOR1)

Lake Gormire is situated on the northeast margin of the Vale of York, just below the scarp of the Hambleton Hills at Whitestone Cliff, 9 km northeast of Thirsk. It is immediately surrounded by woodland and borders the North York Moors to the east and agricultural land to the north, west and south (see Figure 3.8). The Cistercian Abbeys of Byland and Rievaulx lie 6 km to the southeast and 7.5 km to the northeast respectively. At a further distance away stand the ruins of Fountains Abbey 27.5 km to the southwest and Jervaulx Abbey 34 km to the west.

At its widest point, the lake measures approximately 250m and is just under 350m long. There are no permanent inflow or outflow streams to the lake, although pollen may be deposited in the lake basin by overland flow. Kendall and Wroot (1924) in Blackham *et al.* (1981) argue that Devensian ice banked up against the cliff escarpment and that the lake lies in what was probably a marginal drainage channel which was dammed by a landslip from the cliff face during the Devensian Lateglacial. The bathymetry of Gormire indicates that the basin is an "inverted cone" and core GOR1 was taken from approximately the centre of the lake in a position of maximum water depth (see Figure 3.9).

Blackham *et al.* (1981) published pollen sequences from a 9m core and a 2.5m core in order to establish the age and history of the local woodland, although the sampling resolution was relatively coarse, for example 20 cm intervals were used from the short core. Plant macrofossils and palaeomagnetic studies were also undertaken on the full profile. More recent research into the palaeomagnetic signal has been carried out by Wake (pers. comm.), which was accompanied by a pollen profile and elemental chemistry. The organic geochemistry of the lake sediments is currently being investigated by Fisher (pers. comm.).

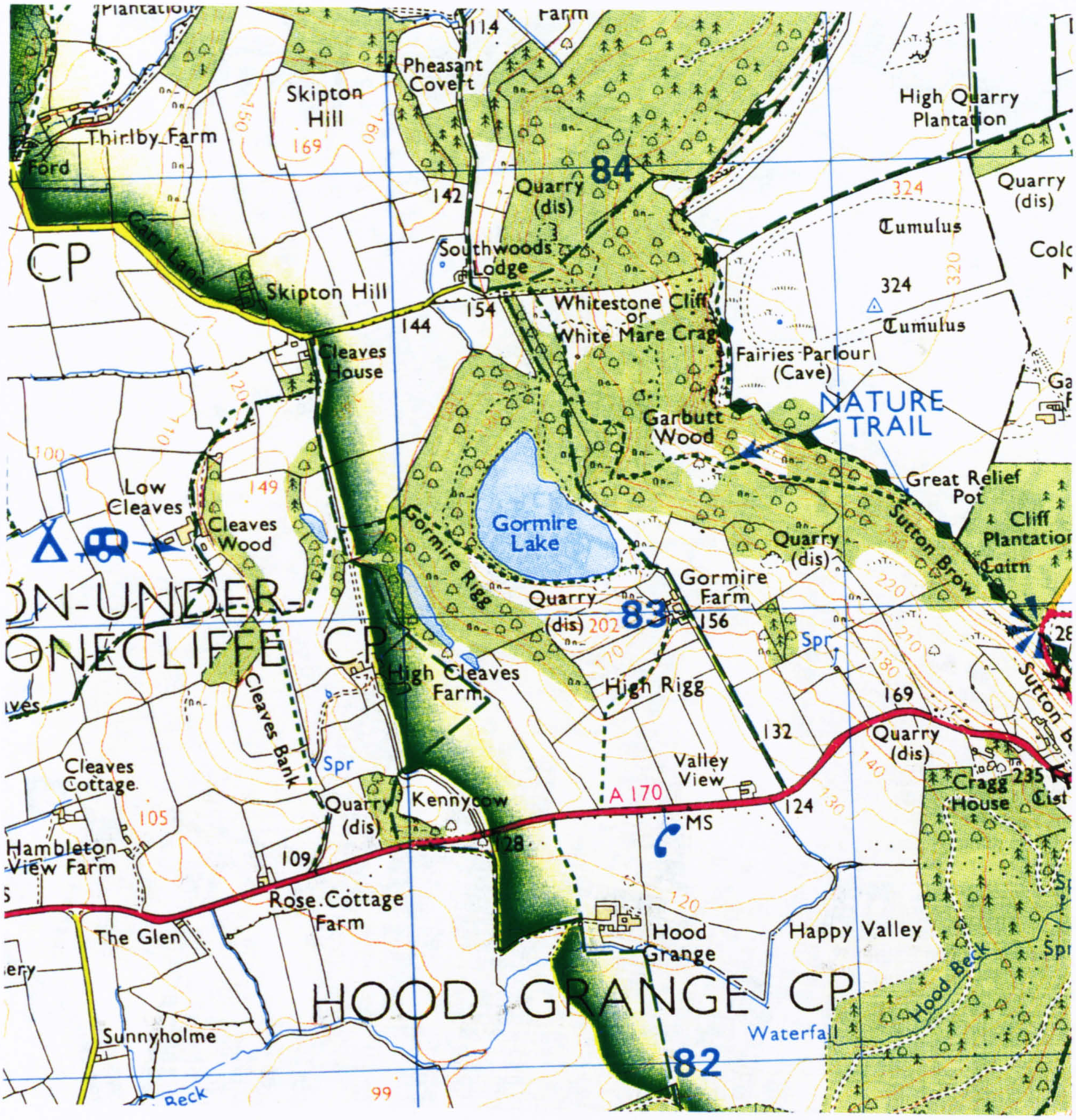


Figure 3.8 Map of Lake Gormire (Source: Ordnance Survey, Outdoor Leisure Series, Sheet No. 26, 1:50,000)

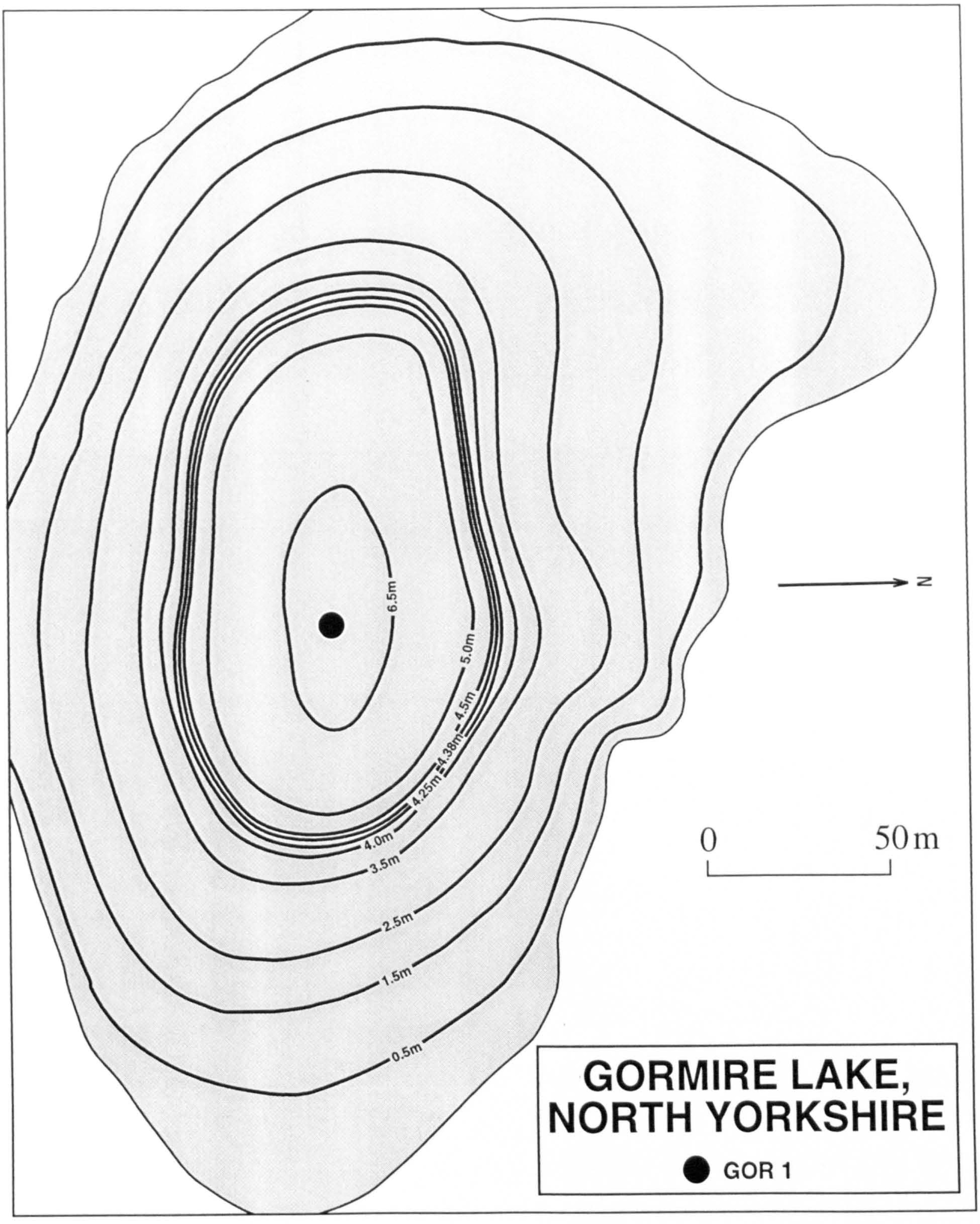


Figure 3.9 The bathymetry of Lake Gormire and location of core GOR1 (from Oldfield, pers. comm.)

3.2.5 Talkin Tarn

Talkin Tarn lies approximately 15 km northeast of Carlisle and 3 km southeast of Brampton in Cumbria. The Augustinian house of Lanercost Priory lies 5 km north of the lake. This 65 acre lake is bordered by woodland immediately to the north, which is dominated by oak, beech, birch and pine, and farmland to the south (see Figure 3.10). This kettle-hole lake is glacial in origin and fed by underground springs. The geology of the Tarn is split so that limestone underlies the eastern section and sandstone the western section. This is then covered by sand and gravel drift. The bathymetry of Talkin Tarn is relatively complex with a sharp increase in water depth creating a small, steeply shelving depression in the western section of the lake. Both cores for this project were taken from flatter areas of the lake basin. Core TAL1 (1m mini-Mackereth) was taken just north of the centre of the lake and core TAL2 (3m Mackereth) was taken from the northern profundal region of the Tarn (see Figure 3.11).

Barber and Langdon (NERC Grant GR9/0413, 1999) are currently investigating the chironimid and loss-on-ignition records from the Tarn, but this is believed to be the first palynological investigation of the lake sediments.

3.3 Field coring strategy

3.3.1 Peat coring

With reference to the discussion of pollen replicability in Chapter 2, a single peat core was taken from the centre of each mire in order to minimise any human disturbance which tended to be greatest at the margins of the deposit. The cores were taken using a 30 cm x 9 cm Barber-Russian corer (Barber, 1984) and a monolith tin for the top 40 cm. Alternate overlapping cores from adjacent boreholes were taken to ensure minimum disturbance of the underlying peat horizons by the borer nose cone and to reduce the possibilities of contamination from younger plant material being brought down the profile in the core chamber (Lowe and Walker, 1984). Assuming an average peat accumulation rate of approximately 12 years/cm for raised mires in Northern England (Barber *et al.*, 1994b), 1.5m of peat were collected in order to cover the last 1,000 years. After the core had been collected, it was transferred from the corer chamber into a section of plastic tubing, labelled, sealed in a polythene bag and stored in the refrigerator at 4°C.

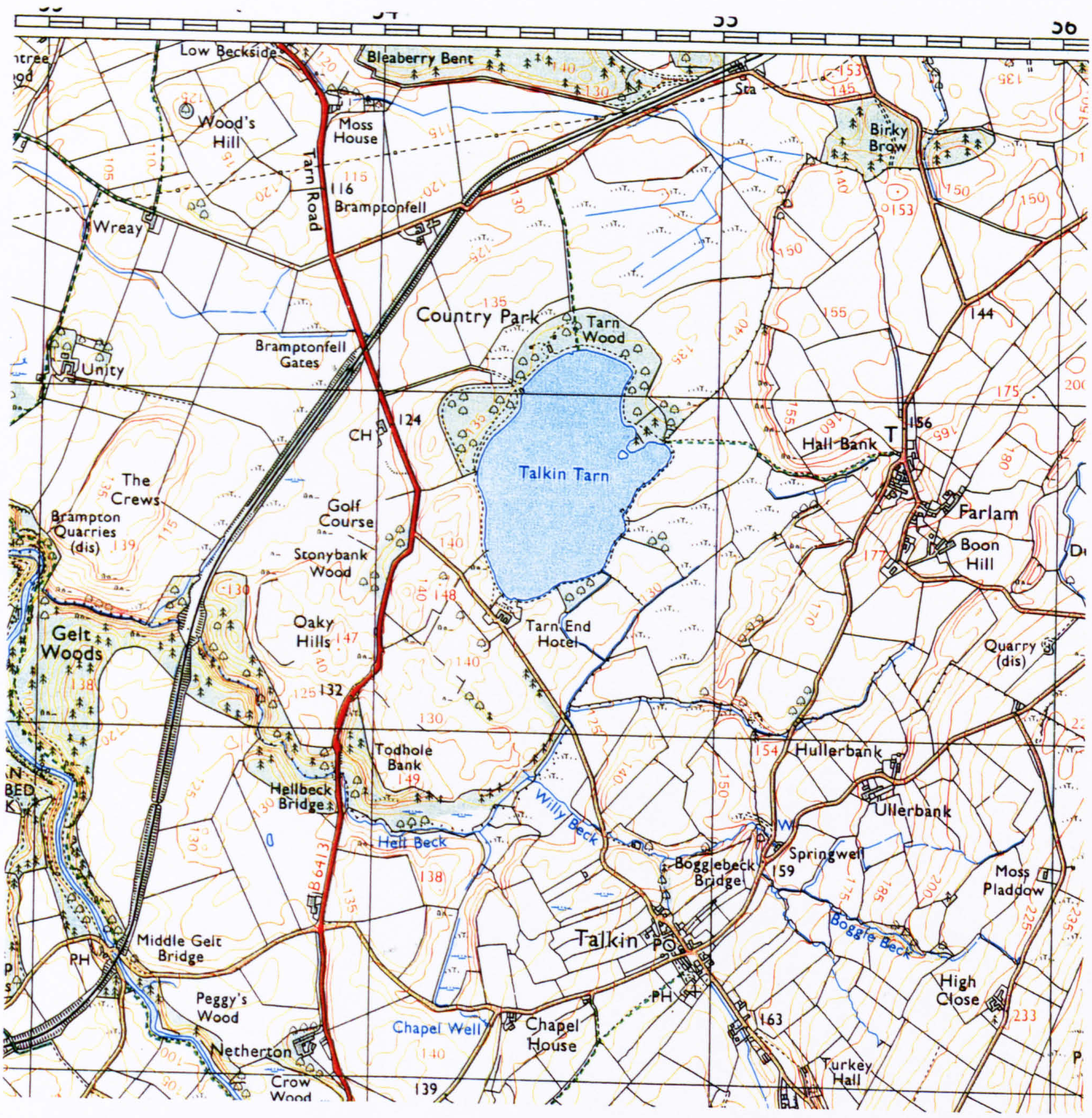


Figure 3.10 **Map of Talkin Tarn (Source: Ordnance Survey, Pathfinder Series, Sheet NY 45/55, 1:25,000)**

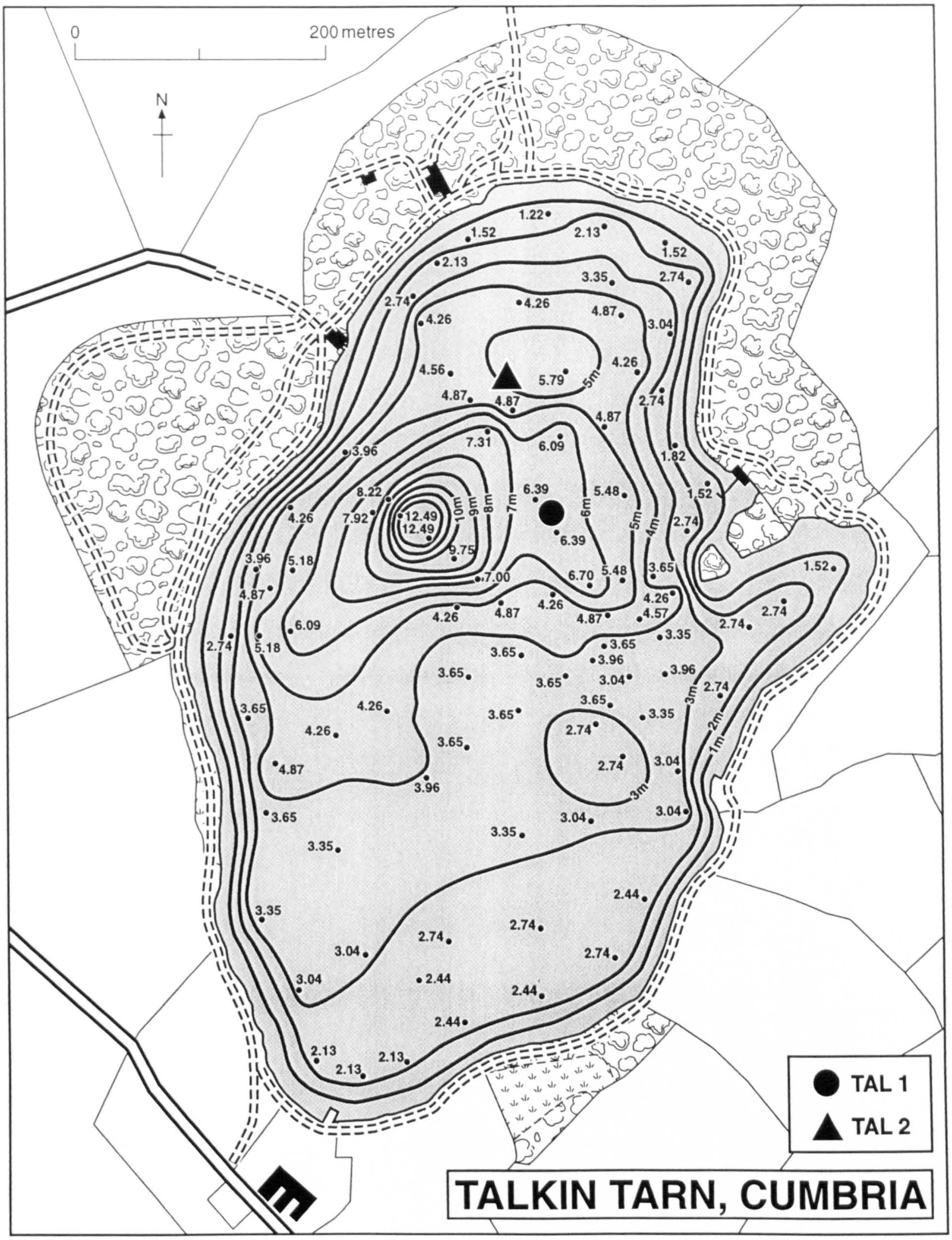


Figure 3.11 The bathymetry of Talkin Tarn and location of cores TAL1 and TAL2

3.3.2 Lake coring

A single core was taken from the deepest section of Lake Gormire using a mini-Mackereth (1m) corer (Mackereth, 1958) from an anchored boat. The sediment/water interface could clearly be seen through the perspex tube, which suggested that the core was relatively undisturbed. The core was transported vertically to the laboratory, where the surface water was pipetted off and the core extruded into 1 cm slices using a piston powered by water pressure. These slices were placed in plastic petri dishes, sealed in polythene bags and stored in the refrigerator at 4°C. The same technique was used at Talkin Tarn, although the necessity for a flat lake bed on which to operate the corer meant that the core (TAL1) was not taken from the deepest part of the lake. A second core (TAL2) was taken from Talkin Tarn with a 3m Mackereth corer. After the core had been collected, the 3m plastic tube was frozen at 1m intervals in the field using liquid nitrogen. The core was then sawn into three equal 1m sections for ease of transportation back to the laboratory for extrusion. Since a 3m Mackereth corer does not capture the mud/water interface and the sediments in this instance were relatively solid, the cores were laid on their side, cut into more manageable 50 cm sections and the length of the plastic tube cut open with a circular saw to expose the sample. The cores were then wrapped in plastic and stored in the refrigerator at 4°C.

3.4 Laboratory methods

3.4.1 Pollen analysis

3.4.1.1 Sampling strategies

Using a clean scalpel and spatula, peat or lake samples of 1-2 cm^3 were initially taken for pollen analysis at 4 cm intervals down the core, in order to produce a "skeletal" pollen diagram (Moore, *et al.*, 1991). With reference to these preliminary results, critical horizons were subsampled at closer stratigraphic intervals, ranging from contiguous 0.5 cm and 1 cm slices to 2 cm counts. In order to avoid contamination possibly introduced during the coring procedure, the surface of the peat monoliths and cores were cleaned by scraping away the uppermost 1-2 mm of sediment prior to sampling. This was not necessary for the lake profiles because these sediments were totally enclosed in a perspex tube.

3.4.1.2 Pollen preparation

The samples for pollen analysis were prepared using the schedule described by Barber (1976) with minor modifications. All samples from the lake deposits were subjected to an hydrofluoric acid treatment. The polleniferous material was mounted in silicon fluid (MS 200/2000 centistokes) to permit the rotation of grains for identification (Andersen, 1965) and to avoid the collapse or swelling of pollen grains which can occur when mounted in glycerine jelly (Praglowski, 1970). Safranin was used to stain the grains.

The following modifications were made to the schedule. *Lycopodium* spore tablets were added to enable the calculation of charcoal concentrations where appropriate (this is discussed more fully in Section 3.4.4). The *Lycopodium* counts were not used, however, to produce absolute pollen numbers and hence concentration data, which when plotted against sediment accumulation rates can be used to calculate pollen influx (Fægri and Iversen, 1989). This was because there are several problems and sources of uncertainty associated with this type of presentation of pollen data. These include the lack of data on pollen production for individual species per unit area, the difficulties of obtaining exactly 1 or 2 cc of peat samples (Dumayne, 1992), the quantity of radiocarbon dates needed to accurately calculate accumulation rates (unless varved sediments are available), changes in sedimentation rates (Webb *et al.*, 1978) and the large number of processes that operate during sediment deposition in lakes such as sediment focusing which could cause irregularities in pollen influx data (Birks and Birks, 1980; Fægri and Iversen, 1989). Furthermore, such diagrams are particularly informative when there are dramatic changes in pollen influx, such as between the Lateglacial and early post-glacial periods (West, 1971; Barber, 1976). Consequently, pollen diagrams based on relative percentage data calculated by the pollen sum (see Section 3.4.1.3), which are less affected by above-mentioned problems than influx values (Webb *et al.*, 1978), were considered suitable for fulfilling the objectives set out in Chapter 1.

The first stage of sediment treatment in Barber's (1976) schedule involving hydrochloric acid to remove carbonates was unnecessary due the essentially acidic nature of the material. The initial 180μm sieving after the potassium hydroxide treatment was supplemented by a second sieving using a 10μm micromesh to remove very small clay particles of the sediment matrix, while the pollen remained trapped in the sieve. Problems were experienced with sediment "clumping" which were not alleviated by the addition of detergent (Moore *et al.*, 1991). Investigation by Francis and Hall (1985) suggests that the polyvinylpyrrolidone in the *Lycopodium* tablets may be the main cause of "clumping", although in this research "clumping" tended to occur after the acetylation rather than after the addition of the tablets. Washing the pellet four or five times with distilled water after the acetylation, combined with manually breaking up the pellet with a wooden spill and mixing the sample thoroughly in silicon fluid did appear to reduce the severity of "clumping" (Dumayne-Peaty, pers. comm.).

3.4.1.3 The pollen sum

Moore *et al.* (1991) identify two types of pollen sum involving both arboreal pollen (AP) and non-arboreal pollen (NAP). The first, "total pollen" (TP), which excludes aquatic plants and spores, has been applied to the lake deposits in this study, although *Alnus* was also omitted because of its propensity to grow on lake margins. The second sum, "total dry land pollen" (TDLP) has been applied to the peat sequences in this project. While excluding aquatics and spores, this sum also omits the pollen of those species which grow on the surface of, and around the margins of mires and in this case include *Alnus* (Janssen, 1959), Ericaceae, Cyperaceae, and mire herbs (e.g. *Menyanthes* and *Potamogeton*). Pollen from these sources are considered local inputs and large fluctuations in these species could seriously distort pollen percentages of non-mire taxa by over-representation and are therefore excluded from the pollen sum when the aim is to reconstruct regional landscapes (Moore *et al.*, 1991). Since grasses do not generally grow on the surface of undisturbed Atlantic bogs (Barber, 1981), the pollen from these species are included in the pollen sum because of their importance as an indicator of pastoral activity (see Chapter 2).

The larger the sum the more representative the sample is of the total fossil pollen and hence the greater statistical significance of the data, fluctuations in pollen curves and the ability to produce continuous curves of less frequently represented types (Barber, 1976). Both the TP and TDLP sums used in this study were based on counts of 400 pollen grains plus extant mire taxa and spores, which is considered to be statistically adequate by Birks and Gordon (1985).

3.4.1.4 Pollen counting and identification

The pollen grains and spores were identified and counted at a magnification of x400 using a Nikon Optiphot microscope. Once the slides had been counted, any pollen grains requiring higher magnification were noted by their co-ordinates on the slide and identified using a x1,000 oil immersion lens. Even using silicon fluid, the greater majority of pollen grains were able to be re-located.

Counting was carried out in systematic traverses of the 18x18mm cover slip, moving the slide one and a half fields of view at the end of every traverse to avoid the duplication of counts. In most cases more that one slide was counted to meet the pollen sum, but for those horizons particularly abundant in fossil pollen, traverses were made near the edges and the centre of the slide to avoid the problems caused by the possibility of non-random distribution (Brookes and Thomas, 1967).

Pollen identification was made with reference to keys, photographs and line drawings (Moore and Webb, 1978; Andrew, 1984; Fægri and Iversen, 1989; Moore *et al.*, 1991 and specifically for cereal types Andersen, 1979; Dickson, 1988; Edwards, 1989) and by comparison with type slides held in the laboratory. Pollen preservation was generally very good. Pollen nomenclature follows Moore *et al.* (1991) with revisions by Bennett *et al.* (1994), based on the taxonomy of *Flora europea* according to Stace (1991).

In terms of pollen identification, certain species require further explanation:

Cannabaceae: Due to the difficulties associated with distinguishing *Cannabis sativa* pollen from that of *Humulus lupulus* using light microscopy (e.g. French and Moore, 1986; Whittington and Gordon, 1987), reliable categorisation was not considered possible and therefore pollen from these species have been amalgamated within *Cannabis sativa* type on the pollen diagrams.

Coryloid: An attempt was made to split the pollen of *Corylus avellana* and *Myrica gale* using light microscopy. However, Edwards (1981) suggests that it is not possible to consistently separate these two species using this technique and therefore some grains may have been wrongly identified. The general behaviour of the *Corylus* frequency curve, however, corresponds well with the other arboreal pollen curves and inversely with the herb species, suggesting that identification has been largely correct.

Grasses: An attempt was made to distinguish *Phragmites* pollen from that of other grasses. According to Fægri and Iversen (1989) those grains less than 26μm with an annulus diameter of less than 10μm and indistinct columellae may be categorised as *Phragmites*, whilst other grasses can be defined as being greater than 26μm but less than 40μm. They also have an annulus diameter of less than 10μm. It must be noted that these measurements refer to glycerol preparations, which tend to be slightly larger than those made from silicon fluid preparations, hence 24μm is taken to be the lower limit in this study. After the difficulties experienced with the *Phragmites* distinctions, further attempts to identify *Molinia* from other grass species were abandoned. Barber (1981) noted similar difficulties, but concluded that since the Poaceae curve fluctuated sympathetically with the other herb frequencies, and inversely with the tree species, the grass pollen recorded was thus likely to represent clearance around the bog rather than changes in local grass abundance.

Cereals: Edwards (1989 p116) noted the probability that "most grains with a mean diameter (average of the sum of the largest diameter and that at right angles to it) greater than 37μm and with an annulus diameter greater than 8μm will be from cereals" (after Andersen, 1979). Fægri and Iversen (1989), however, defined cereals as between 40 – 60μm (although grains were mounted in glycerol rather than silicon fluid). Further identification for classification into the *Hordeum*-group, *Avena-Triticum*-group or *Secale cereale* should involve consideration of pollen size, annulus diameter and surface sculpturing (Andersen, 1979). The grains of *Secale cereale* are usually characterised by their prolate shape and are the only cereal pollen that can be identified by shape alone (Dickson, 1988). In this research, only those grains greater than 40μm with an annulus diameter greater than 8μm were classified as cereal type. Due to the thicker exine of cereals than grasses, they tend to stain more darkly. Furthermore, cereal grains have more distinctive and robust columellae than grass grains. Cereal type on the pollen diagrams is defined as "pollen types which morphologically correspond to those of cultivated grasses but which could include some wild grass species" (Edwards, 1989 p114). Grains of *Secale cereale*, however, were identified as a separate category because of their overall diagnostic morphology.

3.4.1.5 Diagram construction and zonation

Percentage pollen diagrams showing the relative proportions of individual species were calculated and drawn using the computer programmes TILIA and TILIA.GRAPH (Grimm, 1991). The percentages of those species excluded from the sum were calculated as percentages of the basic sum (ΣTP or ΣTDLP) plus their own sum, e.g. ΣTP + ΣAquatics (Birks and Birks, 1980). Inherent in percentage pollen diagrams is the fact that the variables are interdependent proportions and therefore the pollen curves may be subject to certain numerical problems. Thus variations in pollen abundance will affect the curves, they are also subject to the "Fagerlind" effect which means that a real change in variation of one taxa will automatically affect the value of the other curves in a system (i.e. within a sum) of three or more taxa, and there is a decrease in a pollen taxon's ability to reflect vegetation change when it approaches 100% or 0% (Prentice and Webb, 1986; Moore *et al.*, 1991). Although some caution must be applied when interpreting percentage pollen diagrams, "our results support the continued use of pollen percentages" (Prentice and Webb, 1986 p42).

In terms of pollen diagram format, two types of diagram have been constructed. The full pollen diagram from each site appears in the appendices where taxonomic order follows that of Stace (1991) for the herbs and the more or less traditional ordering of trees and shrubs. These diagrams begin (reading from left to right) with the AMS radiocarbon (or ^{210}Pb where applicable) dates, followed by stratigraphic depth, pollen frequency curves, summary diagram of trees, shrubs and herbs, and finally local pollen assemblage zone boundaries. The individual pollen taxa curves have been left as unfilled histograms in order to demonstrate the sampling intervals. The pollen taxa have been split into the following groups:

Trees (including *Ilex* although this could also be considered a large shrub (Stace, 1991))

Shrubs (including *Corylus* and *Salix* although these could have been categorised as trees (c.f. Stace, 1991))

Dwarf shrubs (Ericaceous pollen)

Herbs (of dry land, but may have some wetland taxa where pollen morphology does not allow separation to a lower taxonomic level)

Mire/Aquatics (for species growing on the surface of mire deposits) or **Aquatics** (for lake deposits)
Spores (plus *Tilletia*)

For the diagrams that feature in the main text, an attempt has been made to categorise the relevant indicator species into ecological groups, in order to facilitate interpretation of human impact and land use change. As discussed in Chapter 2, this approach is not without difficulties, yet it was felt that the results would be more meaningful in relation to the research questions raised in Chapter 1. The scheme in Table 3.2 is broadly based on Behre (1981), with explanations of any modifications made. It is realised that some species are not exclusive members of the assigned land use category and may in fact overlap and grow in a range of habitats. It is, however, hoped that by creating an assemblage of likely indicator species for each land use type, significant trends will begin to emerge. Not all species in the following scheme feature in every pollen diagram.

Two types of diagrams have been constructed using this approach. The first shows all of the pollen taxa within each ecological group, as defined in Table 3.2, while the second sums all the taxa from each group to draw a summary curve for that category. It must be noted, however, that these totals include taxa that were excluded from the pollen sum, such *Alnus* and Cyperaceae, meaning that the cumulative values may exceed 100%. The curves do not take account of any differences between the pollen production and dispersion characteristics of individual taxa. All of these diagrams have been formatted so that they begin (reading from left to right) with the AMS radiocarbon (or ^{210}Pb) dates, stratigraphic depth, pollen frequency curves and local pollen assemblage zone boundaries. The explanation of abbreviations used on the ecologically grouped pollen diagrams are as follows:
Hdr – Hedgerows
Heath / Hth – Heathland
Aw – Arable weeds
A/D – Arable/disturbed or waste ground
Th/Wm – Tall herbs/Wet meadows

In order to ease the description, discussion, interpretation of and correlation between pollen diagrams, the sequences have been divided into local pollen assemblage zones (lpaz) (Birks and Birks, 1980; Moore *et al.*, 1991). Birks, quoted in Gordon and Birks

(1972 p962), defined a pollen zone as "a body of sediment with a consistent and homogeneous fossil pollen and spore content that is distinguished from adjacent sediment bodies by differences in the kind and frequencies of its contained fossil pollen and spores". Zone boundaries are thus placed at points where the change in pollen spectra is most marked (Moore *et al.*, 1991) and can be defined either by eye or by utilising statistical methods. There are a number of statistical techniques available, see for example Dale and Walker (1970), Gordon and Birks (1972), Birks and Birks (1980), Birks and Gordon (1985) and Bennett (1996).

While numerical methods for the zonation of pollen diagrams can bring consistency, remove subjectivity and produce repeatable results (Gordon and Birks, 1972), they should not be relied upon completely because profound changes in some local taxa may be selected as the basis of zonation when regional changes of considerable interest but low numerical impact may be ignored (Moore *et al.*, 1991). Given this, and since Gordon and Birks (1972 p973) concluded that "... similar stratigraphical divisions are obtained by all the numerical methods, and that the zonations derived by those procedures generally correspond to those arrived at independently by visual inspection", the pollen diagrams in this study have been zoned by eye.

Table 3.2 Land use / habitat categories for selected indicative pollen taxa

Land use / Habitat	Species	Comments
Woodland	Main tree species (e.g. *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Fraxinus*, *Fagus*, *Alnus*) and *Corylus*	*Corylus* has been included in this group because it can be found in scrub/woodland environments (Stace, 1991).
Hedgerows	*Rubus*, *Prunus/Malus* type, *Prunus spinosa* type Sorbus/*Crateagus* type, *Ligustrum* (*Ulmus* and *Fraxinus*)	After Hall (1989 p90), although it must be noted that "unless the pollen spectrum of the hedgerow is associated with other clear signs of agriculture it may be difficult to distinguish between that produced by hedges and that derived from some other wooded component of the landscape". *Ulmus* and *Fraxinus* have been mentioned in this section because they often colonise or are planted as part of hedgerows.
Heathland (and mires)	*Calluna*, *Erica*	*Vaccinium* and *Empetrum* were excluded from this category because of their relatively small pollen frequencies.
Arable crops and other cultivars	Cereal type, *Secale cereale*, *Fagopyrum*, *Linum*, *Cannabis sativa* type	After Behre (1981).
Arable weeds (segetals)	*Centaurea cyanus*, *Artemisia*, *Polygonum aviculare*, *Sinapis* type, Brassicaceae undiff.	*Artemisia* has been included because it can be an indicator of fallow land (Vorren, 1986) and Oldfield (1963) regards the virtual disappearance of this species as a response to the introduction of deep ploughing in the 19th century. This species was also considered an arable indicator by Fenton-Thomas (1992). Whittington and Edwards (1995) suggest that DCA of pollen data from Scotland may indicate that *Artemisia* was a weed found in barley crops. *Polygonum aviculare* and Brassicaceae have been considered possible arable indicators by Turner (1986), Vorren (1986) and Andrieu-Ponel *et al.* (2000). *Sinapis* can occur in arable situations (Stace, 1991) and Whittington and Edwards (1995) suggest that this species may be a weed associated with hemp cultivation.

Arable/disturbed or waste ground (ruderals)	Chenopodiaceae, *Urtica* type, *Plantago media/major*, *Plantago coronopus*, *Scleranthus* type	It is noted that some species of Chenopodiaceae grow in coastal areas (e.g. Behre, 1981; Scaife, 1991). Similarly *Plantago coronopus* can be found in coastal situations (Stace, 1991). Fenton-Thomas (1992) classified both Chenopodiaceae and *Plantago major* as indicators of arable agriculture, yet since both these species can also be found in disturbed ground they are not assigned the segetals category in this scheme.
Pastoral	*Poaceae*, *Rumex undiff./acetosa/acetosella*, *Trifolium* type, *Plantago lanceolata*, *Sanguisorba minor*, *Jasione*, *Campanula* type, Lactuceae undiff.	Stace (1991) notes that *Sanguisorba minor* can be found in grassland environments. Otherwise the scheme follows that of Behre (1981).
Tall herbs/wet meadows	*Filipendula*, *Centaurea nigra* type, Cyperaceae, *Scabiosa*, *Valeriana* type, *Thalictrum*	Veksi (1998) considered *Valeriana* to be a meadow species.
	Pteridium	Behre (1981) considered *Pteridium* as an indicator of grazed forest, while Oldfield (1963) noted that this species paralleled pasture indicators. Since it can also be found as an understorey species in open woodlands, in heath environments (especially after burning) and may recolonise arable land, this taxa has been separated and the curve discussed individually in the interpretation.

Table 3.2 Land use / habitat categories for selected indicative pollen taxa contd.

3.4.2 Geochemical analyses

One method of developing a multi-proxy approach to evaluate human impact on the environment is to compare and correlate geochemical analyses with pollen profiles. Preliminary geochemical studies on peat deposits were undertaken by Schneider (1963) (in Hölzer and Hölzer, 1998), who suggested that increasing concentrations of iron, aluminium and silica with decreasing depth were the result of wind erosion from the neighbouring mineral soils. Chapman (1964) demonstrated that rises in silica and aluminium in upper peat horizons from Coom Rigg Moss, Northumberland, coincided with increasing NAP curves, especially those of *Plantago*, and were due to the increased supply of wind-blown material as a result of deforestation and the creation of open habitats. The relationship between erosion and organic carbon, sodium and potassium levels in lake sediments and their catchments was investigated by Mackereth (1965). Hölzer and Schloss (1981) demonstrated the connection between silicon in ombrotrophic peat deposits and wind erosion. Similarly, Barber (1981) noted a peak in silica abundances from Bolton Fell Moss at the same time as the pollen data indicated maximum deforestation during the Napoleonic Wars c. 1800 AD. The correlation between silicon, titanium and fire events has been well documented by Hölzer and Hölzer (see for example 1988a; 1995).

The establishment and expansion of settlements, and different farming practices, create changes in the proportion of soil cover, through processes such as deforestation and soil destabilisation, which are reflected by varying intensities of erosion (Hölzer and Hölzer, 1998). This erosional material from bare soils is transported into lakes and ombrotrophic bogs by wind or direct inwash. Silicon (Si) and titanium (Ti) have been identified as good indicators of erosion from forest clearance and farming activities (Hölzer and Schloss, 1981; Görres and Bludau, 1992; Görres and Frenzel, 1993; Kempter *et al.*, 1997). Since they are relatively immobile in the profile, peaks in concentrations can be attributed to increased anthropogenic activity in the late Holocene and subsequently compared to pollen sequences of humanly induced landscape change (e.g. Hölzer and Hölzer, 1988a; 1988b). Another advantage of Si and Ti is that it is possible to measure these elements, even from small samples, with sufficient sensitivity and relatively basic laboratory equipment. Since ombrotrophic peat bogs are rain-fed and therefore mineral poor (Chapman, 1964), they are ideal deposits for studies of this kind because they naturally contain low background values of Si and Ti and therefore even small-scale changes in element abundance can be determined. Lake deposits have also been subjected to geochemical analyses (e.g. Lotter and Hölzer, 1989). However, since lacustrine deposits tend to display a more complicated relationship with their catchment than bogs, and lake sediments may also be subject to processes such as sediment focusing (see Chapter 2), this present study only reports the geochemical results from the peat sites. Furthermore, insufficient material remained from the Lake Gormire core to carry out this technique. Since the pollen and chronological results are similar from both the Southeast and West Bogs at Tregaron, Si and Ti analyses have only been undertaken at the original Southeast Bog site, because it was felt that no more additional information relevant to the aims of this project could be gained.

Pollen indicators of human impact often occur in very low frequencies in pollen diagrams, whereas geochemistry is argued to be a more reliable indication of phases of increased activity (Hölzer and Hölzer, 1994; 1998). This is because human activity, through deforestation and agriculture, results in the immediate mobilisation of Si and Ti particles to deposition sites, whereas pollen production requires germination and then grains are only released during the flowering season for dispersal and deposition. As a result, geochemistry may provide a more rapid response to land use change than pollen analysis. Si and Ti records therefore have the potential to demonstrate short periods of increased activity which may be missed by the pollen record, as well as long-term change. Hölzer and Hölzer (1998) found *Plantago lanceolata* correlated very well with Si and Ti curves, although this species occasionally exhibited a lag behind the geochemical values. The authors suggested that this could be due to the fact that *Plantago lanceolata* recolonises fallow land in rotational farming systems, which would occur some time after the initial ploughing for cultivation. Indeed from their results they argue that peaks of Cereals often precede peaks of *Plantago lanceolata*. They also point out that the degree of time lag is a function of peat accumulation rates.

Hölzer and Hölzer (1998) also argue that Si and Ti analyses provide a more precise erosion signal than the ash content or loss-on-ignition of samples, as these may reflect a composite record of mineral particles as well as calcium carbonate or diatom concentrations, which may have been produced *in situ*. This error is more likely to be a problem in inorganic rather than highly organic sediments.

Si can, however, also be found in certain plants such as Cyperaceae and *Equisetum* in the form of opal phytoliths (Barber, 1981), as well as in diatoms (Hölzer and Hölzer, 1994). Alternatively Ti represents the same parameters as Si but has the distinct advantage of not being found in these sources, although the smaller concentrations of Ti in peats means that it is slightly more difficult to measure. (For example peat sediments contain 0.2% - 2% Si, but only 0.01% - 0.08% Ti (Allen, 1974)). Hölzer and Hölzer's (1998) results show excellent correlations between these two elements, and they argue that concurrent peaks in both proxies are the result of erosion rather than plant or diatom contamination. Ti analysis has been undertaken on the peat sites to complement Si values.

There are some disadvantages, however, with this approach. First, changes in peat composition may influence the geochemical signal, for example the abundance of Si and Ti decreases as wood increases. Secondly, fire affects geochemistry by increasing Si and Ti values. Fire events should, however, be possible to detect during pollen analysis by the identification of macroscopic charcoal remains and those species which are typically associated with the rapid recolonisation of bare soil after burning, such as *Melampyrum*. No significant peaks of charcoal or pollen of this type were identified at Shaw Moss, Tregaron Southeast Bog or Abbeyknockmoy and therefore oscillations in Si and Ti concentrations have been attributed to erosional inputs. Thirdly, in terms of geochemical concentration interpretation, an increase in Si or Ti in a peat layer may be the result of either constant addition coupled with a decrease in peat accumulation rates, or a real increase in Si and Ti addition to the peat surface with a constant peat accumulation rate (Chapman, 1964). Thus the chronology and peat accumulation rate must be taken into account for each site.

In summary "analysis of pollen and geochemistry at very close intervals is better by far than pollen analysis alone, especially with regard to the beginning of an impact and the renewed stabilisation of the vegetation" (Hölzer and Hölzer, 1998 p694). Furthermore, this technique does not appear to have been tested outside of Germany, therefore presenting many opportunities for its application to sites in the British Isles and Ireland.

3.4.2.1 Silicon determination procedure

Laboratory procedures for Si determinations followed Hölzer and Hölzer's method (pers. comm.) of sodium hydroxide fusion and colorimetry by the molybdenum blue method (based on Allen, 1974) with the exception of using ascorbic acid as the reducing solution.

Contiguous 1 cm interval peat samples were dried in an oven at 105°C for four hours and then milled. Using a Mettler A30 balance, 20 mg of the finely ground peat were weighed and placed in nickel crucibles. The crucibles were covered with nickel lids and ashed in a furnace at 250°C for the first 30 minutes and then at a temperature of 550°C for a full day. The crucibles were allowed to cool and three pellets of solid sodium hydroxide were added. The crucibles were immediately covered with lids because the pellets attract water. The covered crucibles were heated in the furnace a second time for approximately three to five minutes at 450°C in order to melt the pellets. The samples were then cooled in a desiccator because of NaOH's attraction of water.

The uncovered crucibles were reheated over a burner with a crucible tong until the solid residue had melted to form a completely clear liquid. After cooling, 15 ml of distilled water were added and the crucibles were placed on a hotplate at a temperature of approximately 90°C until the samples dissolved. The samples were left to cool and then poured into 100 ml polypropylene beakers. The walls of the crucibles were washed with distilled water to ensure the complete transfer of the sample, to a volume of around 35 ml. 5 ml of 5M HCl were added to the beakers and the sample was made up to a volume of 50 ml with distilled water. The samples were then poured into polyethylene bottles.

A blank solution was prepared for each session because conditions had to be kept identical for all samples and standards. To prepare the blank, three pellets of NaOH were placed in a polyethylene beaker, dissolved in 35 ml of distilled water and then 5 ml of 5M HCl were added.

A working Si standard solution also had to be prepared for each batch and this was achieved by diluting 1 ml of Si solution to 100 ml with distilled water.

For the second part of the procedure, three reagents were required. First, the ammonium molybdate–sulphuric acid solution was prepared by dissolving 89g of

$(NH_4)_6Mo_7O_{24}.4H_2O$ in 800 ml of distilled water. Then 62 ml of concentrated H_2SO_4 was diluted to 150 ml by slowly adding it to the water and allowing it to cool. The acid was added to the molybdate solution and diluted to 1 litre. Secondly, tartaric acid was diluted to 28% weight by volume, although the saturated solution of oxalic acid may be used as a cheaper alternative. Finally, 10% weight by volume ascorbic acid was used as the reducing solution rather than Allen's (1974) more complicated reagent. The ascorbic acid solution was shaken to aid dissolution and stored in the dark in the fridge. This solution was prepared every third day.

The method then continued by measuring 5 ml of the blank solution into one polypropylene beaker for the blank and 2 beakers for the standard solutions. 3 ml of the working standard solution (which equals 30 μg of Si) were added to each standard beaker. 5 ml of each of the sample solutions were taken from the bottles and put into separate beakers. As the sample solutions were acidic and the standards alkaline, they were neutralised with 0.1M NaOH and 1+9 HCl dropwise respectively, using phenol red solution as an indicator.

The same method was then applied to the blank, standards and samples. Distilled water was added to each beaker to make the contents up to a volume of 40 ml. Using a "stepper" pipette, 1.25 ml of ammonium-molybdate reagent was added, mixed and left for 10 minutes. Secondly, 1.25 ml of tartaric acid solution was added, mixed and left for 5 minutes. Finally, 1 ml of ascorbic acid was added, mixed and each beaker was diluted with distilled water to a volume of 50 ml. This was left to stand for 15 minutes to allow a stable blue colour to develop. The absorbance of each of the samples and the standards was measured at 810nm using the blank as a reference on a WPA S106 digital single beam spectrophotometer. The calculation used the mean of the two standards, which should measure approximately 0.4. The calibration is linear to at least 50 μg Si/50 ml.

The concentration of Si (ppm) in 1g of peat was calculated from the following equation:

For 20 mg of peat and 5 ml of sample solution –

(30/absorbance of mean standard)*absorbance of sample*50*10 = ppm/g

where 30 represents the 30 μg of Si in the 3 ml of standard solution

50 is needed to multiply 20 mg of peat to obtain 1g

and 10 is needed to multiply the sample size of 5 ml to the total volume of 50 ml

All vessels were washed out with nitric acid before the next preparation to avoid contamination.

Hölzer and Hölzer (pers. comm.) recommend the use of borosilicate glassware. However, this was found to contaminate the samples and as a result polyethylene beakers were used instead. Since these beakers only indicate approximate volumes, the accuracy of the determinations was probably slightly reduced but the magnitude of change should be reliable.

3.4.2.2 Titanium determination procedure

An attempt was made to follow Hölzer and Hölzer's (pers. comm.) laboratory procedure for Ti determinations, which involves fusion with potassium disulphate and then colorimetry by Tiron solution. Unfortunately great difficulties were experienced in trying to obtain the correct Tiron solution, which meant that the Ti analyses were kindly undertaken by Dr. A. Hölzer in Germany. Due to these problems, Ti determinations were made at a coarser resolution than the Si analyses, although the results indicate virtually synchronous peaks in concentrations in the majority of cases, suggesting that the sampling strategy is sufficient for this research. The laboratory method is outlined below.

The peat samples were again dried in an oven at 105°C for four hours and then finely ground. Using a Mettler A30 balance 0.1g of the milled peat were weighed and placed in quartz crucibles. The crucibles were covered with quartz lids and ashed in the furnace at 550°C for a full day. The crucibles were put in a desiccator for cooling. The residual ash was then covered with 0.5g of potassium disulphate powder. The covered crucible was heated over a burner in the fume cupboard using metal tongs for three to five minutes until the ash dissolved and the powder melted to leave a yellow liquid. As this was left to cool, the colour changed from yellow to white or light green.

To avoid spillages the crucibles were placed inside 100 ml polypropylene beakers and opened. 5 ml of 1Molar sulphuric acid were added to the crucibles and washed round the interior of the lids to ensure that none of the sample had been missed. After several minutes a solid pellet formed at the bottom of the crucible which was picked out with plastic tweezers and placed in the beaker. The lids and crucibles were washed out with distilled water and this liquid added to the beaker. The pellets were left to dissolve for two to three hours. The solutions were then poured into 50 ml polyethylene bottles and made up to 50 ml by adding distilled water. These samples could be kept for several days.

A blank solution was also prepared each time using only 0.5g of potassium disulphate, which was heated until it melted and then treated to the same procedure as the other samples.

A working Ti standard solution was also prepared for each batch and this was achieved by diluting 1 ml of Ti solution with 5 ml of 1M sulphuric acid and 44 ml of distilled water.

Three reagents were required for the colorimetric determination. First the sodium acetate-acetic acid buffer solution was prepared by dissolving 136g of sodium acetate trihydrate in 1 litre of distilled water and then 390 ml of glacial acetic acid were added. Secondly, Tiron powder (disodium-1, 2-dihydroxy-benzene-3, 5-disulphate – $C_6H_4O_8S_2.Na_2.H_2O$) was dissolved 5% weight by volume in distilled water. This solution was stored in the dark in the refrigerator and could only be kept for two to three days. Once it had turned yellow it was discarded. Finally, Thioglycollic acid was diluted to 20% with distilled water and this solution could also only be kept for a few days. All work with this acid took place inside a fume cupboard.

The method then continued by measuring 5 ml of the blank solution into one 20 ml volumetric flask for the blank and two flasks for the standard solution. 1 ml of Ti solution (which equals 20µg of Ti) was added to each standard flask. 5 ml of each of the sample solutions were taken from the bottles and put in separate flasks. (The sample volume could range between 1-10 ml, but enough had to be used so that the optical densities of the samples and standards were similar).

The same method was then applied to the blank, standards and samples. 10 ml of the buffer solution was added to each flask and mixed. Using a "stepper" pipette, 2 ml of Tiron solution was added and mixed, followed by 1 ml of Thioglycollic acid and mixed. Distilled water was added to each flask to make up the volumes to 20 ml, the flasks were then shaken and left for one hour to allow a stable colour to develop. The absorbance of each of the samples and standards was measured at 380nm using the blank as a reference on a spectrophotometer. The calculation used the mean of the two standards, which should measure approximately 0.300 – 0.310.

The concentration of Ti (ppm) in 1g peat was calculated from the following equation:

For 100 mg of peat and 5 ml of sample solution –

(20/absorbance of mean standard)*absorbance of sample*10*10 = ppm/g

where 20 represents the 20 μg of Ti in the 1 ml standard solution
        10 is needed to multiply 100 mg of peat to obtain 1g
and   10 is needed to multiply the sample size of 5 ml to the total volume of 50 ml

3.4.3 Tephra

Volcanic ash is one of the tephra products produced during explosive volcanic eruptions. The ash grains of molten glass are violently expelled into the atmosphere and cool without crystallising. The gases trapped inside these tephra shards expand as the pressure is released to produce internal characteristic bubbles or vesicles (Hall and Pilcher, 1993). Tephra shards may be deposited many hundreds of kilometres from their volcanic source (Westgate and Gorton, 1981; Dugmore *et al.*, 1996) forming discrete microscopic layers of fine-grained ash particles that are well-preserved in peat (and some soil), lacustrine and marine environments. Tephra shards can be identified microscopically by their morphology and vesicularity (both of which are controlled by the properties of the magma and the eruptive mechanism) and their isotropism in plane-polarised light (Westgate and Gorton, 1981). Electron probe microanalysis (EPMA) is needed, however, to determine the geochemical composition of individual glass shards, which can indicate the source of the ash and can be used to distinguish between separate eruptions (Dugmore *et al.*, 1996). EPMA is a grain-discrete technique which therefore avoids the problems associated with bulk analysis, such as the presence of inclusions, the occurrence of foreign particles and weathering products on the surface of shards and the possibility of detrital glass reworked from older tephras (Westgate and Gorton, 1981).

Dugmore (1989) was the first to find tephra in the British Isles by recovering ash produced by the Icelandic eruption of Hekla 4 c. 4,000 BP from peat deposits in Caithness, northern Scotland. Since then tephra horizons have been recorded from Shetland (Bennett *et al.*, 1992), Scotland (e.g. Blackford *et al.*, 1992; Dugmore *et al.*, 1995a; 1996; Langdon, 1999), the north of Ireland (e.g. Pilcher and Hall, 1992; Hall *et al.*, 1993; 1994; Pilcher *et al.*, 1996) and northern England (Pilcher and Hall, 1996; Langdon and Barber, pers. comm.). The stratigraphic value of a tephra horizon is only fully realised when its individual characteristics have been isolated and its age determinated. Once these tephra horizons are found from multiple sites they form extensive isochrones or planes of equal age (Dugmore, 1989) that can provide a means of precisely correlating sediments and refining radiocarbon chronologies (Westgate and Gorton, 1981; Hall *et al.*, 1994). The data from such research are being used as a framework to build an increasingly stratigraphically detailed and spatially more extensive tephrochronology of the British Isles.

This framework is based on the assumptions that a tephra horizon is deposited instantaneously (in geological terms) and posses a unique geochemical signature (Hunt and Hill, 1993). Experiments by Dugmore *et al.* (1992) have demonstrated that shards retain their individual geochemical characteristics in spite of different depositional environments and varying distance from source, while also remaining unchanged over a time span of at least c. 4,000 years. Two techniques are being used to construct this tephrochronology (Pilcher *et al.*, 1996). First, historic tephras from the last 1,000 years can be geochemically linked to reliably documented and thus precisely calendar dated eruptions. Hence tephrochronologies are particularly valuable for the last millennium because of the problems associated with the use of radiocarbon dating in this period (Pilcher *et al.*, 1995; Dumayne *et al.*, 1995). A further discussion of this will be presented in Section 3.5. Historic tephra horizons not only constrain radiocarbon chronologies, but also allow precise correlation of contemporaneous pollen analytical events between tephra-dated profiles and enable direct comparison of the palaeoenvironmental record with historical documentation.

The second technique relies on high-precision multisample radiocarbon dating of the sediment matrix containing those ash layers that predate historical records (Pilcher *et al.*, 1995, Dugmore *et al.*, 1995b). Since the present study aims to concentrate on the last 1,000 years, only those historic tephras will be discussed in greater detail. A discussion including prehistoric tephra isochrones in the British Isles can be found in Dugmore *et al.* (1995a), Pilcher and Hall (1996), Pilcher *et al.* (1996) and Langdon (1999).

Larsen *et al.* (1999) geochemically typed nine silicic tephras of historical age produced by the five central volcanoes in Iceland. These consist of the Hekla 1104 AD, 1158 AD, 1510 AD, 1947 AD; Öræfajökull 1362 AD, 1727 AD; Eyjafjallajökull 1821 AD; Torfajökull (Landnám tephra) c. 870 AD; and Askja 1875 AD. They demonstrate that generally the element composition of the glass shards is significantly unique that discriminations between eruptions, even from the same volcano, can be made. There are, however, cases when the chemical signature is not sufficiently different between eruptions for unambiguous determination. For example the shard geochemistry of Hekla 1104 AD is similar to that of Hekla 3 (tree-ring dated to 59 BC by Pilcher, 1993), and Hekla 1947 AD shards are similar to those from Hekla 1510 AD. In these cases, when the difference may be some 2,000 or 450 years respectively, other techniques must be considered such as stratigraphy and radiocarbon assay. Not all of these tephras have been found in the British Isles (see Table 3.3). Indeed, of those isochrones recovered from British sites there is no guarantee that all will be present in any one deposit. This is because the distribution of tephra shards is thought to be closely associated with the pattern of rainfall at the time of and after the eruption, resulting in a "patchy" deposition and thus producing significant spatial variability in the British record (Dugmore *et al.*, 1995a). Finding such tephra layers would therefore benefit the present study, since "firm correlations between those distal tephra deposits and volcanic source areas enable precise, historically documented dates of Icelandic eruptions to be incorporated into the stratigraphic records of the British Isles" (Larsen *et al.*, 1999 p463).

Table 3.3 Historic tephras identified from the British Isles

Historic tephra	Icelandic geochemistry (after Larsen *et al.*, 1999) (mean % for sample population)	British and Irish location and researcher	Geochemical description and comments
Hekla AD 1510	SiO_2 62.69; TiO_2 0.95; Al_2O_3 15.17; FeO 7.82; Mno 0.23; MgO 1.31; CaO 4.5; Na_2O 4.42; K_2O 1.74	Lairg, Sutherland, Scotland and Loch Portain (a), Western Isles, Scotland (Dugmore *et al.*, 1995a; 1996)	SiO_2 57% - 64%
Loch Portain (b) - ? c. 450 rc years BP	Not definitely matched	Lairg and Loch Portain (as above)	Si_2O > 70% The origin of this smaller population is unknown. It could be a second eruption within c. ± 80 years, or the earliest erupted tephra of the AD 1510, although some shards show characteristics similar to Öræfajökull AD 1362 (Dugmore *et al.*, 1995a)
Hekla AD 1510	As above	Garry Bog and Sluggan Bog, north of Ireland (Pilcher *et al.*, 1996)	Garry Bog mean %: SiO_2 62.35; TiO_2 0.98 Sluggan Bog mean %: SiO_2 60.91; TiO_2 1.03
Öræfajökull AD 1362	SiO_2 71.36: TiO_2 0.22; Al_2O_3 13.14; FeO 3.12: MnO 0.10; MgO 0.03; CaO 0.98; Na_2O 5.55; K_2O 3.38	Garry Bog and Sluggan Bog (as above and Pilcher *et al.*, 1995) Garvaghullion Bog (Hall, 1998)	Sluggan Bog mean %: SiO_2 71.63; Al_2O_3 13.41; TiO_2 0.29; MgO 0.03 Garry Bog (Pilcher and Hall, submitted)

Hekla 1 AD 1104	SiO_2 72.24; TiO_2 0.19; Al_2O_3 13.95; FeO 3.23; MnO 0.12; MgO 0.14; CaO 1.85; Na_2O 4.30; K_2O 2.74	Garry Bog and Sluggan Bog (as above) Owenbeg, north of Ireland (Pilcher *et al.*, 1996)	Both the populations at Garry Bog and Sluggan Bog are mixed with shards from other eruptions. Sluggan Bog mean % (excluding shards from another population): SiO_2 71.91; TiO_2 0.26; Al_2O_3 14.37; MgO 0.13 Owenbeg mean %: SiO_2 72.53; TiO_2 0.27; Al_2O_3 15.04; MgO 0.14
"AD 860" layer Radiocarbon dated by Pilcher *et al.* (1996) to AD 776-887	Origin unknown	Sluggan Bog (Hall *et al.*, 1993; Pilcher *et al.*, 1995) Ballyscullian East, north of Ireland (Hall *et al.*, 1993) Langlands Moss, Scotland (Langdon, 1999)	The shards from Sluggan Bog show two distinct populations. Population 1 mean %: SiO_2 74.09; TiO_2 0.21; Al_2O_3 12.76; MgO 0.08 Population 2 mean %: SiO_2 71.89; TiO_2 0.28; Al_2O_3 14.43; MgO 0.42 The results obtained from Ballyscullian East were not reliable because the shards contained high concentrations of K. Langdon (1999) also found two distinct populations.

Table 3.3 Historic tephras identified from the British Isles contd.

In this study, tephra analysis was only undertaken at the three original peat sites (Tregaron Southeast Bog, Shaw Moss and Abbeyknockmoy Bog). Since the profile from the West Bog at Tregaron dates from the same period and has a very similar pollen record to that of the Southeast Bog, this site was not investigated for volcanic ash because similar results were expected. The lake deposits were also excluded from tephra analysis. This was due to the fact that whereas peat deposits are predominantly organic, meaning that tephra can easily be extracted and identified, lake sediments generally contain higher inorganic component, which can be difficult to remove (Rose *et al.*, 1996). If all the inorganic material is not removed, it can obscure the tephra shards, yet choosing chemicals that will only dissolve the mineral debris and leave the tephra intact can also be problematic. Rose *et al.* (1996) have produced a method to isolate tephra from lake sediments, but it is relatively involved and is thought to alter the chemistry of the shards. The complex processes operating in lakes also offers greater potential for the reworking of material (Dugmore *et al.*, 1995a).

3.4.3.1 Ashing procedure

The ashing technique followed that of Pilcher and Hall (1992), with some modifications by Langdon (1999). The cores were sampled at contiguous 5cm intervals and then ashed in the furnace at 600°C for four hours. After the samples had cooled down, the remaining ash was suspended in 10% HCl acid to remove the soluble inorganic fraction, centrifuged and the supernatant acid pipetted off. The samples were then washed in distilled water. Pilcher and Hall (1992) note that samples with a high clay content require sieving at this stage with a 24μm mesh. This was unnecessary for the preparation of samples in this project, and therefore the residues were simply subjected to a second wash in distilled water. The material was pipetted onto heated microscope slides to evaporate off the excess liquid and mounted in Histomount.

The samples were identified at x100 and x400 magnifications using shard morphology, vesicularity and isotropism under plane-polarised light (Westgate and Gorton, 1981). Some problems were experienced when ashing did not remove all of the organic matter because of the potential of obscuring the shards. This only occurred in the top two or three samples of the profiles. Once tephra was identified in a 5 cm slice, the core was subsampled at 1 cm intervals in order to pinpoint the exact stratigraphic depth of the maximum ash horizon.

The temperature at which the samples are ashed alters the alkali content of the shards, thus making it inappropriate for electron probe microanalysis (Dugmore *et al.*, 1995a). Consequently the method for electron microprobe preparation is outlined below.

3.4.3.2 Electron microprobe slide preparation and operating procedure

Tephra shards for EPMA were isolated using an acid digestion technique (Dugmore, 1989). Inside a fume cupboard, 3 cm^3 of peat were taken from the horizon of sediment containing the highest concentration of shards and disaggregated in a conical flask. 50 ml of concentrated H_2SO_4 were then added to the flask. A few ml of concentrated HNO_3 were added to the flask by pipette and the vessel was shaken gently. A few drops of Octan-2-ol may be necessary if there is a vigorous reaction producing an excess of foaming. Once brown fumes were given off and the foam disappeared quickly after shaking the flask, the solution was brought to the boil and then left to simmer on a hotplate for approximately one hour, or until the contents of the flask turned clear or pale yellow. More drops of concentrated HNO_3 were added slowly if the fumes turned white. After cooling, 500 ml of distilled water were added and the samples left to stand for three hours. The supernatant liquid was decanted off and the remaining sediment washed several times in distilled water until the contents were neutral. The wet residue was pipetted into a small petri dish where the excess liquid was left to evaporate.

Slide preparation for microprobe analysis follows the method described by Langdon (1999). Slides were frosted using a 600 grit carborundum powder and then cleaned in an ultrasonic bath in petroleum ether. Araldite was mixed with an hardening epoxy resin in proportions of 9 to 1 and then placed on the slide. The dried sample was collected from the petri dish using a spatula and dropped in the resin mixture and stirred thoroughly. The slide was left to harden on a hot plate for approximately five hours, until the resin formed a solid layer of between 200-250 μm above the slide surface.

In order to expose some of the tephra shards from the resin, the surface of the hardened araldite was ground down to 70-100 μm above the slide surface using wet 600 μm and 1,000 μm carborundum paper. The slides were then washed in petroleum ether in an ultrasonic bath. The surfaces of the slides were polished with a diamond paste. A preliminary polish using a 6 μm diamond paste was followed by a second polish with 1 μm diamond paste to ensure that as many grooves as possible were removed leaving the surface smooth enough for EPMA. Finally the slides were coated in carbon to provide a conducting surface layer and to create a path for the probe current (Reed, 1993). To complete the preparation, the edges of the slides were covered in colloidal graphite, with a small amount touching the sample to ensure maximum conductivity across the slide.

The samples were then analysed by a Cambridge Instruments Microscan V electron microprobe at the Geology Department, Edinburgh University, through the NERC Tephrochronology Unit. This technique bombards the individual tephra shards with an electron beam in order to produce X-rays. The sample composition can be determined as the X-ray energy is unique to each element, and their intensity is proportional to the amount of element present (Hunt and Hill, 1993). Grains of tephra were first identified on the slides by using energy dispersive spectrometry and then quantitatively analysed for their geochemical composition by using a standard wavelength dispersive technique. Once this has been determined, the population of tephra shards can be correlated to known tephra isochrones. Analyses were carried out using an accelerating voltage of 20kV, beam current of 15nA and a beam diameter of 1-2μm.

The beam current was allowed to stabilise for approximately 30 minutes, after which the verification procedure was carried out whereby any spectral drift of the probe was measured. The microprobe was calibrated by checking the standards of the nine major elements at the beginning of each session, which consisted of silicon (Si), sodium (Na), potassium (K), titanium (Ti), magnesium (Mg), manganese (Mn), iron (Fe), calcium (Ca) and aluminium (Al). An andradite standard of known geochemical composition was measured before and after each sample of tephra grains to ensure that the beam was operating under stable conditions. Unfortunately, the small number of tephra shards meant that background counts, which would render a shard useless for quantitative analysis, could not be undertaken in this instance (P. Hill, pers. comm.). Background counts were therefore retrieved by the computer from the previous user of the probe.

Each tephra shard was analysed by two spectrometers so that five passes were sufficient to measure the nine major elements mentioned above, with a counting time of 10 seconds for each element. Due to the volatilisation of Na when exposed to an electron beam, this element was measured at both the beginning and end of each shard analysis, which allowed some assessment of the mobility of Na during the measurement procedure. The results of each analysis were recorded by computer and the data were corrected for counter dead time, atomic number effects, fluorescence and absorptions using a ZAF correction program based on Sweatman and Long (1969). The results from the EPMA are shown in Chapter 4.

3.4.4 Charcoal

Charcoal has been defined by Patterson *et al.* (1987) as an amorphous organic carbon compound which results from the incomplete combustion of plant tissues, which should not be confused with carbonaceous particles originating from oil and fossil fuel combustion. The identification of microscopic charcoal from sediments is a key technique for reconstructing past fire regimes (including frequency and intensity of fires) and previous fire importance (Tolonen, 1986; Clark, 1988a). It has been assumed that aerial deposition and post-fire erosion of charcoal produced by fires close to lakes and bogs will result in increased charcoal abundance in fossil sediments (Patterson *et al.*, 1987). In contrast to pollen analysis, the theory underlying microscopic charcoal investigations has been somewhat neglected, although there are discussions such as those by Patterson *et al.* (1987) and Clark (1988a).

The amount of charcoal recorded from stratigraphic levels in a profile depends on the quantity originally produced, which is then affected by dispersal and deposition processes (Cwyner, 1978), as well as by preservation, sampling, preparation and counting methods. "The ability to identify the extent to which each of these variables influences charcoal data would add much to our understanding of source areas of charcoal and so permit sound interpretation of results" (Clark, 1988a p68).

Rhodes (1998) reviews the different methods available for microscopic charcoal analysis. The majority of previously published investigations quantified charcoal abundances from pollen microscope slides, largely because simultaneous charcoal and palynological counts reduced the number of sample preparations needed and minimised counting times. He describes four main strategies for quantifying charcoal from pollen slides: "absolute particle abundance" where all particles are counted (e.g. Davis, 1967); "size class methods" where particles are categorised according to predetermined size groups depending on diameter or surface area (e.g. Swain, 1978); "point count methods" which record the number of hits on charcoal particles scored by a standard number of points on an eyepiece graticule during scans of a predetermined area of slide (Clark, 1982); and "subjective estimates" made on five or seven point scales or estimating percentages (e.g. Tallis, 1975). "The method of charcoal quantification adopted is at the discretion of the analyst as no single method has been proved to be superior to all the others" (Rhodes, 1998 p116).

The pollen slide technique is subject to a number of problems. First, the sieving, centrifuging and stirring necessary for pollen preparations may break up the charcoal fragments into smaller particles, with obvious implications for size classifications (Rhodes, 1998). Secondly, charcoal can be susceptible to oxidation and degradation from the chemicals used in pollen extraction techniques. Thirdly, charcoal is generally identified by three characteristics: an angular morphology, uniformly black in colour and completely opaque (Tinner *et al.*, 1998), yet it can be confused with other microscopic remains such as pyrite crystals and some organic matter (Patterson *et al.*, 1987). Furthermore, Clark (1988a) notes that different preparation techniques can result in the preservation of different size fractions of charcoal particles. For example charcoal from pollen slides tends to be between 5 - 80μm in diameter, whereas the alternative technique of petrographic thin sections (Clark, 1988b) preserves microscopic charcoal remains between 50 – 10,000μm in diameter.

Other techniques which have tried to overcome these problems include automated image analysis (MacDonald *et al.*, 1991); chemical digestion techniques (e.g. Rhodes, 1998) - although they may not be able to discriminate between burnt organic material and carbon produced from the combustion of fossil fuels - as well as disaggregating peat samples in water and estimating percentage charcoal cover from gridded petri dishes (Simmons and Innes, 1981). Rummery *et al.* (1979) and Rummery (1983) investigated the possible use of environmental magnetics to indicate periods of increased fire activity. This was based on the fact that when soils are burnt they undergo magnetic enhancement due to the production of secondary ferrimagnetic oxides, which would then be eroded into lake sediments. Such enhancement forms magnetically distinct persistent layers in the profile, which may be detected using the magnetic parameters of susceptibility (χ) and saturation isothermal remanent magnetisation (SIRM). Tinner *et al.* (1998), however, found that this technique does not always prove to be entirely reliable when results are compared to documented fire histories.

In addition to inconsistencies in the methods used for charcoal analysis between different researchers, which can hamper inter-site comparisons, there is still much debate over the interpretation of charcoal data. Clark *et al.* (1989) state that consideration of the relative sizes of charcoal fragments could provide a framework for estimating the distance of fire from the deposition site. For example Clark (1988) argues that the smaller particles found on pollen slides record regional fire histories because they remain in suspension longer and therefore have the potential to be transported greater distances than larger charcoal fragments found on thin sections, which are deposited in closer proximity to the fire and are thus indicators of local or within-catchment fire episodes. Alternatively Pitkänen *et al.* (1999) found that particles collected during an experimental low-intensity fire included the same sizes as those that are found on pollen slides and therefore these small charcoal fragments of approximately 50 - 600μm^2 may also be indicative of local fires within the catchment. Although they did conclude that it was often impossible to identify individual fire events from pollen slide-sized charcoal. Patterson *et al.* (1987) suggest that Jacobson and Bradshaw's (1981) model of pollen source area in relation to size of deposition site (see Chapter 2) might be applicable to charcoal analysis. This would therefore suggest that small lakes could reconstruct local fires within 20 – 30m of the site, whilst large sites would record more regional fire histories, yet it does not seem to take into account charcoal particle size. Further difficulties in terms of the interpretation of fire records stem from the fact that the charcoal could derive from a number of sources. This could include the burning of standing vegetation (whether it be natural, such as fires caused by lightning strikes, or anthropogenically induced), or the result of burning firewood for domestic use or stubble burning (Edwards, 1990). Finally, unless annually varved lake sediments are available, there is always the problem of trying to correlate an individual fire event with the fossil record that is often amalgamating 5 – 20 years of sediment accumulation per sample (Clark, 1988a).

The more successful reconstructions of fire histories appear to be from either wooded areas (e.g. Cwynar, 1978; Swain, 1978) or prehistoric sequences prior to large scale clearance where increases in charcoal abundances may be linked to pollen evidence for early agriculture (e.g. Clark *et al.*, 1989; Tinner *et al.*, 1999).

In this study, microscopic charcoal remains from Talkin Tarn (TAL2) were counted simultaneously with pollen grains from microscope slides using routine pollen preparation techniques due to the reasons discussed. All charcoal fragments were counted, but they were not assigned size classifications because it has been shown that the smallest size class often strongly correlates with the larger size groups (Tolonen, 1986; Edwards, 1990; Tinner *et al.*, 1998). Charcoal concentrations were calculated from counting a proportion of a known quantity of exotic *Lycopodium* spores (Tinner *et al.*, 1998), and using the equation:

$$\text{Charcoal concentration} = \frac{\text{charcoal counted}}{\textit{Lycopodium}\text{ counted}} * \frac{\text{number of }\textit{Lycopodium}\text{ added}}{\text{cm}^3\text{ of sediment}}$$

Since samples from Lake Gormire had been submitted to magnetic susceptibility measurements (courtesy of Dr. Andrew Roberts, Southampton Oceanography Centre and Prof. Frank Oldfield and Prof. John Dearing, University of Liverpool, see section 3.6.1), it was hoped that periods of increased fire activity would be identified by this technique (c.f. Rummery, 1983). Charcoal particles were not counted from the peat sites because of the uncertainties as to whether the record was reacting to *in situ* burning of the mire surface or aerial deposition from fires in the catchment (c.f. Edwards, 1990). There is some doubt, however, as to how useful the fire records can be from such unlaminated recent deposits in a relatively open environment, with the sources of charcoal being so diverse.

3.5 AMS radiocarbon dating

Radiocarbon (the ^{14}C isotope) is formed continuously by the action of cosmic rays on nitrogen atoms in the upper atmosphere, where these ^{14}C atoms combine with oxygen to form CO_2 which then becomes incorporated into the Earth's carbon cycle (Pilcher, 1991a). The continual radioactive decay of ^{14}C is balanced by its perpetual production to form a dynamic equilibrium (Lowe and Walker, 1984). Initially, radiocarbon theory was based on the assumption that the production of ^{14}C was constant, thus resulting in a constant amount of ^{14}C in the atmosphere (Pilcher, 1991a). All living matter absorbs ^{14}C atoms through the CO_2 cycle in a ratio which is equal to that of atmospheric CO_2 and ^{14}C decay is constantly replenished in organic tissues by new ^{14}C from the atmospheric reservoir (Lowe and Walker, 1984). Following death, however, ^{14}C decay continues within the organic tissues but no replacement can take place (Bell and Walker, 1992). Hence, if the rate of decay is known, the date of death can be computed by measuring the ^{14}C activity. Radiocarbon convention uses the Libby half life of 5568±30 years, with AD 1950 as the base year (i.e. the present) for calculating radiocarbon years before present (BP) (Stuiver and Polach, 1977).

Pioneering work by de Vries (1958), however, demonstrated that atmospheric concentrations of ^{14}C have varied over time. Since it does not vary systematically there is no theoretical equation that can be applied to convert radiocarbon ages to calendar ages (Pilcher, 1991b). Instead, empirical calibrations using "combined, high-precision ^{14}C/dendrochronological data sets based on Irish and German oaks, Douglas fir, sequoia and bristlecone pine now document about 9800 years of dendrochronological time with 20-year (bidecadal) time-ring segments" (Taylor *et al.*, 1996 p656), such as those of Stuiver and Pearson (1993) and Pearson and Stuiver (1993). Decadal calibrations also exist, such as those of Stuiver and Becker (1993). Such calibrations convert conventional radiocarbon ages of ^{14}C time (Stuiver and Polach, 1977) to calibrated time (cal. years BP or cal. BC/AD). Since the calibration relationship is not regular, a single calibrated radiocarbon date may in fact represent several "true" ages or fall somewhere between a range of ages (Aitken, 1990; Pilcher, 1991a). Furthermore, much larger ranges of calibrated ages may be experienced if the sample ^{14}C age happens to coincide with a plateau on the calibration curve (Taylor *et al.*, 1996).

There can be several sources of error in ^{14}C dating. For example the combined effects of industrial activity and atomic explosions mean that modern organic samples are not suitable for radiocarbon dating (Lowe and Walker, 1984). This is obviously an issue for the timeframes being considered in this research, and explains why there are few radiocarbon determinations from the surface sediments. A second source of error stems from the fractionation of carbon isotopes by plants (Pilcher, 1991a). In this case, different groups of plants selectively absorb carbon isotopes in slightly different proportions, thus creating a different ratio to that contained in atmospheric CO_2. The radiocarbon laboratory should apply an isotopic fractionation correction factor to compensate for this (Stuiver and Polach, 1977). Thirdly, errors may potentially be introduced through the "hard water" effect. This generally applies to lacustrine sediments where aquatic plants, and organisms living off them, use CO_2 or bicarbonates that have been dissolved in the lake water, but actually have been derived from much older carbonate rock in the catchment (such as limestone or chalk) and therefore are not in equilibrium with atmospheric CO_2 (Pilcher, 1991a). For example, 200 to 1200 years were added to the apparent age of samples at Diss Mere due to the limestone geology (Peglar *et al.*, 1989).

Contamination is also an issue which occurs when older or younger ^{14}C has been added to the sample prior to, or during collection, preparation and measurement (Lowe and Walker, 1984). For instance older carbon may be eroded from organic material in catchments and washed into accumulating lake sediments, or through the reworking of older and more resistant plant material (Wohlfarth *et al.*, 1998). In peats, rootlet penetration may bring younger carbon down to stratigraphically older layers, whereas the "reservoir effect" may store fossil carbon on Ericaceous rootlets thus resulting in the uptake of older carbon (Kilian *et al.*, 1995). Furthermore, Shore *et al.* (1995) found that different age estimates could be obtained from dating the fulvic acid, humic acid and humin fractions of the peat matrix, while Wohlfarth *et al.* (1998) suggested that modern fungi and micro-organisms could contaminate macrofossil samples if stored in cool, wet conditions for any length of time.

Radiocarbon determinations for age estimates may be undertaken on bulk sediments or AMS (Accelerator Mass Spectrometry) techniques can be used on samples several orders of magnitude smaller than those for bulk estimates. This latter method separates ^{14}C atoms by their difference in mass rather than radioactivity. Since AMS dates involve manually selecting the above-ground material that is to be dated (van Geel and Mook, 1989), they can avoid some of the problems presented by bulk dates where "peats normally consist of a mixture of short lived components (mosses), remains of older components such as *Calluna* stems and the roots of younger plants that will have penetrated the sediment from above, together with mobile soluble material" (Pilcher, 1991a p20). While it is recognised that AMS dates are not more precise than bulk dates due to greater statistical counting uncertainties (Oldfield *et al.*, 1997), they may be more accurate because of the smaller sample size required which relates directly to the pollen spectrum being analysed (Hedges, 1991). Furthermore, the small size of AMS samples in contrast to an approximately 8 cm thick stratigraphic slice of peat for a bulk date allows determinations to be more closely spaced down a profile, which is important when relatively short timeframes are being investigated and substantial changes in pollen profiles can occur over only 2-3 cm of peat (Dumayne *et al.*, 1995).

Thus all the radiocarbon dates on the peat sites in this research are from AMS determinations, while due to the lack of macrofossils at some levels in the Talkin Tarn profiles, some lake mud itself had to be dated. Lake Gormire was considered unsuitable for radiocarbon dating because of outcrops of limestone in the catchment which could have resulted in the sediments being subjected to the "hard water" effect. Dating for this site is detailed in the following section.

Although the selection of plant macrofossils for their contemporaneity with the horizon of matrix to be dated may help to avoid some of the problems mentioned by Shore *et al.* (1995), the choice of macrofossils themselves for AMS dating is important. For example Kilian *et al.* (2000) found that pure *Sphagnum* samples (>98%) produced the best correlation with the calibration curve, similarly *Sphagnum* with higher quantities of other above-ground remains did not produce observable deviations from the atmospheric ^{14}C record, whilst charred material was more problematical. In this last case, charred macrofossils of *Calluna vulgaris* resulted in a ^{14}C age consistent with pure *Sphagnum* samples, suggesting a local origin for this material, but the sample containing unidentified burnt wood fragments was 350 ^{14}C years too old, suggesting that it had originated from a fire event near the bog margins. Consequently in this study, samples where possible of pure *Sphagnum* were submitted to the NERC Radiocarbon Laboratory, but in some cases, especially from the very decomposed peat horizons, mixed samples had to be selected. Every effort was taken to ensure that charred material was of *Ericaceae* type, rather than unidentified wood.

Due to the very detailed fluctuations in the calibration curve (wiggles), large numbers of AMS dates at narrow and sometimes consecutive stratigraphic intervals can be used to produce a section of floating calibration curve that can be correlated to wiggles on the established calibration curve. This is known as wiggle match dating (van Geel and Mook, 1989) and has been used successfully by Clymo *et al.* (1990), Kilian *et al.* (1995) and van Geel *et al.* (1998) amongst others. Due to the large numbers of dates required for wiggle match dating and thus the expense involved, only one site (Tregaron Southeast Bog) was originally considered for this technique. However, in light of the range finder dates that indicated a possible hiatus in this profile, it was decided that wiggle match dating was not suitable in this case.

The four peat profiles in this research received a total of 20 AMS dates from the NERC Radiocarbon Steering Committee, while the two cores from Talkin Tarn (TAL1 and TAL2) received two and nine dates respectively. All radiocarbon dates were calibrated using the online version of CALIB 4.3 (http://radiocarbon.pa.qub.ac.uk/calib/calib.html) (Stuiver and Reimer, 1993; Stuiver *et al.*, 1998). All ages are quoted as calibrated years

AD/BC to two standard deviations (except for those from the TAL1 profile which is of Lateglacial origin and are quoted in calibrated years BP), meaning that there is a 95% probability that the "true" date lies somewhere in the stated age range. Age-depth models of peat accumulation (see Chapter 4) have been constructed on the basis that the time-depth relationships of peat deposits are generally linear (c.f. Mauquoy and Barber, 1999; Kilian *et al.*, 2000), although Clymo (1984) argues that they may be slightly concave due to long-term decay. Similar assumptions were used to construct an age-depth model for the TAL2 profile from Talkin Tarn.

Problems of correlating events registered in radiocarbon dated pollen diagrams with calendar dated archaeological or historical events have been well documented (Dumayne *et al.*, 1995). Baillie (1991) demonstrated that there are two consequences when comparing calibrated ranges of radiocarbon time with calendar dates produced by dendrochronology. First, there is the "suck-in" effect, where for example a palynological "event" with a relatively large calibrated age range, may be assigned to a known archaeological or historical phenomenon which happens to fall in that age interval. Secondly, the converse situation may occur when a synchronous event is "smeared" across a wide period of radiocarbon time, possibly as the result of inflections in the calibration curve. Therefore to answer specific chronological questions about a single pollen analytical event may require a series of closely spaced, if not contiguous, high-precision or AMS wiggle matched dates (Dumayne *et al.*, 1995). There are, however, constraints in terms of costs and the number of dates available, and it is hoped that in this study horizon-specific AMS dates combined with correlation to the documentary record, the possibilities of tephrochronologies and a "realistic appraisal of the situation" (Aitken, 1990 p99) will be sufficient to answer the research aims and test the hypotheses set out in Chapter 1.

3.6 ^{210}Pb dating

Lead-210 (^{210}Pb) has been used to date and estimate sedimentation rates in recent lacustrine deposits (e.g. Appleby *et al.*, 1979; Dearing, 1992; Varvas and Punning, 1993). This technique has been applied to Lake Gormire in this study since radiocarbon dating is not suitable in this instance due to possible errors from the "hard water effect" (see Section 4.3.1). ^{210}Pb is a naturally produced radionuclide which forms part of the ^{238}U (uranium) decay series and has a half life of 22.26 years (Lowe and Walker, 1984; Oldfield and Appleby, 1984). Disintegration of the intermediate isotope ^{226}Ra (radium) produces the inert gas ^{226}Rn (radon) which in turn decays through a series of short-lived isotopes to form ^{210}Pb (Oldfield and Appleby, 1984). ^{226}Ra is washed into lake sediments as part of the erosional input from the catchment and the ^{210}Pb concentration formed by the *in situ* decay of this isotope is known as "supported" ^{210}Pb, which is assumed to be in radioactive equilibrium with the ^{226}Ra (Oldfield and Appleby, 1984). This equilibrium is upset by the deposition of ^{210}Pb in lake basins by dry fall-out and it is also washed out of the atmosphere by precipitation. This is known as the "unsupported" or "excess" ^{210}Pb.

The supported ^{210}Pb activity is usually calculated from measurements of the ^{226}Ra activity and subtracted from the total ^{210}Pb activity to give the unsupported ^{210}Pb activity (Wise, 1980). In this study, total ^{210}Pb activity was determined by a proxy method through measuring its granddaughter nuclide ^{210}Po (Cundy, pers. comm.). As the unsupported ^{210}Pb decays according to the radioactive exponential decay law, the supported activity becomes relatively more important down-profile, until it makes the measurement of unsupported ^{210}Pb inaccurate (Wise, 1980). This therefore imposes a limit on the dating potential of this method to approximately the last 100 to 150 years (Lowe and Walker, 1984).

In this research the ^{210}Pb dating was carried out courtesy of Dr. Ian Croudace and Dr. Andy Cundy at the Southampton Oceanographic Centre and the age/depth profile of Lake Gormire was calculated using the "simple model" of ^{210}Pb dating after Robbins (1978) (Cundy, pers. comm.). This approach is based on the assumptions that the supply of unsupported ^{210}Pb to lake sediments and the sedimentation rate are both constant, so that the concentration of unsupported ^{210}Pb per unit weight of sediment will decline exponentially with depth (Wise, 1980). The sedimentation rate can be determined graphically by the slope of the least squares fit for the natural log of the unsupported ^{210}Pb activity versus depth (Cundy, pers. comm.).

The assumption of a constant sedimentation rate, however, cannot always be satisfied (Wise, 1980), especially when human impact has often led to changes in the sediment accumulation rate due to processes such as catchment erosion and eutrophication. Oldfield and Appleby (1984) discuss alternative models which take account of varying sedimentation rates and therefore may produce more reliable results which could have better agreement with independent dating evidence. There are also problems associated with these models because not enough is known about the routing of ^{210}Pb through the environment. Thus if large quantities of ^{210}Pb enter lake sediments via catchment soils or vegetation, then the total amount of ^{210}Pb incorporated into the sediment surface each year is less likely to be constant (Wise, 1980).

It is understood that "the choice between alternative models has a major impact on the results and their interpretations" (Appleby *et al.*, 1979 p53), but unfortunately access to all the parameters necessary for such alternative models is currently unavailable. It is hoped that the "simple" approach will provide a rough estimate of age and sedimentation rate that can be compared to existing accumulation rates for Lake Gormire (Oldfield and Wake, pers. comm.).

An attempt was made to constrain the ^{210}Pb dates by measuring ^{137}Cs (caesium) activity, courtesy of Dr. Croudace and Dr. Cundy at the Southampton Oceanography Centre. ^{137}Cs is an artificial radionuclide that is only produced in significant quantities through fission reactions, such as atmospheric thermonuclear weapons testing after 1954 AD (Wise, 1980). The concentrations of this isotope are known to have varied temporally and thus peaks in profiles can be correlated to the following documented years of increased activity: 1957-59, 1962-64 and 1971. Secondly, the pine pollen concentrations from the Lake Gormire core (GOR1) should give a depth estimate for the date of c. 1800 AD when local pine plantations were established.

Since problems with the results of the "simple" ^{210}Pb dating model are recognised, an attempt was made to correlate the existing core (GOR1) with previously ^{210}Pb dated cores, which used alternative dating models, based on magnetic susceptibility measurements (Oldfield and Wake, pers. comm.).

3.6.1 Magnetic measurements

The magnetic susceptibility of individual samples, reinforced by the measurement of other magnetic parameters such as SIRM (as discussed with relation to fire history in section 3.4.4), is a recognised method for correlating lake cores from the same basin (Thompson *et al.*, 1975; Bloemendal *et al.*, 1979). Thus the magnetic measurements from core GOR1 should allow correlation with the previously analysed and ^{210}Pb dated cores from the same area of the lake (Oldfield and Wake, pers. comm.). The magnetic parameters of core GOR1 were measured at contiguous 1 cm slices using a Bartington MS2B dual frequency susceptibility sensor courtesy of Dr. Andrew Roberts at the Southampton Oceanography Centre and at 2 cm intervals by a Molspin Pulse Magnetizer and Bartington Susceptibility Meter courtesy of Prof. John Dearing, Prof. Frank Oldfield and Mr. Bob Jude at the University of Liverpool. The results of both the ^{210}Pb and magnetic analyses are discussed in Chapter 4.

3.7 Historical Documentation

The majority of documentary evidence referred to in this project has come from secondary sources involving books, reports and journals. Some primary sources were used in this research, including early editions of maps and photocopies of early 20th century agricultural records (courtesy of the Central Statistics Office, Cork). Access to the archival collection containing some original copies of books published in the 19th century (e.g. Tuke, 1800) was kindly permitted by Southampton University Library (Special Collections). Some facsimilies of books published in the 18th and 19th centuries were also available to the author. Visits were made to record offices local to the sampling sites, although unfortunately much information was too specific for comparison with the pollen and geochemical reconstructions of vegetation and land use change.

3.8 Other techniques considered

3.8.1 Spheroidal carbonaceous particle counts

Spheroidal carbonaceous particles (SCP's) are produced by the incomplete combustion of fossil fuels (Rose *et al.*, 1999). These particles are deposited in lake and bog sediments and provide an historical record of recent atmospheric pollutant deposition. This record shows similar patterns from sites in both Britain and Ireland and the "SCP dating approach relies on relating consistent particle trends in undated cores to those which have previously been dated using a reliable technique such as ^{210}Pb chronology or varve counting" (Rose *et al.*, 1995 p330).

The characteristic shape of the particle record usually allows three dates to be recognised. First, the start of the SCP profile has been attributed to developments during the Industrial Revolution, which has been dated to c. mid-19th century in England and generally slightly later in Ireland. Secondly there is a rapid increase in particle concentrations after World

War II in the 1940's due to expansions in both energy demand and the power generation industry. Finally a sub-surface peak due to increased coal consumption in the late 1970's and early 1980's is followed by a sharp decline in concentrations, which is thought to be the result of more stringent air pollution legislation (Rose *et al.*, 1995). These dates do differ within and between regions of the UK and Ireland due to differences in local industrial histories, therefore meaning that to obtain the most accurate dating correlation, an undated core ideally needs to come from a region which has previously been investigated and where a detailed chronology has been established. Unfortunately, two sites in this investigation come from areas where a regional reference record has yet to be established, such as northeast England and mid to south Wales, and currently there is only one dated profile from the Galway region of Ireland (Rose *et al.*, 1995).

Furthermore, the start of the SCP record and the rapid increase in concentrations appear to cover broad bands of time which may make assigning precise dates difficult, although Rose *et al.* (1995) argue that the errors are no worse than those encountered using ^{210}Pb dates for this period. In addition, experiments by Rose *et al.* (1999) on the within-basin variability of SCP profiles indicated that although all the lake cores considered demonstrated the characteristic pattern used for dating, several profiles shared considerable " noise", possibly due to localised sediment focusing or disturbance, which again raised questions over the potential accuracy of the dates.

Since pine pollen peaks had already been obtained for each pollen profile from the palynological investigations, which are generally taken to represent c. 1800 AD as a result of the establishment of plantations, it was decided that SCP counts would not be undertaken as well. Although SCP concentrations have been used successfully (e.g. Chambers *et al.*, 1999), it was felt that the recent dating potential this techniques offers would not contribute much more detail than the pine data and would therefore not aid significantly in meeting the aims and objectives set out in Chapter 1. Furthermore, evidence from the caesium results at Lake Gormire indicate that some mixing has occurred in the surface sediments (see Chapter 4) therefore suggesting that SCP's would not be appropriate at this site because "mixing .... would seriously affect the resolution of the surface peak, making it a lower and broader feature with a wide range of attributable dates" (Rose *et al.*, 1995).

3.8.2 Detrended correspondence analysis

Whittington and Edwards (1995) used numerical ordination techniques to arrange pollen taxa so that those behaving in a similar manner are graphically situated close together. There are a number of ordination techniques available, but detrended correspondence analysis (DCA) is recognised as being one of the most sophisticated and widely used (Whittington and Edwards, 1995). They suggest that such numerical studies of pollen data may reveal changes in crop regimes and land use over time. Consequently, this technique was considered for the present research.

Several difficulties with the method were encountered and therefore it was decided that this area of research could be more thoroughly investigated in the future. First, Whittington and Edwards (1995) suggest that a taxon should attain at least 2% of the pollen sum in a minimum of one stratigraphic level from each zone on which the DCA was to be performed. This 2% limit was chosen so as to reduce the possibility of any spurious correlations resulting from taxa represented by extremely low frequencies. However, many of the indicative species for anthropogenic activity from the pollen diagrams in this project did not meet this 2% criterion and therefore many species had to be excluded from the analysis. Down-weighting for such species was considered, but this was thought likely to bring subjective bias to the results. Indeed in a similar ordination exercise undertaken by Turner (1986) the down-weighting of taxa with low frequencies was omitted because it was considered unwise to bias further a data set in which taxa of different pollen productivity and dispersal were already involved. Furthermore, the authors mentioned above do not indicate whether the data are transformed or not, and it is also unclear as to whether those taxa not included in the pollen sum should be treated by the DCA in the same way as those taxa included in the sum calculations.

3.9 Summary

The use of geochemical analyses in addition to palynological investigations allows a multi-proxy approach to reconstructing human impact and land use change over time. This is believed to be the first time that silicon and titanium records have been correlated with pollen analytical evidence of anthropogenic activity in Britain and Ireland. These techniques, combined with detailed comparison to the historical record are considered suitable for meeting the aims and objectives of the project set out in Chapter 1.

Chapter 4 – Chronology

4.0 Introduction

In order to compare the palaeoecological evidence for human impact and land use change with the documentary record, a sound and relatively detailed chronology is necessary for each core under investigation. The pollen analytical results (see Chapter 5) were used to identify horizons of particular interest for AMS radiocarbon determinations. AMS radiocarbon dates are, however, subject to a number of errors (as discussed in section 3.5), as well as the problems related to "suck-in" and "smear" (Baillie, 1991) which can cause difficulties when comparing radiometric age estimates to absolute calendar years (Dumayne *et al.*, 1995) (see section 3.5). As a result, a multi-proxy strategy to dating has been adopted in order to minimise these potential problems. Thus AMS radiocarbon dates (see section 3.5) have been supplemented by tephra (where available) (see section 3.4.3), pine rise data (see section 4.1.1 and Chapter 5) which can provide a date in recent sediments where radiocarbon assays are not suitable, and ^{210}Pb dates on Lake Gormire, where radiocarbon determinations were not applicable (see section 3.6). Magnetic susceptibility measurements (see section 3.6.1) were also used at Lake Gormire to correlate the ^{210}Pb chronology with an existing ^{210}Pb profile from the same site.

4.1 AMS radiocarbon dating

The results of 31 AMS radiocarbon assays, courtesy of the NERC Radiocarbon Steering Committee, from the NERC Radiocarbon Laboratory, East Kilbride, are presented in Table 4.1. Following Dumayne *et al.* (1995) the mid-point of the two sigma error range for each date was used to construct an age-depth model for the individual peat sites and the profile from TAL2. An age-depth model was not constructed for the TAL1 profile since only two AMS dates were obtained, especially as they demonstrated significant hiatuses in sediment accumulation. A linear regression model was fitted to each of the sets of radiocarbon dates to enable calculation of the average peat accumulation rate (Brew and Maddy, 1995). A high R^2 value represents a "good" fit of the data by the linear regression model, which can be considered the best estimate of average peat accumulation rates (Barber *et al.*, 1994b). The accumulation rate has been used to interpolate the age of pollen analytical or geochemical events that fall between dated horizons. Such interpolations assume that peat growth remained constant between the radiocarbon dated samples from the linear model, and therefore only offer approximate age estimates.

Tephra horizons have been used to constrain the radiocarbon chronology and thus the age-depth model at Abbeyknockmoy Bog (see section 4.2).

All radiocarbon dates received for this research were calibrated using the online version of CALIB 4.3 (Stuiver and Reimer, 1993; Stuiver *et al.*, 1998) (see section 3.5). All ages are quoted as calibrated years AD/BC to two standard deviations (apart from the dates on the profile of Lateglacial origin, which are quoted as calibrated years BP), meaning that there is a 95% probability that the "true" date lies somewhere in the stated age range. Dates published by other authors are quoted in their original form, rather than being calibrated or re-calibrated using CALIB 4.3 unless where stated. On the following age-depth models (Figures 4.1 to 4.6c), AMS radiocarbon determinations included in the regression are denoted by filled circles; outlier AMS dates excluded from the trend line are identified by blank squares; tephra horizons are demonstrated by blank triangles; and the pine rise is indicated by a filled diamond. The reasons for excluding certain radiocarbon dates from the linear regression models are discussed in the relevant section for each site.

4.1.1 Pine rise data

Historical records indicate that planting generally began on country estates in the late 18th century in Britain and Ireland, which became more widespread in the 19th century as a result of the establishment of commercial plantations, which have continued to increase throughout the 20th century (see Chapter 7). This is reflected particularly well in the pollen diagrams by the increase in *Pinus* pollen (see Chapter 5). The first increase above background levels is thought to originate from the late 1700's AD, with more substantial frequencies dating from the beginning of the 1800's AD. This pine rise event has been added to the age-depth models since radiocarbon determinations are not suitable for dating more recent sediments (see Chapter 3). The pine rise data have not been used in calculating the following linear regression models.

4.1.2 Abbeyknockmoy Bog

Figure 4.1 shows the age-depth model from Abbeyknockmoy Bog, where a linear regression model fits the data with an R^2 value of 0.9822. An outlier date (AA36264) is obvious from the graph and has thus been excluded from the age-depth model. This date is several hundred calibrated radiocarbon years younger than would be expected from its stratigraphic position within the peat core, which may be the result of contamination by rootlet penetration bringing more modern carbon down the profile. Using this model, an average peat accumulation rate of approximately 21.3 years/cm can be calculated. A similar accumulation rate of 29.2 years/cm was obtained from a 2.5m core from the same site based on an age-depth model of ten radiocarbon dates (Barber, *et al.*, in prep.). This is somewhat slow for an Atlantic raised bog and may reflect some shrinkage of the peat due to marginal cutting and draining.

Table 4.1 AMS radiocarbon results

Laboratory No.	Site	Depth (cm)	Sample contents	^{14}C date BP	$\delta^{13}C_{PDB}$‰ (± 0.1)	Cal. range AD/BC (2 sigma)* - BP where applicable	Mid-point of the 2 sigma cal. range (rounded to nearest decade)
AA36260	AKM'99	23	*Sphag*; *C v*-c; *R a*; *E t* - c	285±40	-25.90	1488 – 1789 AD	1640 AD
AA36261	AKM'99	30	*E t*; *C v*	570±40	-28.50	1304 – 1425 AD	1370 AD
AA36262	AKM'99	44	*Sphag*	935±45	-25.90	1019 – 1199 AD	1110 AD
AA36263	AKM'99	67	*C v*; *E t*	1220±45	-28.90	686 – 937 AD	810 AD
AA36264	AKM'99	79	*Sphag*; *R a*; *C v*	440±45	-28.9†	1407 – 1624 AD	1520 AD
AA36265	AKM'99	96	*E t*; *C v* – c; *Sphag*	1940±50	-28.9†	45 BC – 213 AD	80 AD
CAMS-64375	TRE'98	20	*Sphag*; Eric-c; *E v* spin	820±40	-27.70	1128 – 1284 AD	1210 AD
CAMS-60857	TRE'98	37	*E v* spin	1610±40	-26.40	347 – 544 AD	440 AD
CAMS-60859	TRE'98	54	*Sphag*; Eric-c	1820±40	-27.00**	86 – 327 AD	210 AD
CAMS-60858	TRE'98	71	*Sphag*; *Polyt*; Eric-c	2090±40	-27.90	202 BC – 2 AD	100 BC
CAM-66652	TRWA2000	30	*Sphag*	900±40	-26.4	1034 – 1214 AD	1120 AD
CAM-66651	TRWA2000	54	*Sphag*	1060±40	-22.6	894 – 1026 AD	960 AD
CAM-66650	TRWA2000	97	*Sphag*	1540±40	-25.4	429 – 603 AD	520 AD
CAM-66649	TRWA2000	115	*Sphag*; *C v*	1700±40	-27.0	250 – 421 AD	340 AD
CAM-66648	TRWA2000	146	*Sphag*	1910±40	-28.1	19 – 218 AD	120 AD
AA36255	SAW2	39	*Racom*; *Men t*; *Sphag*	1885±50	-26.70	18 – 244 AD	130 AD
AA36256	SAW2	60	*Sphag*	2145±45	-25.10	358 – 49 BC	200 BC
AA36257	SAW2	72	*Sphag*	2415±55	-25.40	762 – 395 BC	580 BC
AA37708‡	SAW2	96	*Sphag*	2790±48	-25.1	1046 – 827 BC	940 BC
AA36259	SAW2	120	*Sphag*	2705±50	-25.90	968 – 798 BC	880 BC
CAMS-68461	TAL1	46.5	Detrital mud	3560±30	-27.50	3961 – 3723 BP	3840 BP
CAMS-68462	TAL1	70.5	*Drep ex*	10250±40	-27.30	12346 – 11700 BP	12020 BP
CAMS-70069	TAL2	24	Detrital mud	2440±40	-26.7	761 – 404 BC	580 BC
CAMS-70068	TAL2	34	Detrital mud	2340±40	-26.2	536 – 234 BC	390 BC

CAMS-70067	TAL2	46	Detrital mud	2010±40	-27.0	148 BC - 79 AD	30 BC
CAMS-70066	TAL2	58	Detrital mud	1600±50	-27.1	342 - 597 AD	470 AD
CAMS-68463	TAL2	74	Detrital mud	1670±40	-27.10	256 – 529 AD	390 AD
CAMS-70065	TAL2	90	Detrital mud	3640±40	-27.7	2136 - 1891 BC	2010 BC
CAMS-70064	TAL2	106	Detrital mud	3050±40	-28.2	1410 - 1132 BC	1270 BC
CAMS-68464	TAL2	117	Detrital mud	2660±50	-28.00	918 – 777 BC	850 BC
CAMS-70063	TAL2	138	Detrital mud	3040±40	-28.4	1407 - 1132 BC	1270 BC

Key:

Sphag – *Sphagnum* leaves and stems

C v – *Calluna vulgaris* leaves and wood

C v-c – *Calluna vulgaris* (some remains charred)

R a – *Rhynchospora alba* seeds

E t – *Erica tetralix* leaves and wood

E t-c – *Erica tetralix* (some remains charred)

Eric – Ericaceae leaves and wood

Eric-c – Ericaceae leaves and wood (some remains charred)

E v spin – *Eriophorum vaginatum* spindles

Polyt – *Polytrichum* branches

Racom – *Rhacomitrium* stems

Men t – *Menyanthes trifoliata* seeds

Drep ex – *Drepanocladus exannulatus* leaves

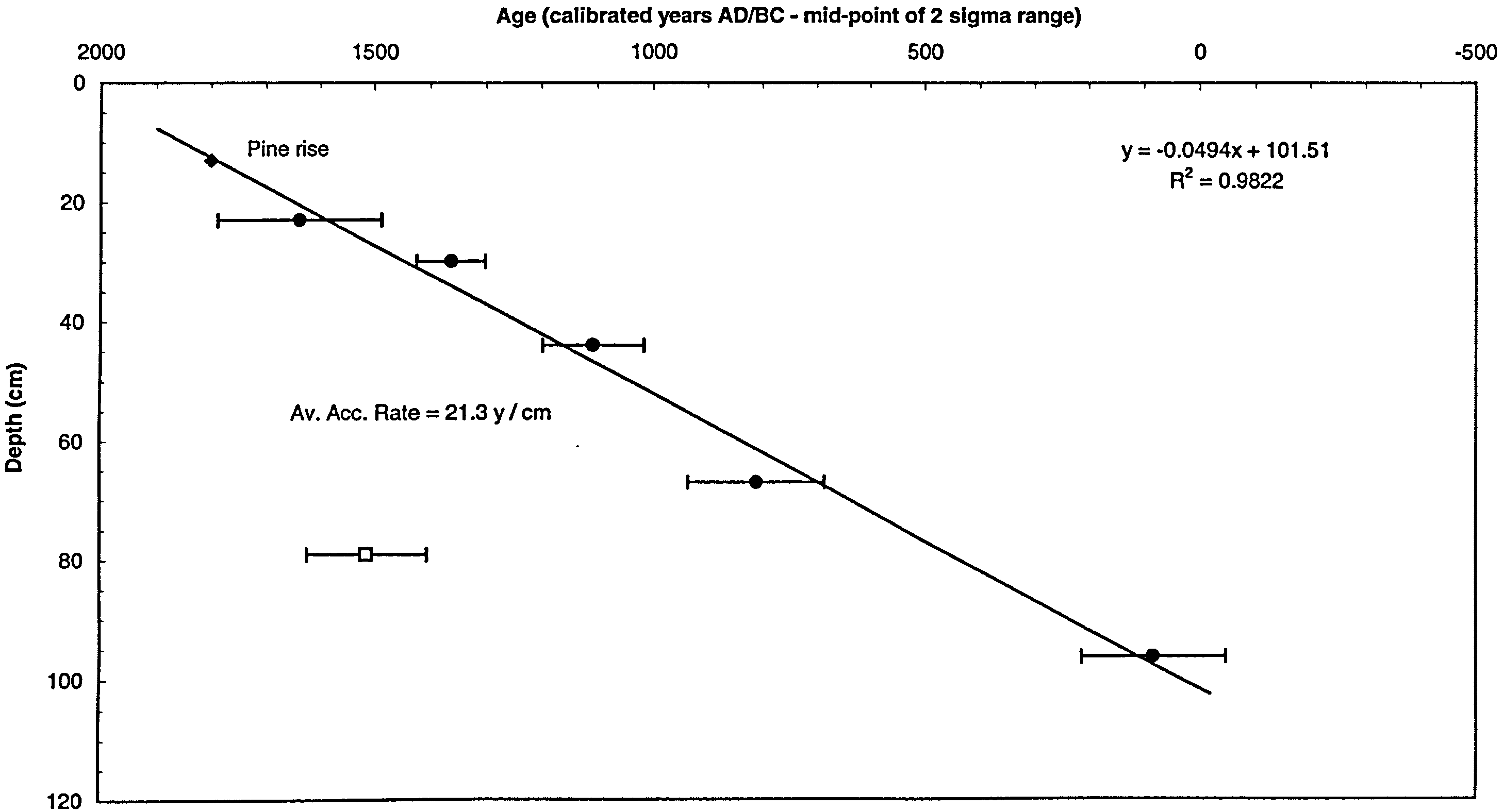
* calibrated using Calib 4.3 (Stuiver and Reimer, 1993; Stuiver *et al.*, 1998)

† estimate $\delta^{13}C$ value – insufficient sample material for an independent $\delta^{13}C$ measurement

** M/Spec trace was bad; no back-up for $\delta^{13}C$, estimated value used

‡ The original AMS determination at this level (AA36258) produced poor currents and therefore yielded poor precision. The archived gas was graphitised and re-dated (AA37708).

Figure 4.1 Age-depth model for Abbeyknockmoy Bog (AKM'99)



The radiocarbon chronology indicates that the top metre of peat accumulated over c. the last 2,000 years. The age-depth model for this site is constrained by one geochemically typed tephra isochrone, although the other tephra horizon found in this profile remains unknown (see Figure 4.9). The tephrochronology of Abbeyknockmoy Bog is discussed in more detail in section 4.2.1.

4.1.3 Tregaron Bog

In light of the radiocarbon results received from the Southeast Bog, which proved to be approximately 1,000 years older than anticipated, a second core was analysed from the West Bog at Tregaron in an attempt to reconstruct the last millennium in more detail (see section 3.1). The age-depth models for each bog are discussed below.

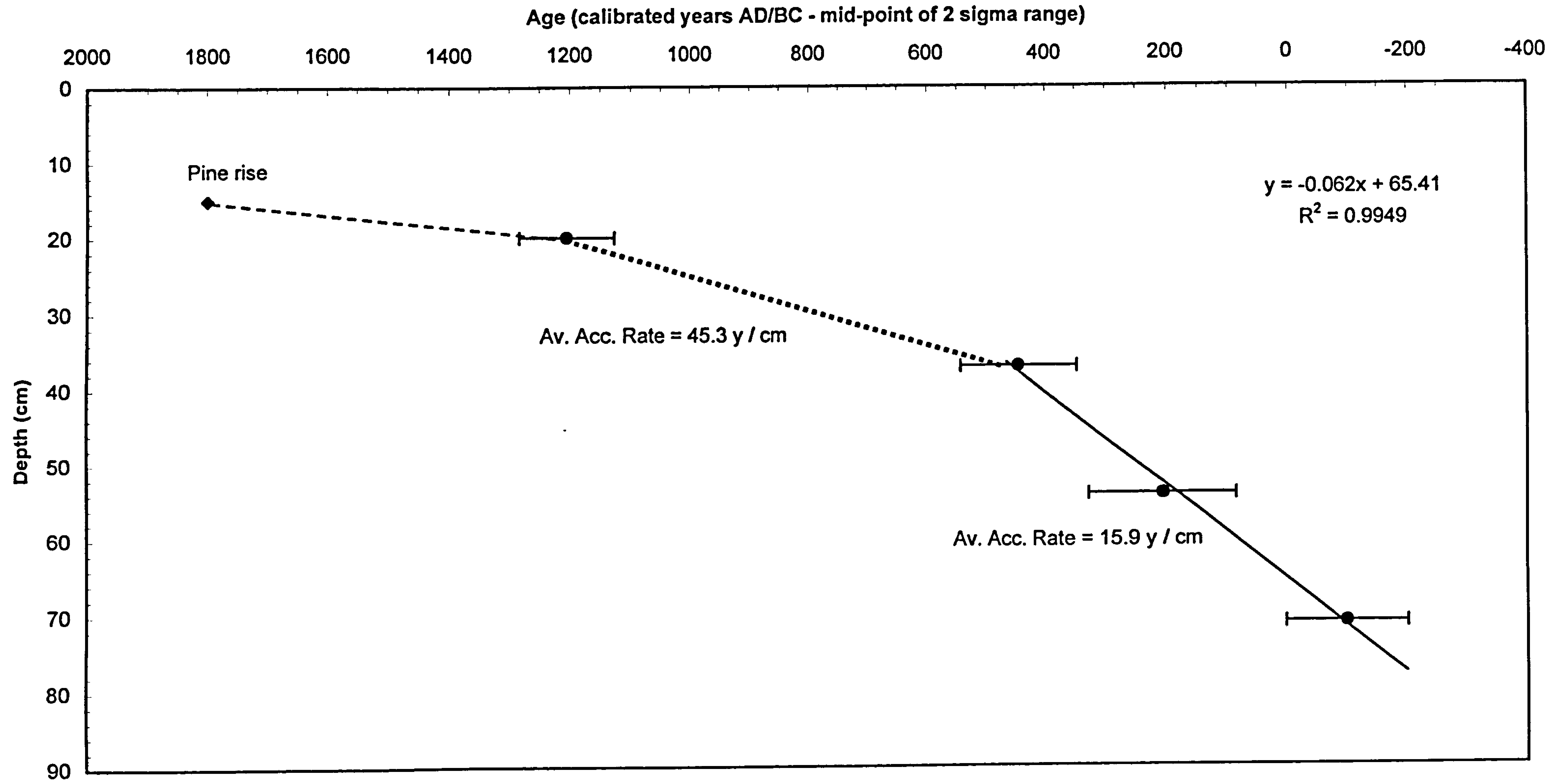
4.1.3.1 Southeast Bog

Several different trend lines for the age-depth model from this profile were explored, including a linear regression through all the radiocarbon determinations and a second order polynomial fit, although a two-stage linear regression appears to be most representative of the data (see Figure 4.2) (c.f. Lowe *et al.*, 1995). The first stage of the linear regression, incorporating the three stratigraphically lowest points, produces an R^2 value of 0.9949 and results in an average peat accumulation rate of approximately 15.9 years/cm, a growth rate similar to that of an ombrotrophic bog investigated in Cumbria (Barber *et al.*, 1994b). The second "leg" of the regression is fitted to only two radiocarbon dated horizons and indicates that the average peat accumulation rate dropped between c. cal. 450 AD – 1200 AD to approximately 45.3 years/cm. Indeed Turner (1964b; 1965) found a similar pattern in a core taken from the eastern edge of the Southeast Bog where peat accumulation rates varied between (all dates mentioned below are uncalibrated):

170 cm – 63 cm (696 bc – ad 473) = 10.9 years/cm
170 cm – 82 cm (696 bc – 404 bc) = 3.3 years/cm
82 cm – 63 cm (404 bc – ad 473) = 46 years/cm
63 cm – 52 cm (ad 473 – ad 1182) = 64 years/cm (from Barber, 1982).

Despite the fact that a date of c. cal. 1200 AD is recorded from a depth of 20 cm (see Figure 4.2), the overlying peats must date from c. 1800's AD onwards due to the high frequencies of pine pollen counted (see Chapter 5 for pollen analytical results). This presents the question, what caused such a dramatic decrease in peat accumulation rates?

Figure 4.2 Age-depth model for Tregaron Southeast Bog (TRE'98)



This question will be considered in more detail in section 4.1.3.3, after discussion of the chronology established from the West Bog.

4.1.3.2 West Bog

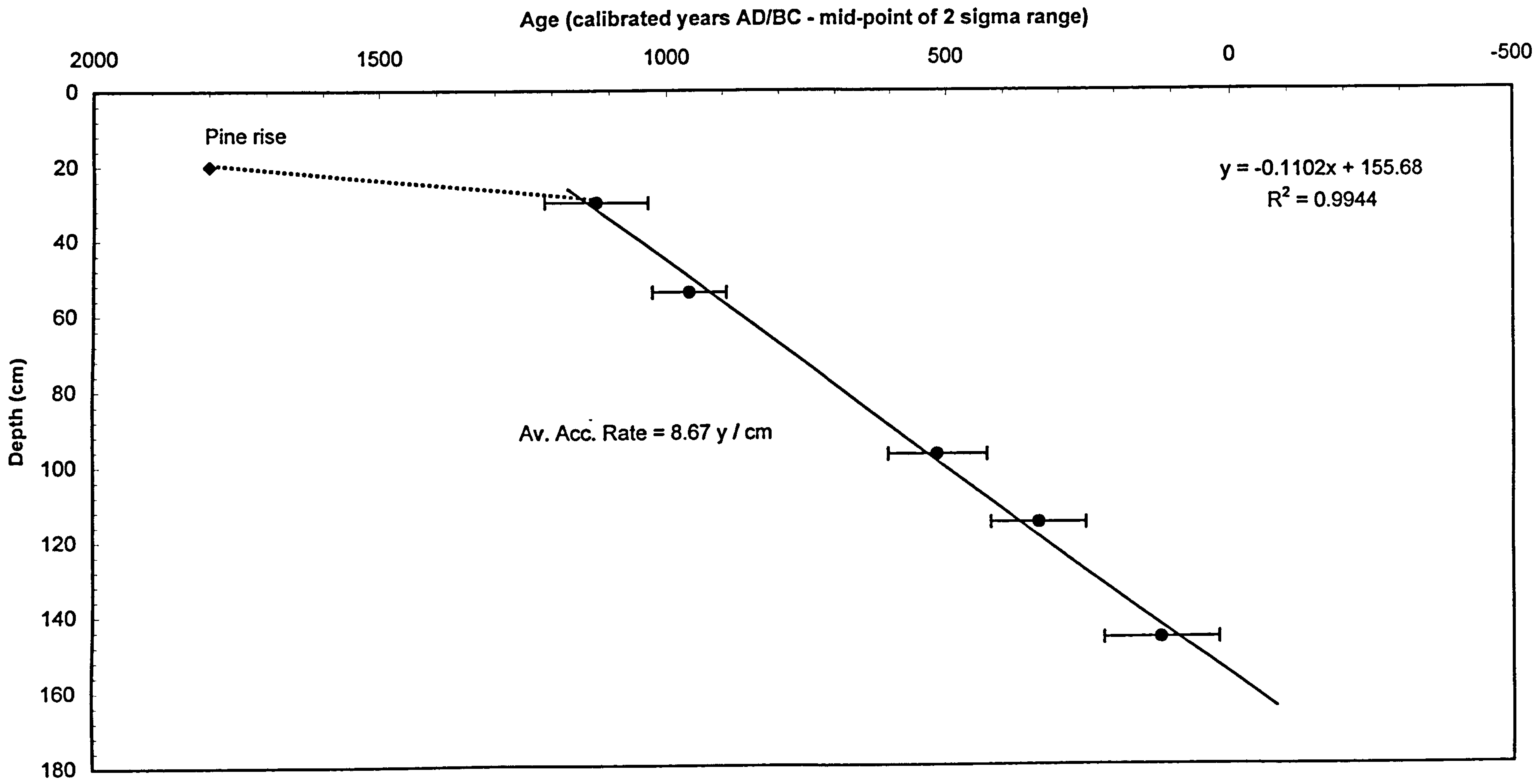
A linear regression best fits the data with an R^2 value of 0.9944 (see Figure 4.3). This can be used to calculate an average peat accumulation rate of around 8.67 years/cm until c. cal. 12th century AD at a depth of 30 cm. Again, however, the overlying peats are thought to be relatively modern (c. 1800's AD) due to the high frequencies of pine pollen present (see Chapter 5 for pollen analytical results). Therefore an event, or combination of events, appear to have caused a decline in peat accumulation rates similar to that at the Southeast Bog.

4.1.3.3 Possible causes of changes in peat accumulation rates

There are several potential causes for the decline in peat growth rates at both the Southeast and West Bogs. First, there is the possibility of uniform cutting of the entire peat surface across both bogs. This, however, is considered unlikely due to no references of cutting on such a scale in the documentary record or previous research (e.g. Godwin and Mitchell, 1938; Godwin and Conway, 1939). There are also no indications of such widespread activity from the aerial photo of the mire complex (see Plate 3.2), from the undisturbed nature of the current mire surface vegetation, or from the pollen evidence which demonstrates that there is no simultaneous sharp change across all of the pollen frequency curves, as would be expected from an hiatus caused by large-scale peat removal by cutting.

Marginal cutting may have had a more significant effect on the mire deposits. Godwin and Conway (1939) note that the Southeast Bog suffered more heavily from marginal cutting than the West Bog, which can be seen from Plate 3.2 and from the plate in Appendix 8. Such activity may have affected the hydrology of the bogs. Indeed, Godwin and Conway (1939 p320) noted cutting at the southern, southwestern and northern margins of the West Bog, "the effect of which has been to remove the natural rand and to drain the neighbouring parts of the bog surface. It has in particular, given a steepened run-off to marginal streams so that in the southwest especially large areas are being rendered bare by the early stages of water erosion".

Figure 4.3 Age-depth model for Tregaron West Bog (TRWA2000)



If this did occur at the Southeast Bog in the c. cal. 5th and 6th centuries AD, it may explain why the peat accumulation rate drops from approximately 15.9 years/cm to around 45.3 years/cm between c. cal. 450 AD – 1200 AD as parts of the surface of the bog could have dried out and shrunk. Further cutting encroaching deeper into the centre of the Southeast Bog may then have taken place in the c. cal. 12th and 13th centuries AD, resulting in an even slower accumulation rate prior to the development of the upper 15 cm of peat. Perhaps the smaller scale of marginal cutting at the West Bog in relation to its large areal extent accounts for the steady peat accumulation rate of approximately 8.67 years/cm until c. cal. 12th century AD, when peat cutting may have become significant enough to affect the hydrology of the bog. The surface vegetation, however, shows no signs of large-scale disturbances.

The River Teifi runs between the Southeast and West Bogs and it is possible that a drop in water level of the river might affect the hydrology of the bogs. Indeed, Godwin and Mitchell (1938) found evidence of fluctuating water levels from the stratigraphy of the Southeast and West bogs. Such a phenomenon could perhaps be the result of human influence, for example through building weirs and dams, or straightening sections of the river's course, or through clearance activity in the river's catchment. It is interesting to note that peat growth rates from both profiles slowed rapidly in the c. cal. 12th and 13th centuries AD, which coincides with known monastic activity in the vicinity of the bogs from 1164 AD onwards with the establishment of Strata Florida Abbey (Jones Pierce, 1950). Although Cistercian monks were well known for their agricultural activities (e.g. Bowen, 1950; Lekai, 1977) caution must be expressed when assigning this a possible causal factor due to the "suck-in" effect associated with radiocarbon age ranges (Baillie, 1991) (see section 3.5).

Another possible explanation concerns burning of successive peat surfaces by local fires caused by the railway that bordered the northeastern margin of the Southeast Bog. This is thought unlikely because it would be difficult for fires caused by the debris from steam trains to cross the River Teifi and cause extensive burning on the West Bog. Furthermore, very little macroscopic charcoal has been found in the fossil record from the West Bog (Schülz, in prep.), although Godwin and Conway (1939) documented that the Southeast Bog had suffered from burning in the 1930's.

The decline in accumulation rates in both the Southeast and West Bogs may alternatively be the result of natural climatic factors. This explanation may account for the fact that accumulation rates drop virtually synchronously in terms of both time (c. cal. 1206 AD and c. cal. 1124 AD respectively) and depth (20 cm and 30 cm) at both mires. Indeed, Godwin and Mitchell (1938) identified a "retardation layer" consisting of a band of black, very well humified, amorphous peat in all three of the remaining bogs in the Tregaron complex. At one profile from the Southeast Bog, this layer occurred at a depth of between c. 30-45 cm, although unfortunately the technique of radiocarbon dating had not been established when this research was carried out. This stratigraphically distinct horizon is over- and underlain by fresher, less humified, lighter coloured *Sphagnum* peat (Godwin and Mitchell, 1938). It is possible that this black, well humified peat layer was the result of the surface of the mire drying out causing a "phase of arrested bog development" (Godwin and Conway, 1939 p 355). This could possibly have occurred during the Medieval Warm Period (MWP) in c. the 12th and 13th centuries AD. Godwin and Conway (1939) explain that during dry periods, bogs lose water through transpiration and evaporation faster than it can be replenished by precipitation, resulting in a general lowering of the water table. Thus desiccation occurs in the highest, central area of the bog first as the peripheral lower regions of the bog remain wet because they are still supplied by the water table, which although now flatter, retains its convex shape allowing water to flow towards the bog margins. This would have the effect of reducing peat accumulation rates in the centre of the mires, which is where both cores were collected from.

It is, however, interesting that the resumption of peat growth does not appear to have been triggered by the cooler, wetter climate of the Little Ice Age (LIA) in the c. 14th and 15th centuries AD. This may have been because the water table in the bogs dropped to such a depth that climatic conditions in the LIA were not sufficient to increase the water table to a level that would have changed the surface plant communities back to *Sphagnum* mosses. Detailed analyses of the macrofossils from the West Bog during these two periods are currently underway (Schülz, in prep.), which may provide more evidence to support this hypothesis and provide an explanation for why the peat should resume accumulating in a later century.

The behaviour of mire growth demonstrated here may provide evidence for various theoretical models of bog development. For example Osvald (1923) put forward the idea of "Stillstand" where peat accumulation stops for a period of time. Alternatively, these age-depth models may provide evidence for the "ground-water mound" theory (Ingram, 1982; Ingram and Bragg, 1984). This theory states that a raised peat bog consists of two components; a core of humified peat ("catotelm") which occupies most of the deposit and is overlain by a thin (25-50 cm) "acrotelm" which is the active layer of peat growth. The catotelm is held in a permanent state of saturation by "impeded drainage" or more specifically through a dynamic equilibrium between replenishment from the atmosphere and seepage of water into lagg streams. The bog's water table is close to the surface of the peat in the acrotelm. This is known as a "ground-water mound" which follows the elliptical shape of a raised bog.

If the theory is correct, it follows that the removal of peat from the edge of the elliptical mound near a lagg stream would force the ground-water mound to drop and then re-adjust to the new profile of the bog. This would result in a drop in water table level, especially at the crown of the bog, leaving this section to be more exposed to drying out and ultimately decreasing peat accumulation rates. It is worth noting, however, that this theory is not universally accepted (e.g. Brown, 1997).

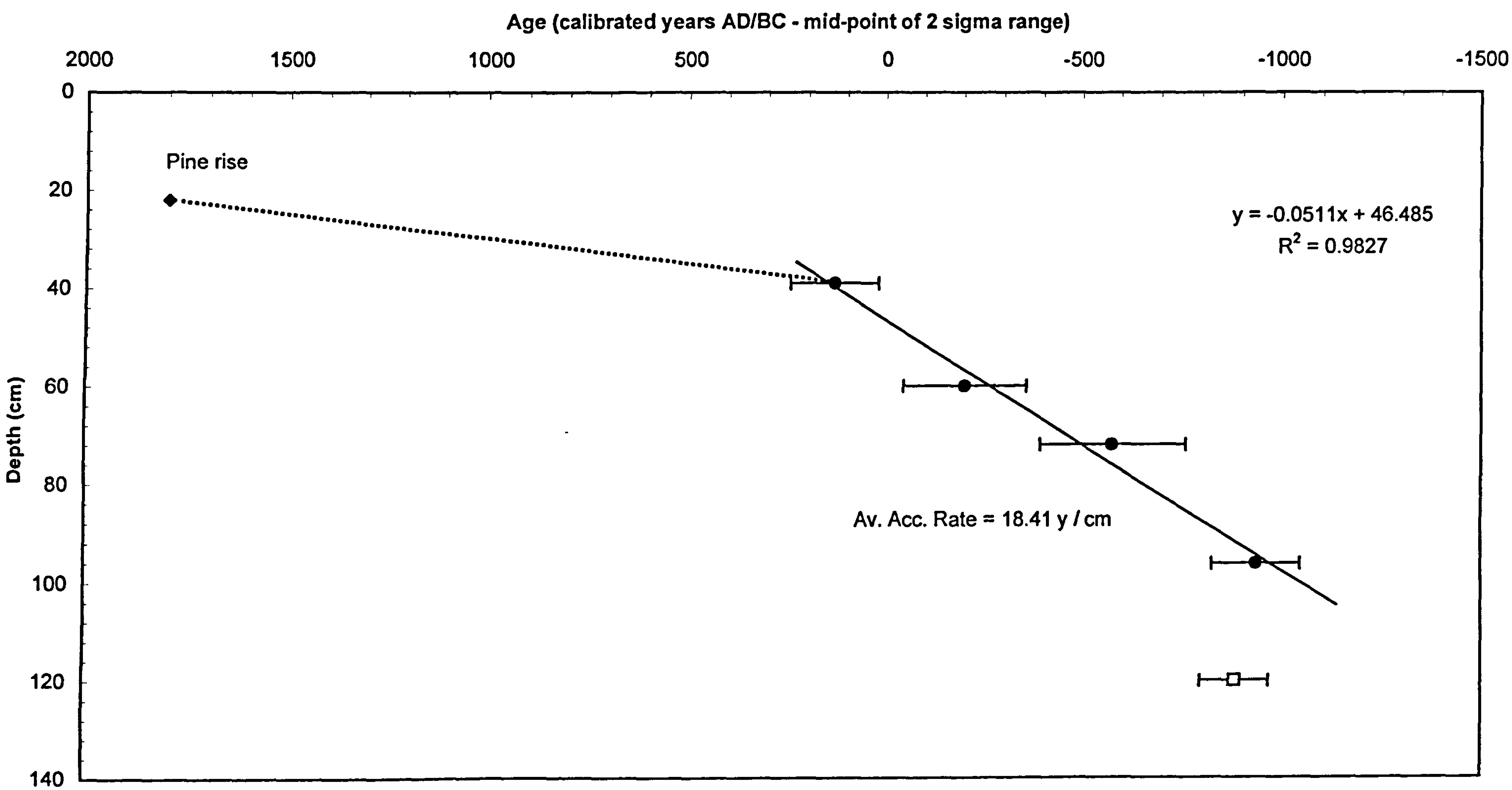
A very tentative explanation is put forward here, although it is recognised that further research into the macrofossil, testate amoebae and past climatic records are required to fully understand this question. It is suggested that some marginal cutting took place at the Southeast Bog in c. cal. 5th century AD causing some drying of the peat surface as discussed by Godwin and Conway (1939), while the West Bog was not affected at this time. It is then speculated that drier and/or warmer climatic conditions during the MWP dried out the surface of both bogs at around the same time in c. the 12th and 13th centuries AD, possibly causing the black, well humified, amorphous layer of peat identified by Godwin and Mitchell (1938). This may have been coupled with more extensive cutting (including the possibility of some monastic interference with the river's course as well as agricultural activity in the basin catchment), all of which could have resulted in a sharp reduction in peat growth rates at this time. It is interesting that such factors appear to have been severe enough to limit peat growth during the LIA, when a wetter, cooler climate would have created favourable conditions for the resumption of peat accumulation. Peat growth could possibly have been triggered again in c. the late 18th century onwards as the result of a wetter climate combined with a cessation of cutting due to increases in the use of coal. Indeed from their survey of the West Bog in the 1930's, Godwin and Conway (1939 p357) noted that "the vegetation structure is being re-established over an old drier surface, and probably represents some degree of renewed bog-growth after a phase of retardation or standstill which is still expressed by the drier communities of the bog centre". It is also interesting to compare Turner's (1964b) radiocarbon results on a profile from the Southeast Bog with the present research, because changes in accumulation rates appear to occur at very similar times (see section 4.1.3.1). It is re-emphasised that the research needed to fully answer this question is beyond the scope of this project, but is currently underway (e.g. Schülz, in prep.).

4.1.4 Shaw Moss

Several peat accumulation models were tested on the AMS radiocarbon data from Shaw Moss including linear and second order polynomial regressions on all data points and then with the exclusion of a reversed date (AA36259), in order to obtain the best fit of the data. Figure 4.4 shows the age-depth model which appears to be the most representative of the data, where an R^2 value of 0.9827 was achieved through fitting a linear regression which excluded the discordant date of AA36259. From this model, it appears that this date is several hundred calibrated radiocarbon years too young than its stratigraphic depth within the peat profile would suggest. Again this reversal may possibly be the result of contamination by more modern carbon through rootlet penetration. This age-depth model has been used to calculate an average peat accumulation rate of around 18.41 years/cm, implying the same order of magnitude for peat growth in raised mires in Cumbria (Barber *et al.*, 1994b).

The AMS radiocarbon results indicate that the majority of the profile dates from the prehistoric period, although relatively modern peats of the c. last two centuries are thought to be present at the surface due to the high concentrations of pine pollen recorded (see Chapter 5). Therefore this site has also been subject to allogenic disturbance such as human activity, climate change or possibly a combination of the two, that have caused a dramatic reduction in peat accumulation rates. The pollen frequency curves do not respond with a synchronous rapid change in concentrations at any one stratigraphic depth which suggests that cutting of the entire peat surface may not have occurred. The West Cumbrian Railway line, which dissects the eastern side of the bog, may have caused some burning of the peat surface through fires caused by the deposition of steam train debris. It is beyond the scope of this project to investigate the macrofossil record, but future research in this area may indicate levels of high macroscopic charcoal concentrations.

Figure 4.4 Age-depth model for Shaw Moss (SAW2)



It is known that a section of peatland at the eastern margin of Shaw Moss was cut, drained and reclaimed for agricultural purposes between 1840 and 1974 AD, and such activity may have affected the hydrology of the bog sufficiently to cause the crown area of the mire to dry out, thus reducing peat accumulation rates. Wimble *et al.* (2000) found a similar pattern of peat accumulation at White Moss in the Duddon Estuary, where they suggest that drainage and turbary have destroyed the majority of raised mire systems in the region, leaving only relict fragments amongst the drained agricultural land. Alternatively, climatic change, as discussed in the previous section, may have also played a part in slowing down peat accumulation rates. Further research involving detailed investigation of the macrofossil and testate amoebae records may provide more information as to the possible causes of this event and until such work has been undertaken possible explanations remain tentative.

4.1.5 Talkin Tarn

In light of the radiocarbon results received for TAL1, which demonstrated that the profile was of Lateglacial origin, a second core was analysed from the lake (TAL2) in order to reconstruct vegetation and land use change from the historic period.

4.1.5.1 TAL1

The radiocarbon determinations from TAL1 are shown in Figure 4.5. An age-depth model has not been constructed since there are only two dates which appear to confirm a hiatus in the profile. Due to the disturbed nature of the sediment core and its age, it is not considered in great detail since it does not contribute towards the research aims and questions set out in Chapter 1.

4.1.5.2 TAL2

The radiocarbon determinations from TAL2 are shown in Figure 4.6a. Initial examination of the results suggests that the samples have either been contaminated in some way or perhaps subject to slumping and reburial (c.f. Virkanen, 2000), resulting in a series of age-depth reversals. This is a common problem with bulk samples of detrital mud from lake sediments (Stevenson *et al.*, 1990). However, on detailed comparison with the loss on ignition record for this core (see Figure 4.6b source: Barber and Langdon, pers. comm.) it would appear that the outlier dates (indicated on Figure 4.6c by the blank squares) correspond with episodes of rapidly changing loss on ignition values. This may suggest that these dates have been contaminated by the deposition of older carbon from the lake catchment during inwash events (Langdon, pers. comm.). Whellan (1860) states that the Blacksyke coal-pit was located on the common of Talkin Township, thus providing a potential source for the contaminant carbon and a possible explanation for the reversed dates. Exclusion of these anomalous determinations (CAMS-70069, CAMS-70068, CAMS-70067, CAMS-70065 and CAMS-70064) leaves four AMS dates which produce a consistent age-depth model, to which a linear regression model with an R^2 value of 0.9787 can be fitted. Extrapolation of this age-depth model correlates well the palynological evidence for the pine rise at c. 1800 AD (see Figure 4.6c) and produces an average wet sediment accumulation rate of around 23 years/cm.

Figure 4.5 Radiocarbon dates from Talkin Tarn (TAL 1)

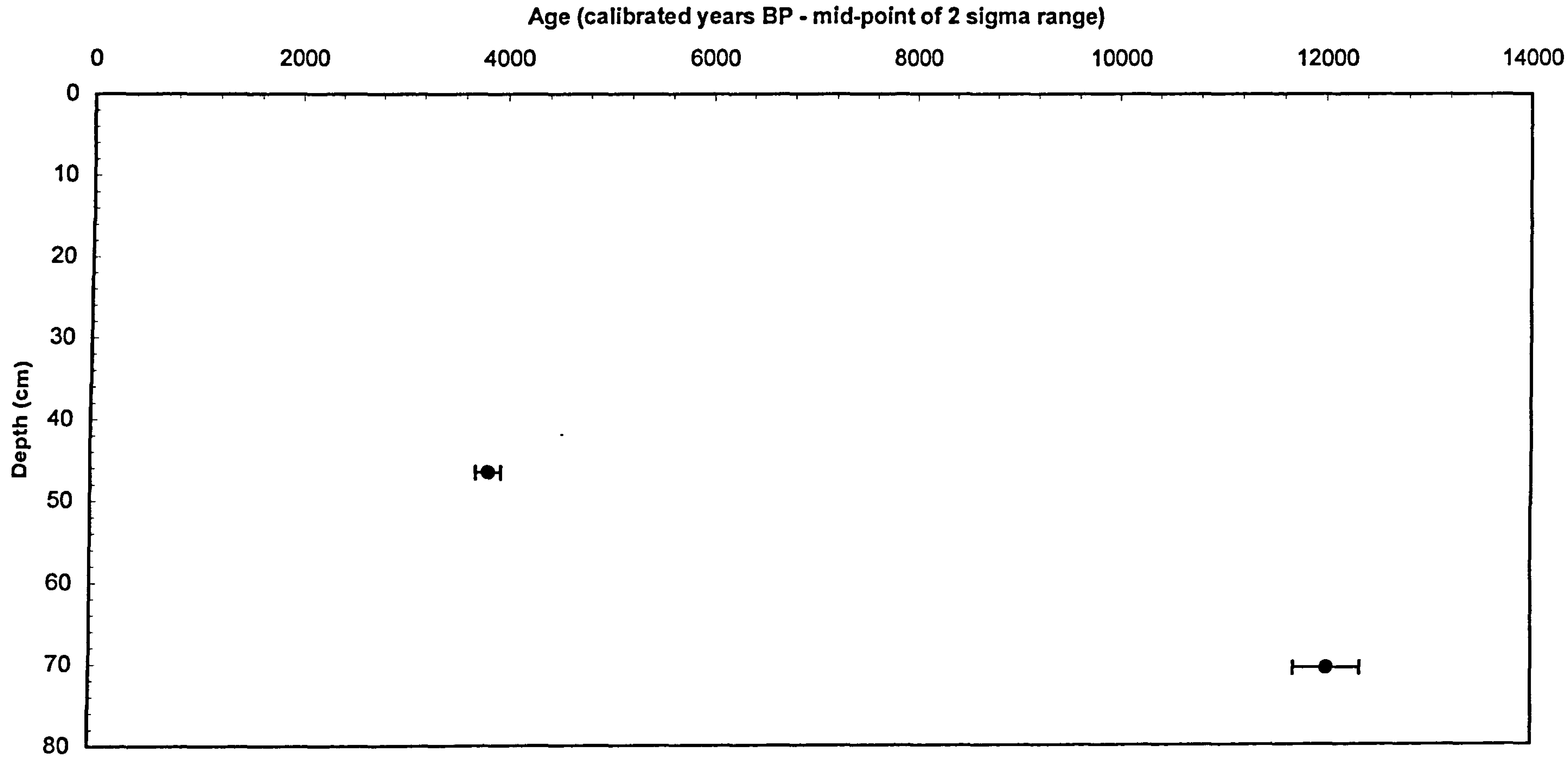


Figure 4.6a Radiocarbon dates from Talkin Tarn (TAL2)

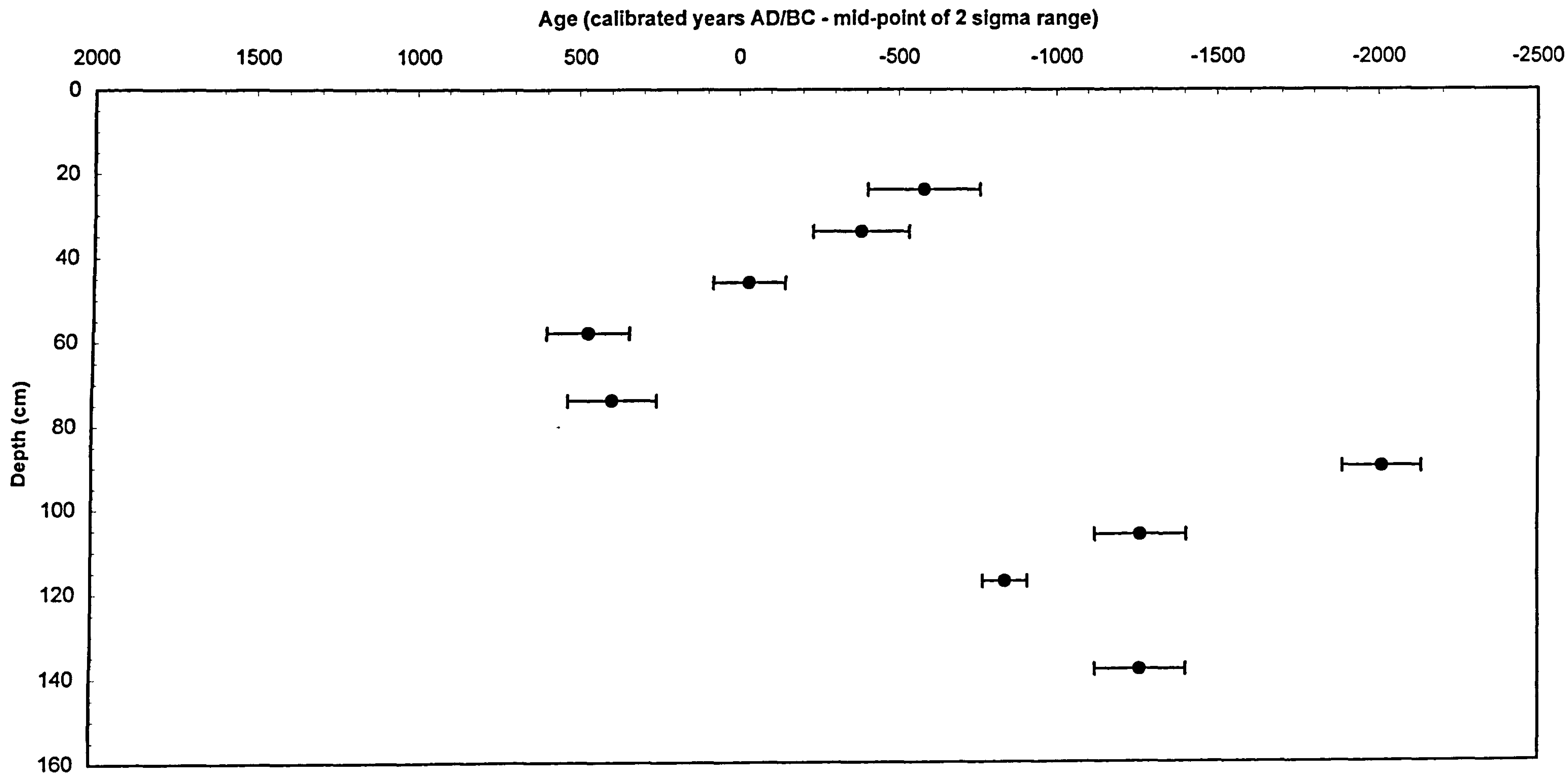


Figure 4.6b Loss on ignition data from TAL2 (Source: Barber and Langdon, pers. comm.)

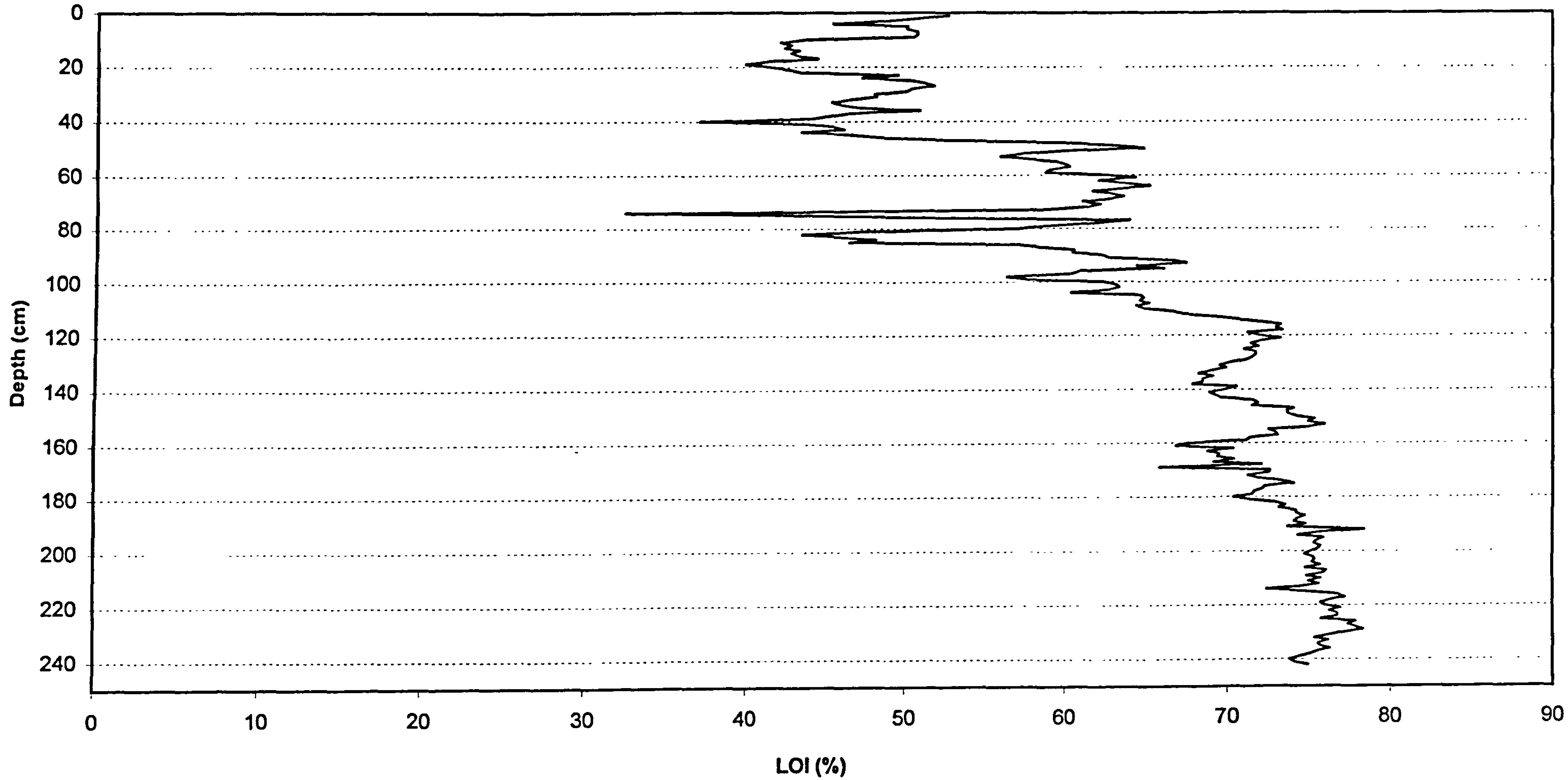
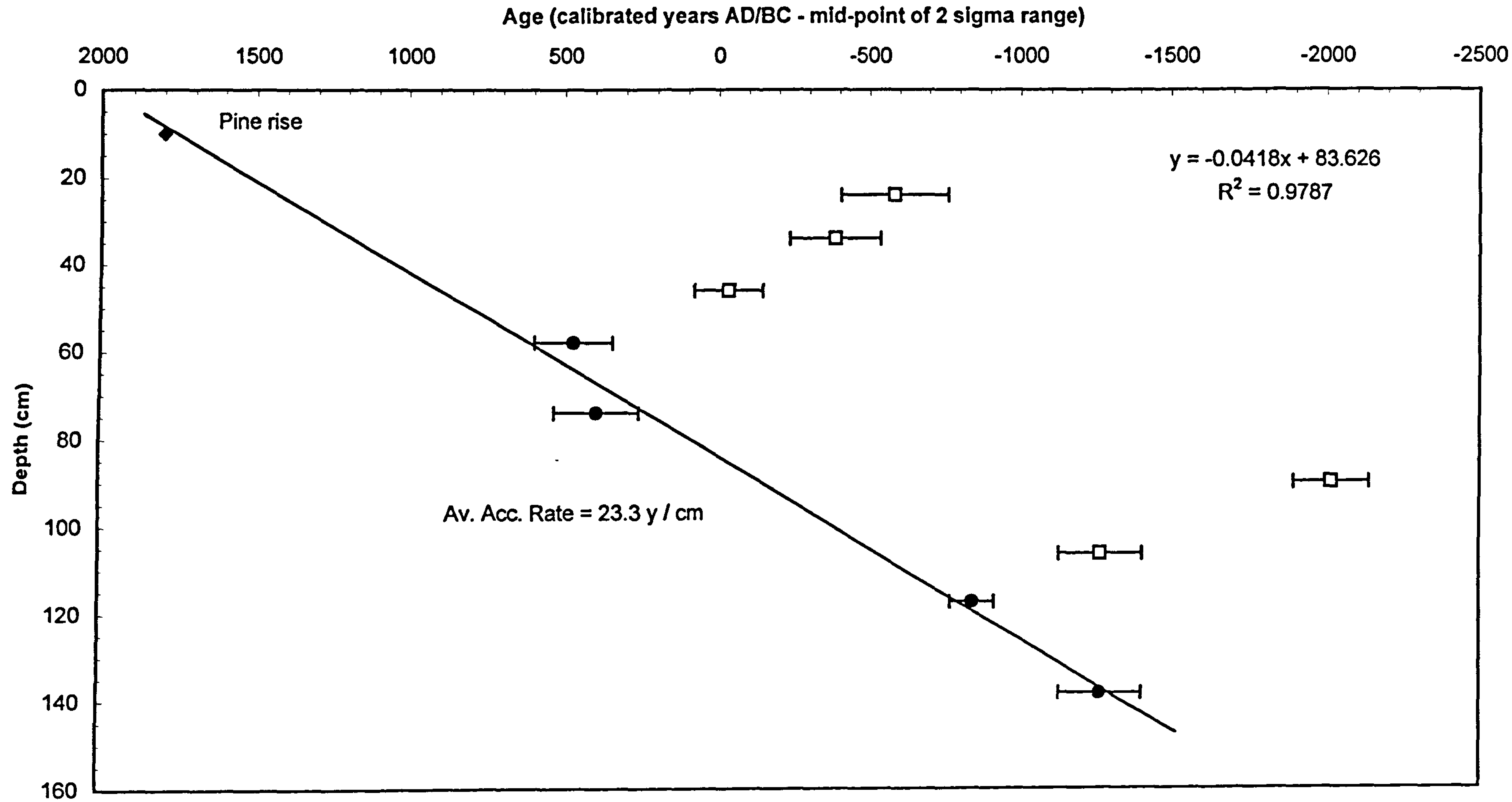


Figure 4.6c Age-depth model for Talkin Tarn (TAL2)



4.2 Tephrochronology

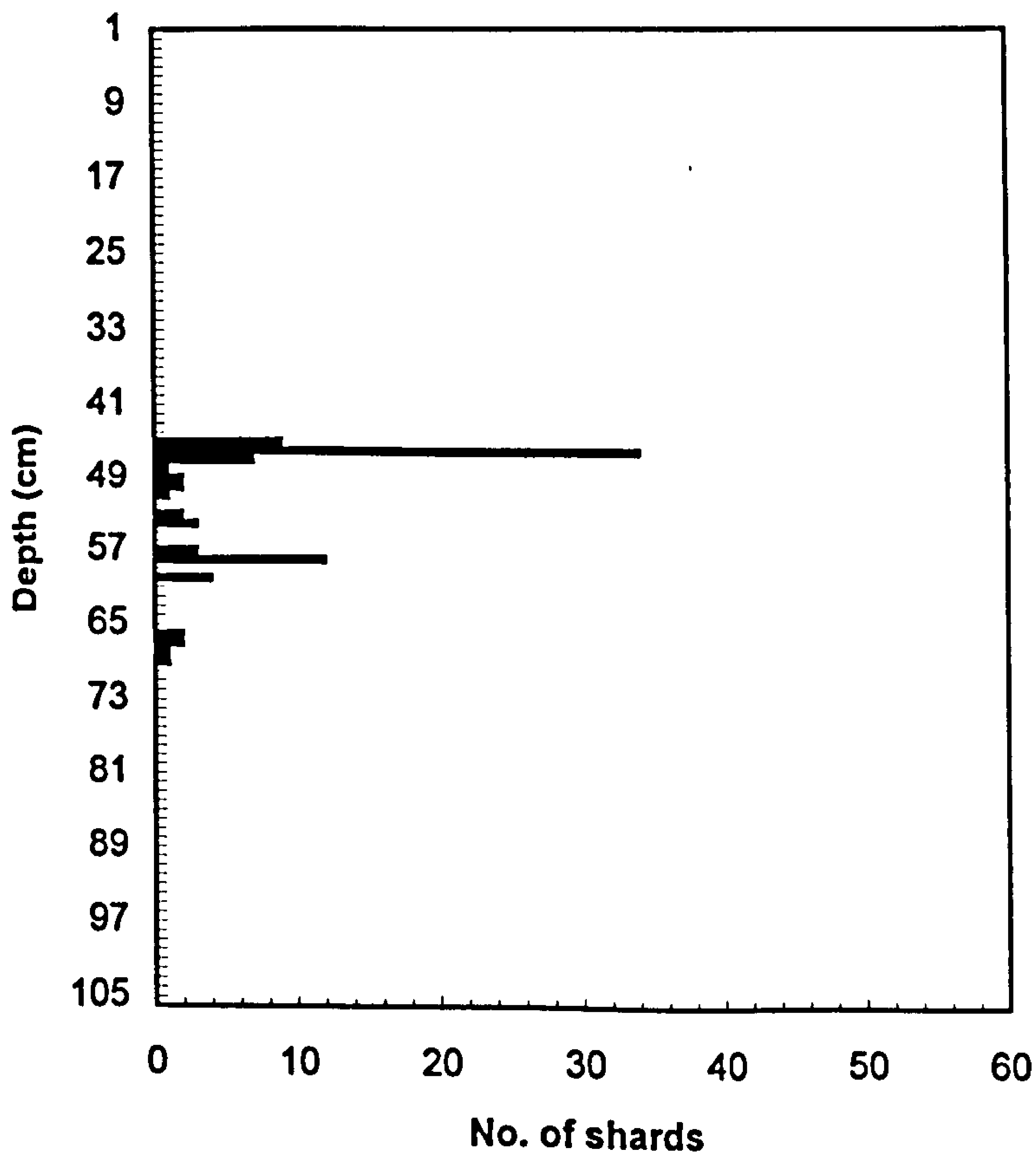
As discussed in section 3.4.3, stratigraphically discrete tephra horizons can be identified in peat sediments by microscopic analysis. Geochemical typing of the individual tephra shards allows correlation to previously dated tephra isochrones of known volcanic eruptions. Tephra layers are important in terms of their ability to constrain radiocarbon chronologies and historical tephras provide a calendar date that can allow direct comparison to the documentary record.

4.2.1 Abbeyknockmoy Bog

4.2.1.1 Ashing results

Following the method described by Pilcher and Hall (1992), a preliminary investigation of tephra concentrations was undertaken at contiguous 5 cm x 1 cm intervals. Levels containing tephra shards were then subsampled at contiguous 1 cm intervals to find the peaks in shard concentrations and the results from Abbeyknockmoy Bog are shown in Figure 4.7. The graph demonstrates a large peak in abundances at a depth of 45 cm and a secondary peak at 57 cm.

Figure 4.7 Tephra shard abundance at Abbeyknockmoy Bog (AKM'99)



When small quantities of shards are recorded stratigraphically close to horizons of peak concentrations, it has been suggested that particles may have been moved down-profile by plant roots or through dead root channels (Langdon, 1999). Dugmore *et al.* (1995a), however, offer three possible alternative explanations for the occurrence of low concentrations of tephra shards at many stratigraphic levels. They suggest that either each tephra deposit may represent a primary tephra air fall, or that they may be reworked grains, or some combination of the two. Their data indicate that such deposits in raised peats are more likely to be the result of primary volcanic events. Geochemical investigations were undertaken on shards from both of the peaks in concentration.

4.2.1.2 Geochemical results from microprobe analysis

Geochemical results from EPMA are expressed as percentages by weight of each of the nine major elements analysed. These percentages are summed to produce the total amount of oxides contained within each tephra shard. Since hydrogen cannot be measured by EPMA because this element does not produce X-rays, the water content of a tephra grain cannot be determined, thus meaning that totals rarely achieve 100% (Hunt and Hill, 1993). As a result, it has been suggested that data should be normalized to 100% (Froggatt, 1992), although Hunt and Hill (1993) argue that this technique should never be applied since it can obscure bad analyses, blur and extend the element range of a particular tephra leading to the possibilities of wrong correlations and overlapping geochemical fields, and prevent comparison of results by different researchers.

There is also much debate in the literature regarding what constitutes an acceptable total of oxides. Froggatt (1992) recommends that values of 90% and above are sufficient, whereas Hunt and Hill (1993) suggest that ideally totals lower than 98% should be excluded since totals less than this value may indicate either high water contents which could be associated with glass alteration, poor point selection or poor slide preparation. In practice many workers have assumed a lower limit of 95% (e.g. Dugmore *et al.*, 1995a; Pilcher and Hall, 1996) since Dugmore *et al.* (1995a) have shown that totals ranging between 95 – 97% are consistently reproducible from distal British tephras. Furthermore, these authors argue that lower totals may be the result of glass transformation through increasing vesicularity which is common in fine-grained British tephras. Totals lower than 95% have been accepted by a number of researchers, such as Pilcher *et al.* (1995) and Turney *et al.* (1997). In light of this, 93% was accepted as the lower limit for the more abundant tephra shards recorded from a stratigraphic depth of 45 cm (c.f. Langdon, 1999), although due to the very limited number of grains found at 57 cm, 91% and above was considered adequate.

The results of EPMA of tephra shards from Abbeyknockmoy Bog are shown in Tables 4.2 and 4.3. Figures 4.8a to 4.8e demonstrate the two distinct isochrones found at AKM'99, with filled diamonds representing the shard horizon at 45 cm and unfilled triangles the tephra layer at 57 cm. All these diagrams appear to indicate that the isochrone at 57 cm contains two populations with one shard showing very similar characteristics to the isochrone at 45 cm. This may be the result of some contamination of the isochrone at 57 cm by particles moving down-profile through dead root channels (Langdon, 1999).

Table 4.2 Results of EPMA of tephra shards at a depth of 45 cm from AKM'99: Hekla 1 – 1104 AD

Shard No.	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total % Oxide
1	71.28	0.23	13.89	3.24	0.19	0.12	2.75	3.97	2.82	98.49
2	70.31	0.55	13.68	2.88	0.12	0.11	2.01	4.46	2.51	96.63
3	70.91	0.17	13.67	3.10	0.14	0.12	1.96	3.98	2.86	96.91
4	71.43	0.22	14.08	3.15	0.13	0.14	1.94	3.79	2.81	97.69
5	71.07	0.15	13.90	3.28	0.13	0.15	2.10	4.18	2.81	97.77
6	72.11	0.18	13.95	3.15	0.21	0.11	1.97	4.19	2.87	98.74
7	72.36	0.22	13.83	3.10	0.14	0.13	1.89	4.10	2.73	98.50
8	68.73	0.22	12.93	3.01	0.10	0.13	1.79	3.96	2.70	93.57
9	71.08	0.18	13.85	3.07	0.15	0.16	1.93	4.07	2.72	97.21
10	71.19	0.19	13.69	3.10	0.08	0.10	1.92	3.59	2.68	96.54
11	69.29	0.19	13.33	3.27	0.13	0.15	1.94	3.71	2.73	94.74
Mean	70.89	0.23	13.71	3.12	0.14	0.13	2.02	4.00	2.75	96.98
Áfangagil*	72.24	0.19	13.95	3.23	0.12	0.14	1.85	4.30	2.74	
Slugganf†	71.91	0.26	14.37	3.04		0.13	1.92	4.52	2.67	
Owenbeg‡	72.53	0.27	15.04	3.16		0.14	1.92	4.80	2.46	

Total iron is expressed as FeO

Mean values from:
* Larsen *et al.* (1999)
† Pilcher *et al.* (1995)
‡ Pilcher *et al.* (1996)

Table 4.3 Results of EPMA of tephra shards from AKM'99 at a depth of 57 cm: origin unknown

Shard No.	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total % Oxide
1*	67.65	0.83	14.58	3.32	0.05	1.17	2.92	3.30	2.94	96.76
2	60.73	1.41	14.32	8.31	0.23	1.27	4.08	4.95	2.26	97.56
3	58.81	1.24	12.62	8.59	0.25	1.08	3.91	3.46	2.09	92.05
4	60.05	1.15	13.04	7.47	0.16	0.46	3.61	3.87	1.96	91.77
Mean (incl. 1)	61.81	1.16	13.64	6.92	0.23	1.00	3.63	3.60	2.31	94.54
Mean (excl. 1)	59.86	1.27	13.33	8.12	0.21	0.94	3.87	4.09	2.10	93.79

Total iron is expressed as FeO

1* This shard appears to form a separate population

The AMS radiocarbon determination (AA36262) taken from 44 cm produces a calibrated date of 1019 – 1199AD. This range encompasses the Icelandic Hekla 1 eruption of 1104 AD (Larsen *et al.*, 1999). Comparison with the relevant published datasets and the information held on Tephrabase at Edinburgh University (http://www.geo.ed.ac.uk/tephra/basehom.html) would suggest that the geochemical composition of the isochrone at 45 cm does match that of Hekla 1 (H) in 1104 AD (see Table 4.2 for comparative mean totals of the major elements for other sites with H 1104 AD tephra). Furthermore, Larsen *et al.* (1999) state that this tephra may be distinguished from the other historical tephras of similar SiO_2 content on plots of FeO:MgO, K_2O:TiO_2 and Al_2O_3:CaO. This isochrone found at AKM'99 has therefore been plotted against the H 1104 AD tephra found at Áfangagil, Iceland, and Sluggan Bog and Owenbeg in Ireland (see Figures 4.8f – 4.8h). The plots demonstrate the strong geochemical correlation between these four tephras, providing further evidence that the isochrone at 45 cm is the Hekla 1 tephra of 1104 AD. In addition, the triplot (see Figure 4.8a) demonstrates the ratio of CaO, FeO and K_2O in the glass shards found at AKM'99 in relation to the geochemical field for H 1104 AD tephra analysed from Iceland (Dugmore *et al.*, 1995a). Therefore this tephra isochrone of 1104 AD at a depth of 45 cm tightly constrains the radiocarbon date at 44 cm which ranges from 1019 – 1199 AD (see Figure 4.9).

The lower tephra horizon at 57 cm does not appear to correlate well with any of the published data on historical tephras previously found in Britain and Ireland. Extrapolating from the age-depth model, this tephra would appear to date from c. 9th century AD, although the geochemical composition does not match that of the published isochrones for either the "AD 860" layer (e.g. Hall *et al.*, 1993; Pilcher *et al.*, 1995) or the Landnám tephra of c. 870 AD (Larsen *et al.*, 1999). It is possible that the shards analysed here represent a different part of the eruption which has not been identified before. At present, however, this horizon remains untyped and is thus of unknown origin and date.

Figure 4.8a Triplot showing the proportion of iron, potassium and calcium oxides from glass shards at Abbeyknockmoy Bog, Ireland. Hekla 1 1104 AD tephra is represented by filled diamonds and the unknown tephra by unfilled triangles. The outline of the 1104 AD geochemical field is shown (after Dugmore *et al.*, 1995a).

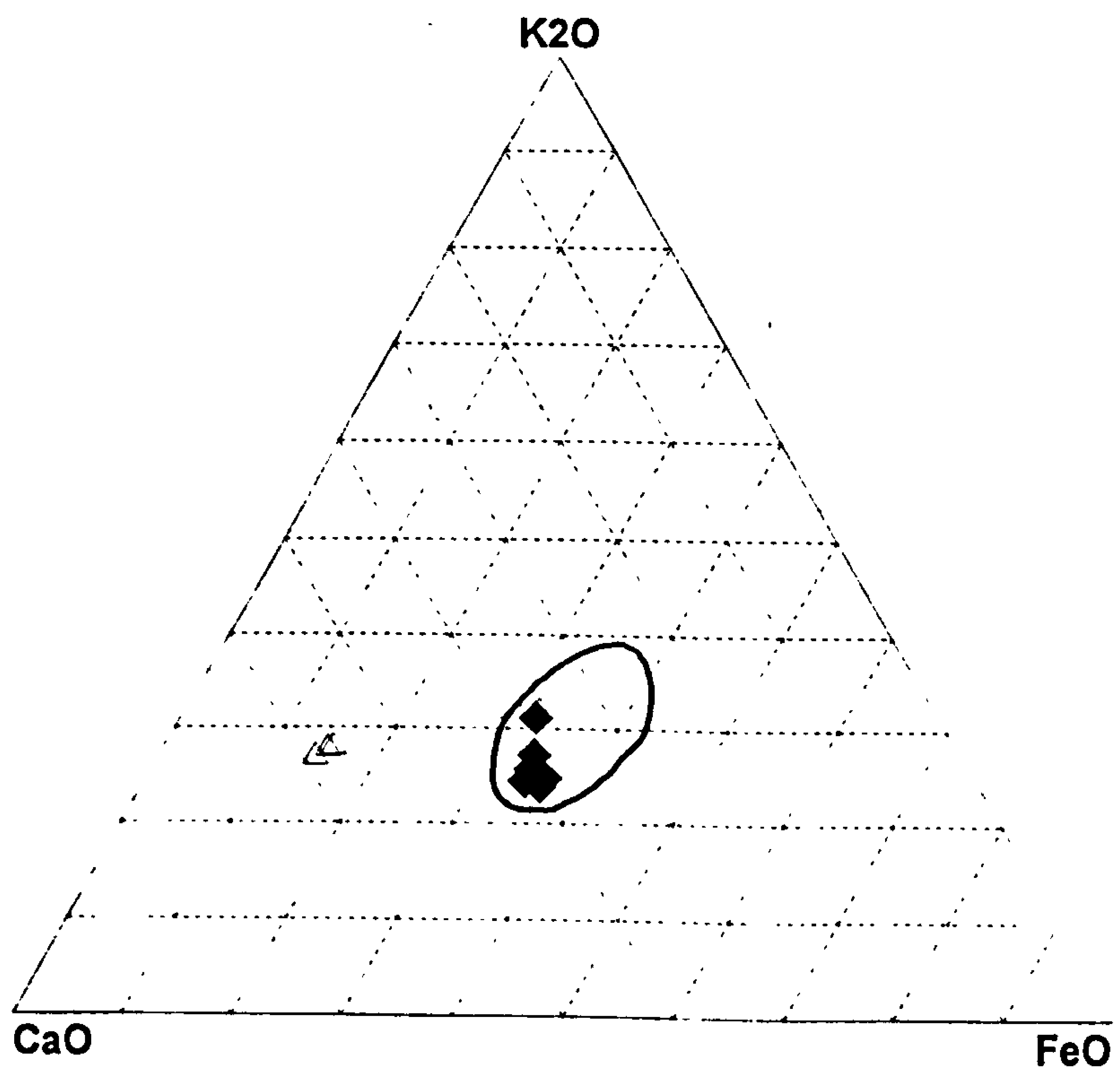


Figure 4.8b Binary plot of FeO against CaO for both Isochrones found at AKM'99

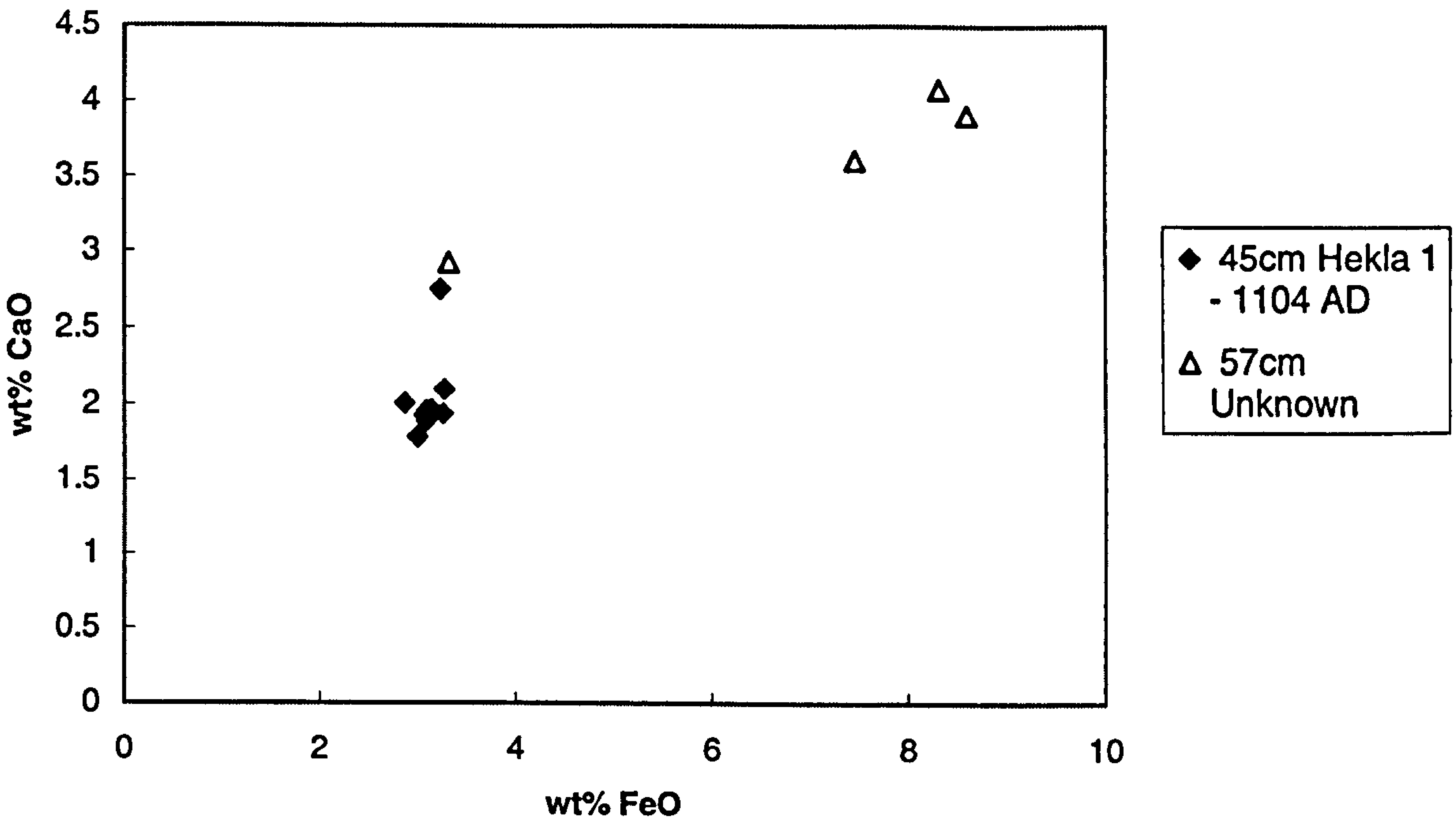


Figure 4.8c Binary plot of FeO against TiO2 for both Isochrones found at AKM'99

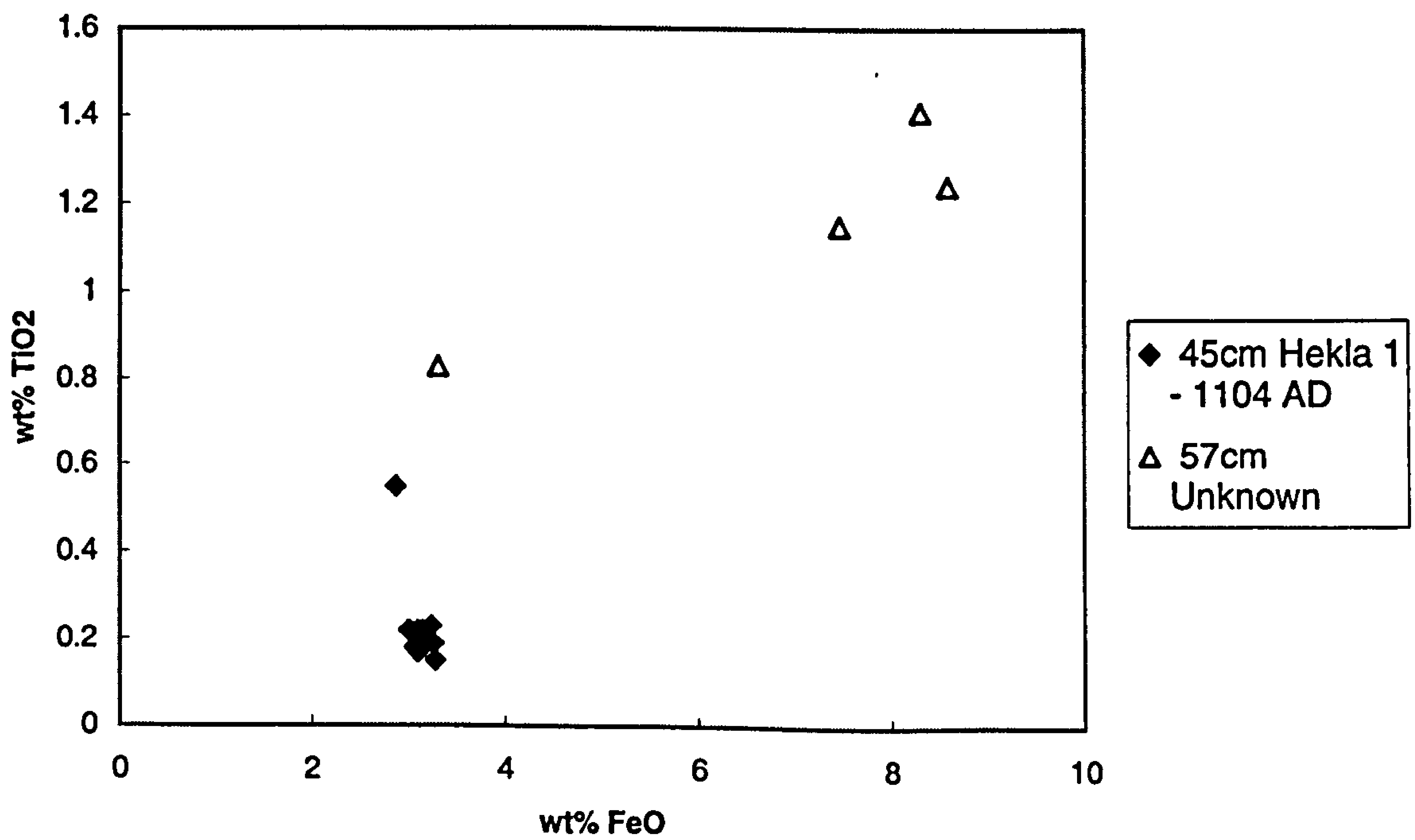


Figure 4.8d Binary plot of K2O against TiO2 for both isochrones found at AKM'99

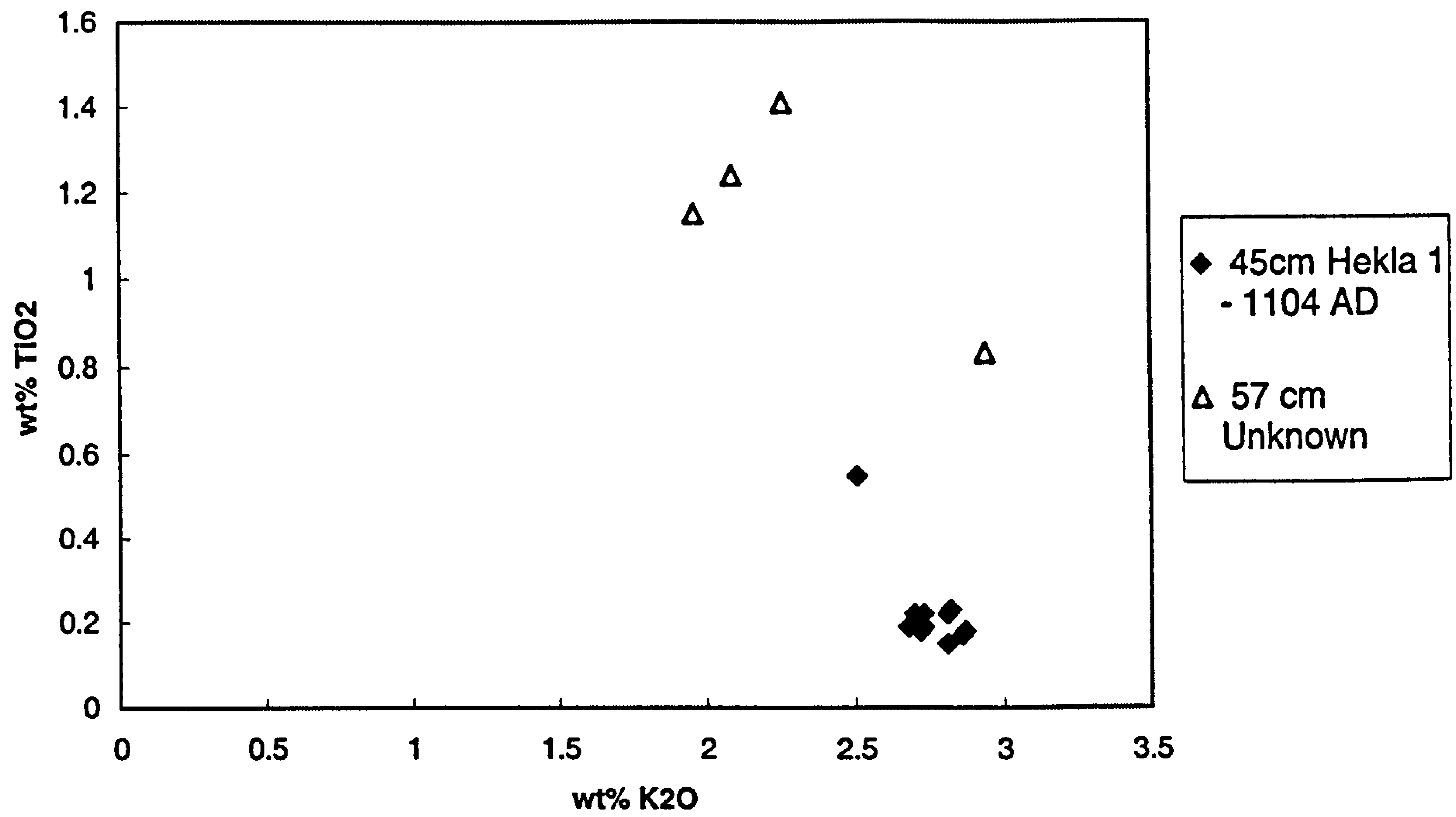


Figure 4.8e Binary plot of Al2O3 against CaO for both isochrones found at AKM'99

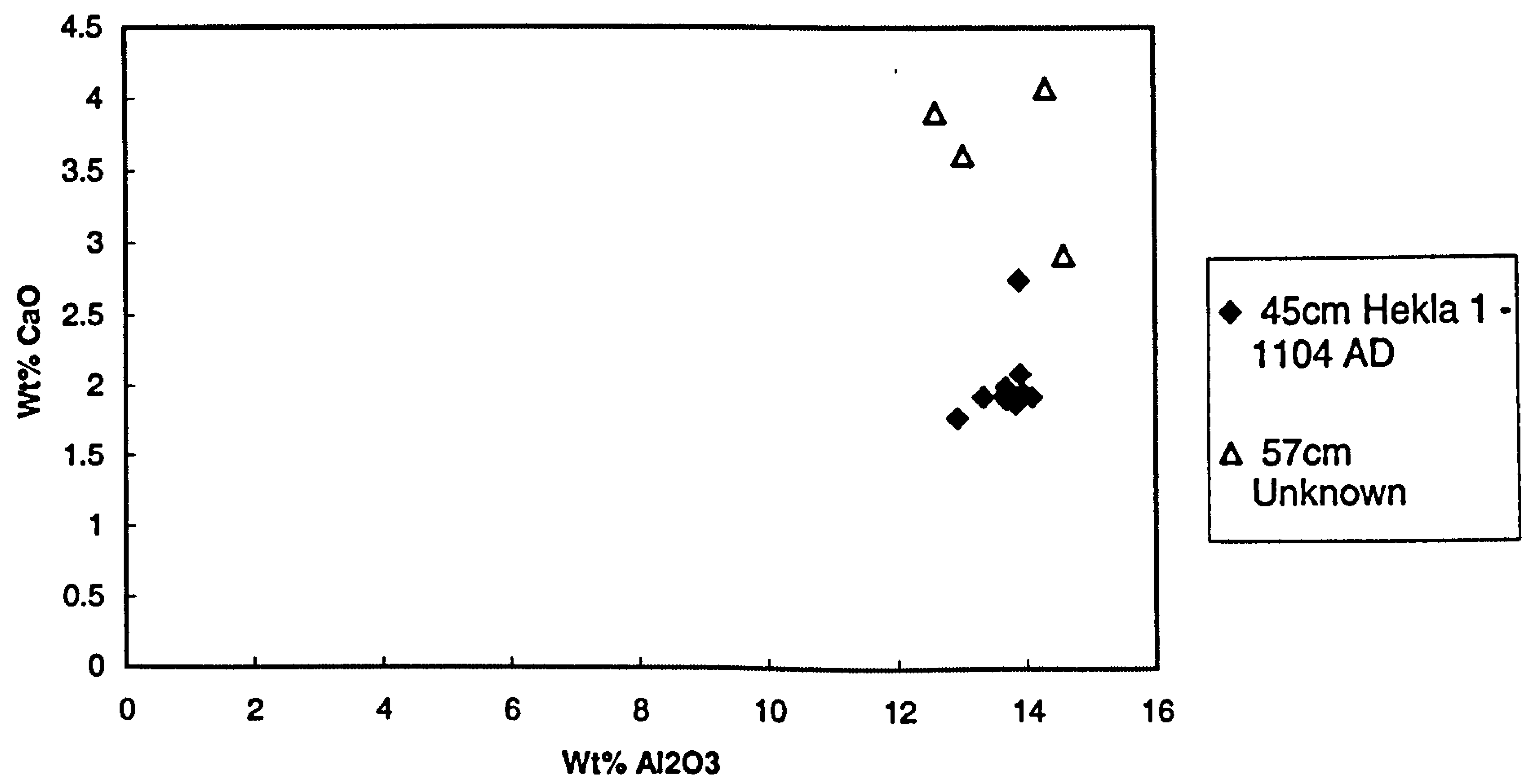


Figure 4.8f Binary plot of FeO against MgO for sites with Hekla 1 (1104 AD) tephra

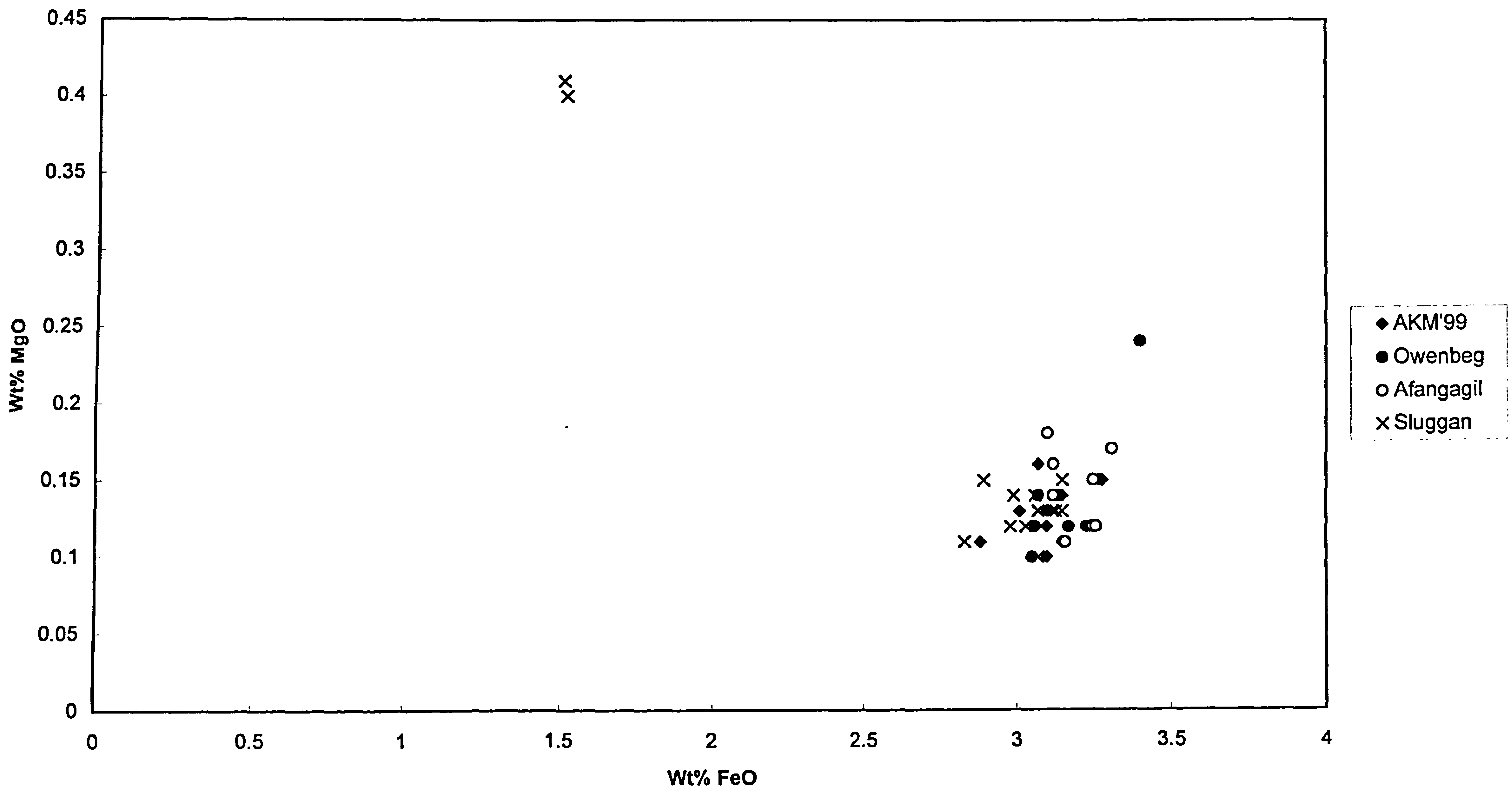


Figure 4.8g Binary plot of K_2O against TiO_2 for sites with Hekla 1 (1104 AD) tephra

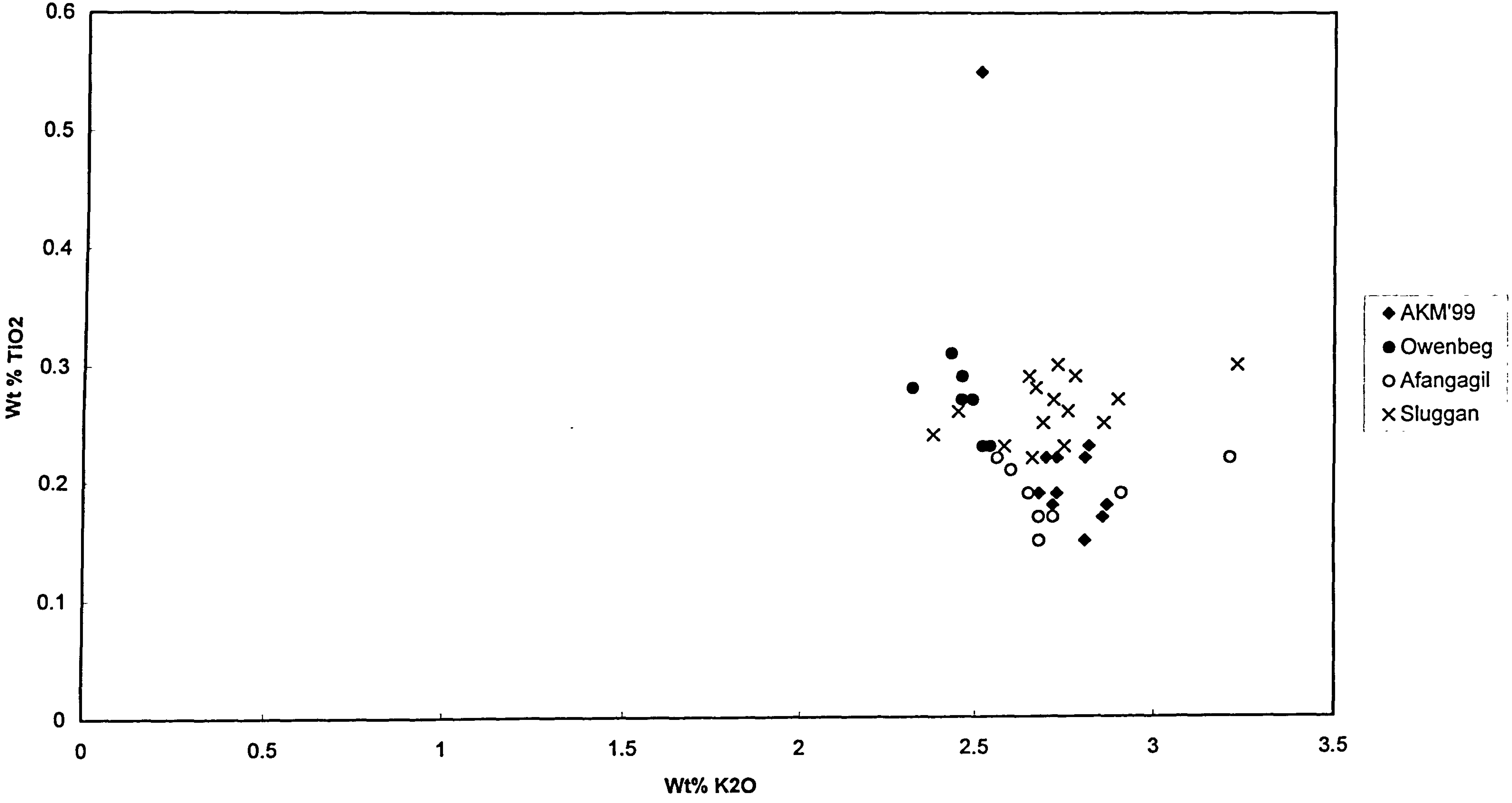


Figure 4.8h Binary plot of Al2O3 against CaO for sites with Hekla 1 (1104 AD) tephra

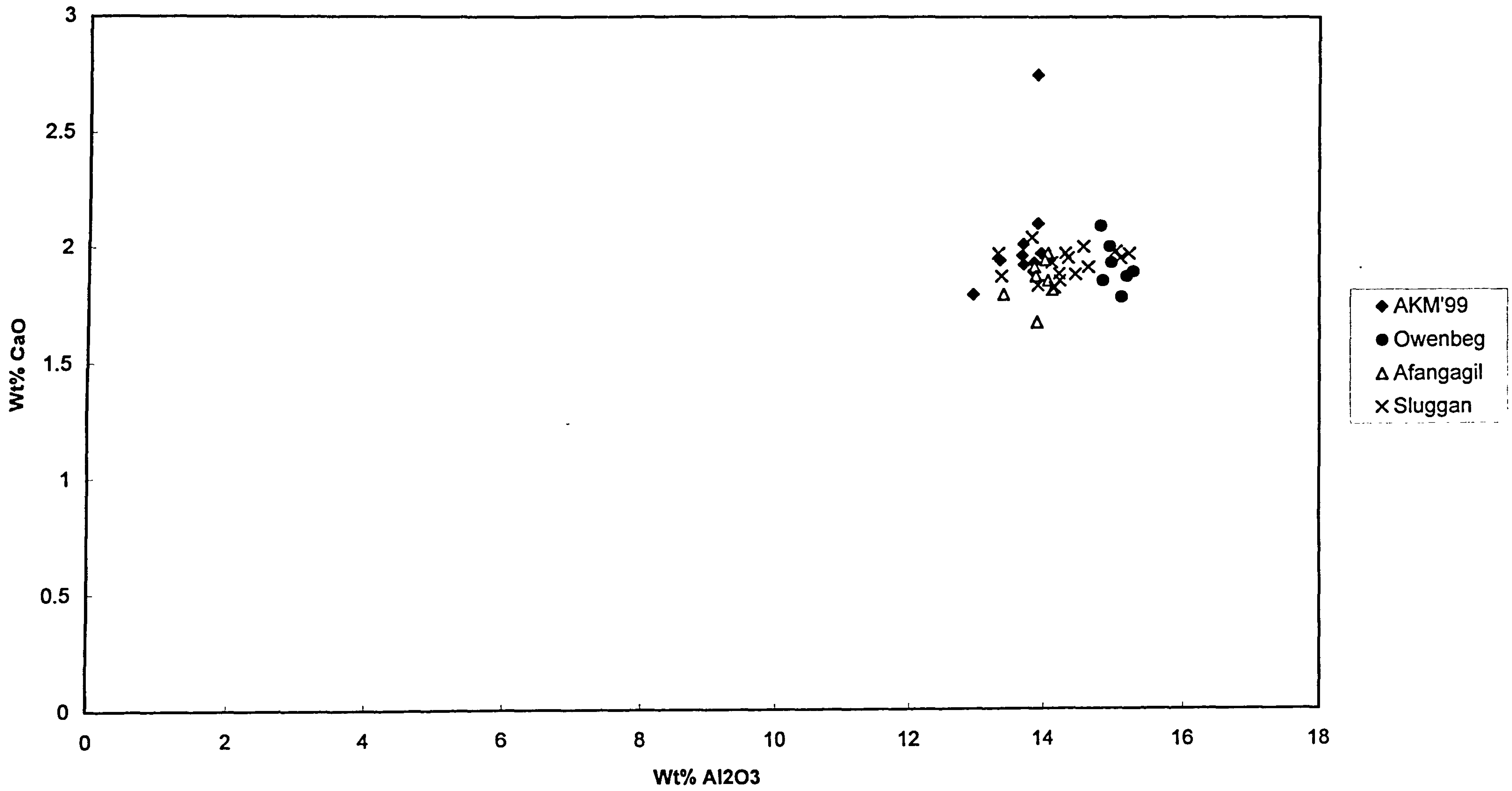
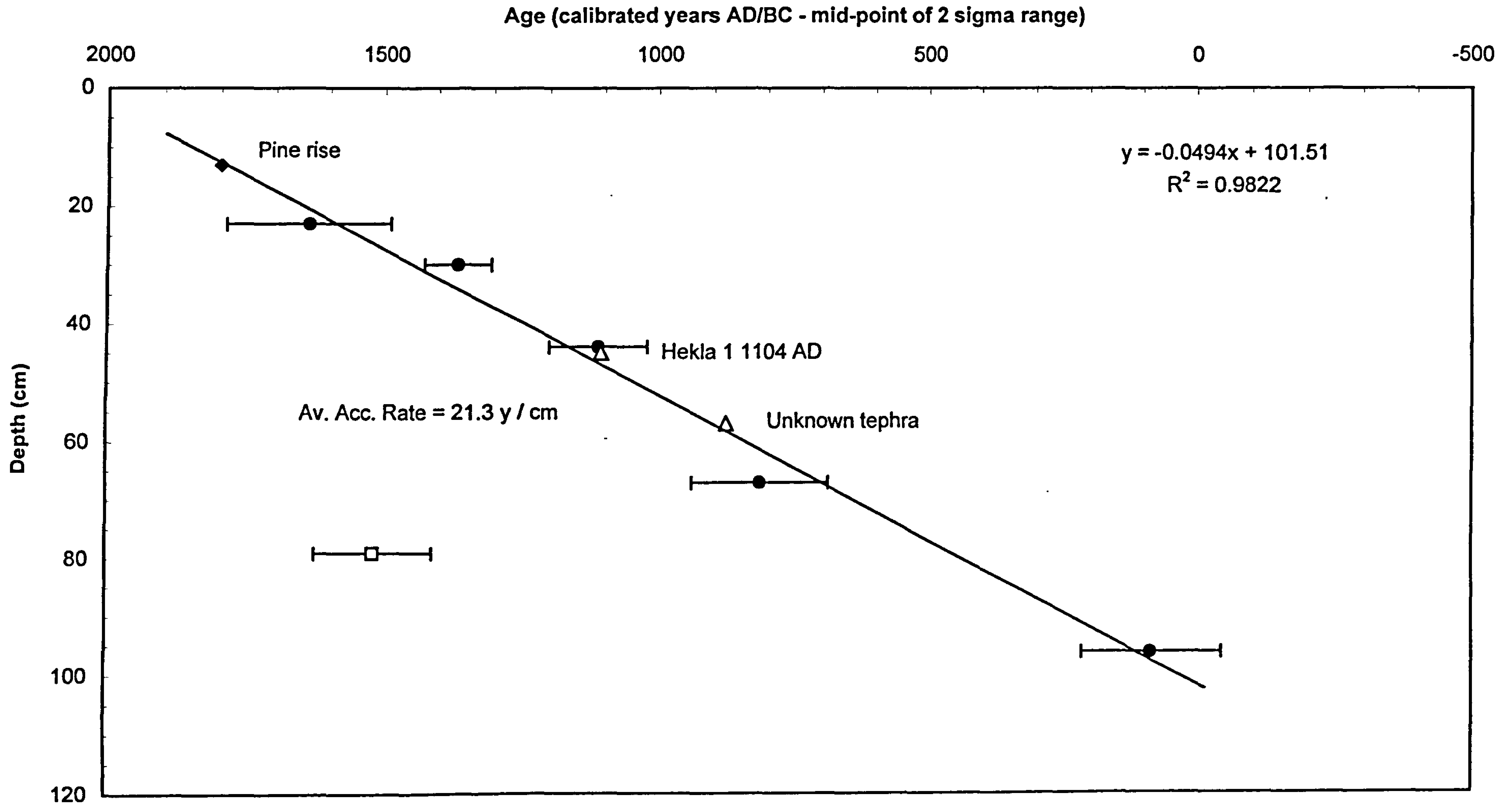


Figure 4.9 Age-depth model for Abbeyknockmoy Bog (AKM'99) including tephra isochrones



4.2.2 Ashing results from Shaw Moss

The same method was employed at Shaw Moss but unfortunately only four tephra shards were identified from a depth of 95-100 cm and two shards from a depth of 105-110 cm. Such low concentrations of shards did not warrant more detailed investigation because they are not suitable for microprobe analysis.

4.2.3 Ashing results from Tregaron Southeast Bog

Unfortunately no tephra shards were recovered from this profile. Due to this negative result, it was considered unlikely that tephra horizons would be recorded from the West Bog and consequently this profile was not ashed for tephra.

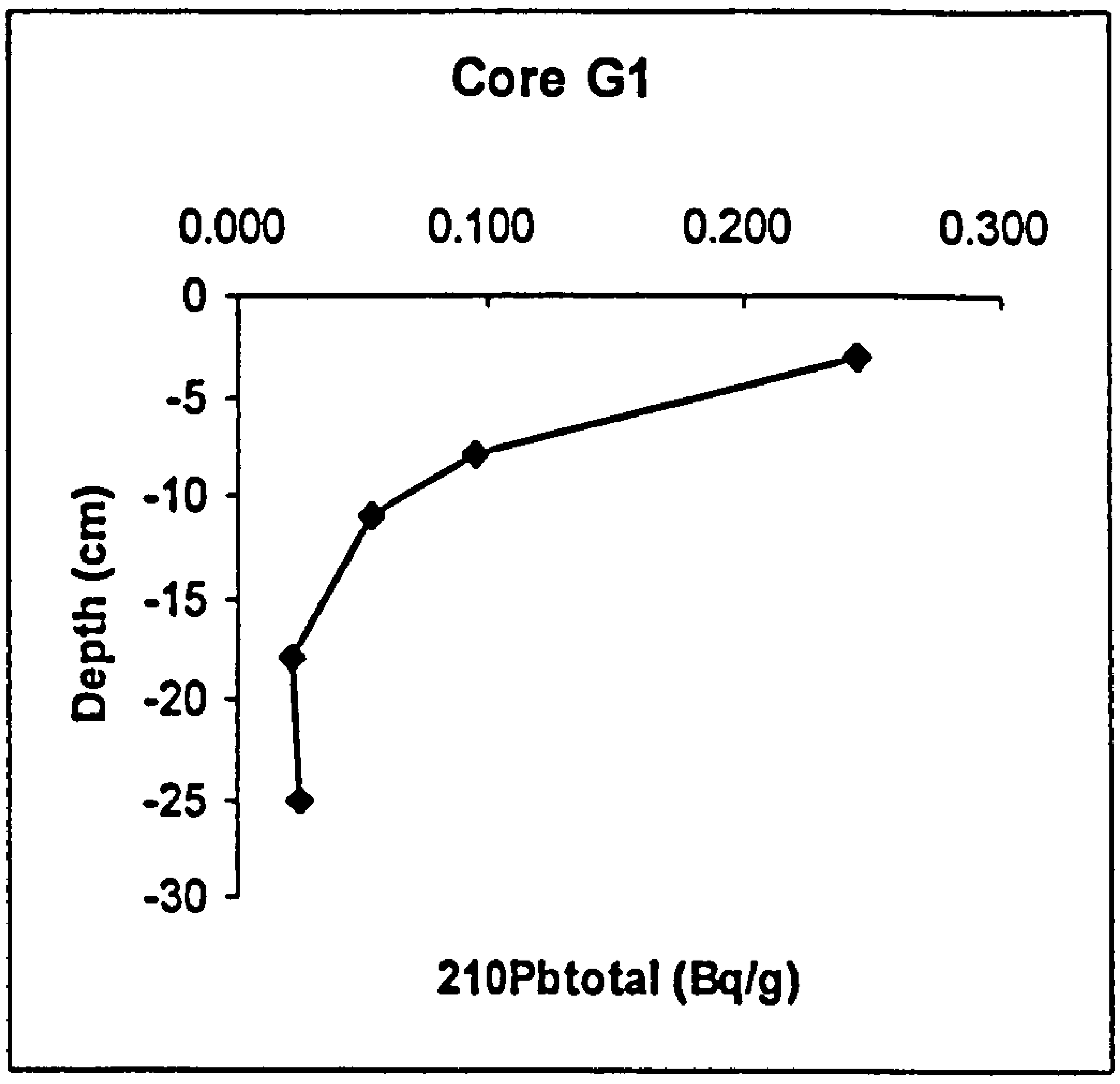
4.3 ^{210}Pb dating at Lake Gormire

^{210}Pb dating was employed at Lake Gormire because outcrops of limestone in the basin's catchment meant that radiocarbon determinations were not considered suitable due to the possible errors introduced through the "hard water effect" (see section 3.5). The ^{210}Pb dating was undertaken by Dr. Ian Croudace and Dr. Andy Cundy at the Southampton Oceanographic Centre. ^{137}Cs concentrations were measured, courtesy of Dr. Ian Croudace, in order to provide an independent control for the ^{210}Pb dates.

4.3.1 Results

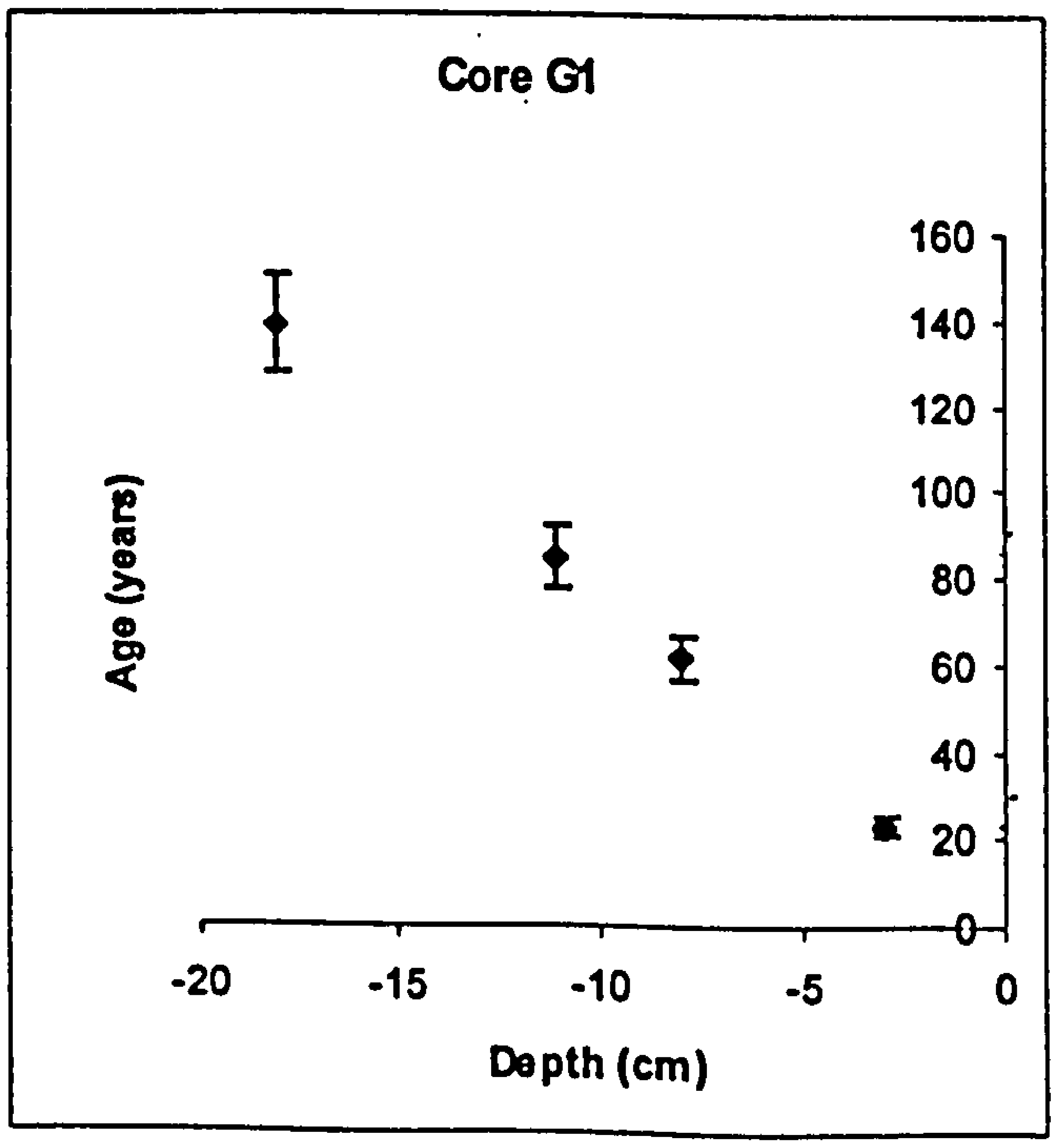
Sedimentation rates for the upper section of the profile from Lake Gormire were determined using the "simple" model of ^{210}Pb dating (Robbins, 1978). This is where the accretion rate is calculated by the slope of the least squares fit for the natural log of the $^{210}Pb_{excess}$ activity versus depth (Cundy, pers. comm.) (see section 3.6). The results are shown in Figure 4.10, from which an average accumulation rate of 1.3 mm/year over a depth of 25 cm can be calculated (with a standard error range of 1.2 – 1.4 mm/year and a two standard deviation range of 0.7 – 4.8 mm/year) (Cundy, pers. comm.).

Figure 4.10 Sediment accumulation rate for the upper section of the profile from Lake Gormire (GOR1) (based on the "simple" model) (Source: Cundy, pers. comm.)



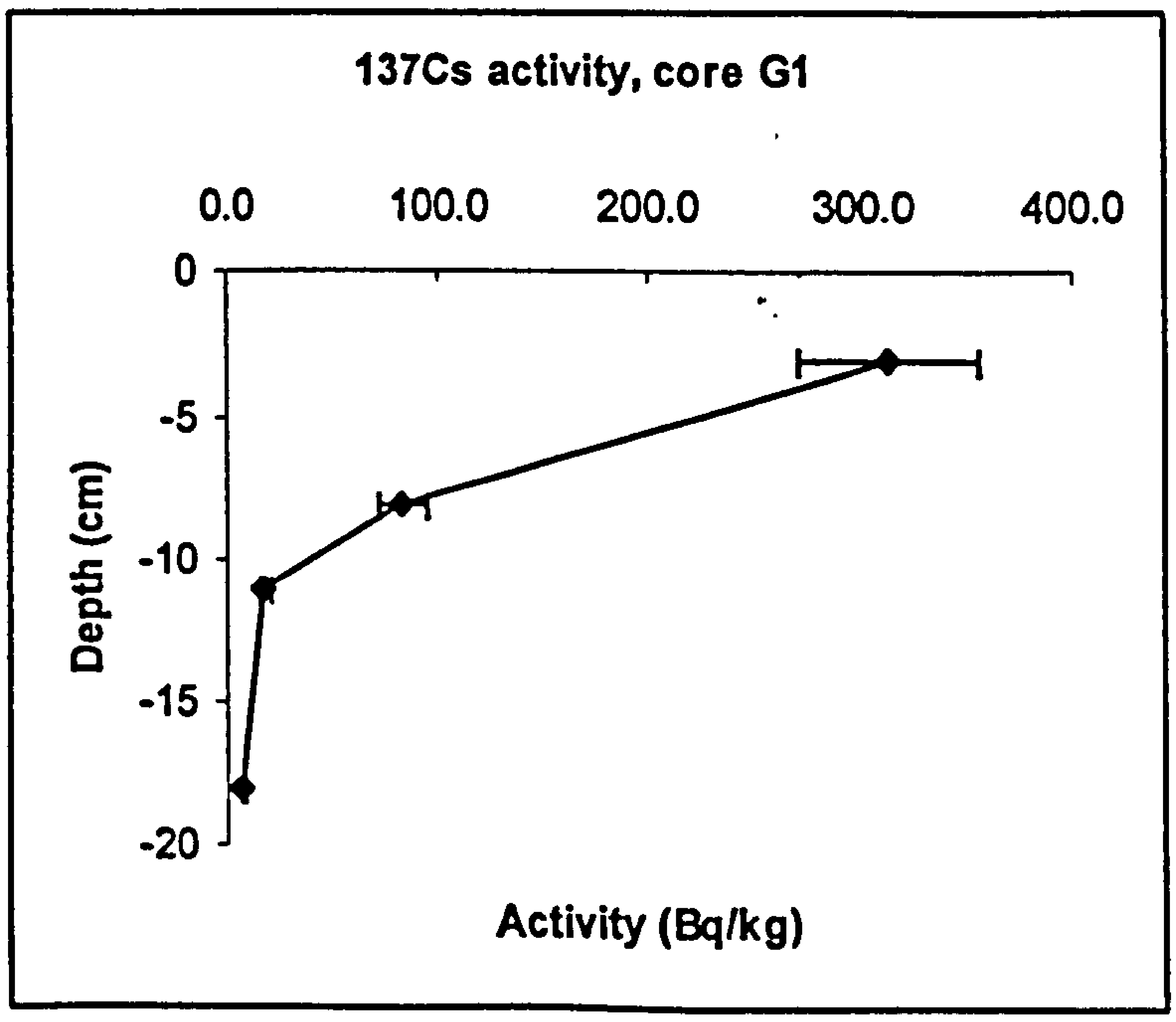
Using these results, an age-depth model for core GOR 1 can be calculated (see Figure 4.11). The error bars shown on the graph are calculated using the standard error on the gradient of the linear regression fit of $ln^{210}Pb_{excess}$ versus depth.

Figure 4.11 Age-depth model for core GOR1 based on the "simple" model (Source: Cundy, pers. comm.)



However, the ^{137}Cs results indicate that there are some complications with the accumulation rate and age-depth model calculated from the ^{210}Pb determinations. The ^{137}Cs record should begin in 1954, when this artificial radionuclide was first released into the atmosphere in large quantities, followed by two peaks in concentration which are known to have occurred in 1963 due to weapons testing and 1986 as a result of the Chernobyl disaster. As can be seen from Figure 4.12, the lack of subsurface maxima in ^{137}Cs activity means that downward sediment mixing has occurred, possibly as a result of the process of bioturbation. This means that the ^{137}Cs cannot independently confirm the ^{210}Pb chronology. Such evidence for bioturbation, coupled with the relatively slow sediment accretion rates, means that the sedimentation rate calculated by the ^{210}Pb activity is likely to be a maximum value, and that the actual sediment deposition rate may be significantly lower than 1.3 mm/year (Cundy, pers. comm.). Thus it is emphasised that the accumulation rate and age-depth model for Lake Gormire calculated here are only broad estimates with the possibility of large error margins.

Figure 4.12 ^{137}Cs activity versus depth from core GOR1 (Source: Cundy, pers. comm.)

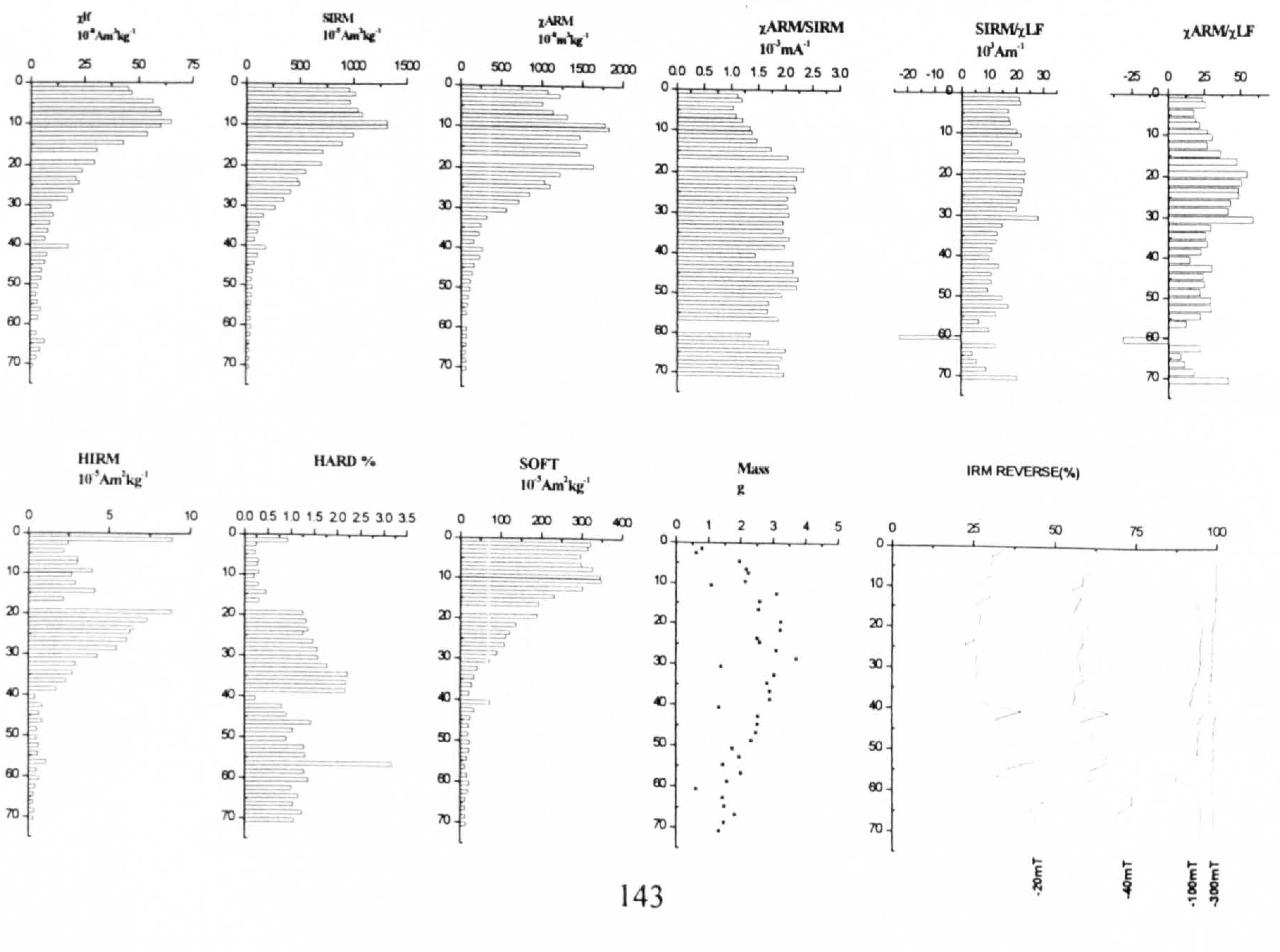


Use of the "simple" model for determining accumulation rates from ^{210}Pb activity is also recognised as having a number of limitations (discussed in Section 3.6). A more accurate interpretation may be achieved through the use of an alternative model which takes into account varying sedimentation rates (Oldfield, pers. comm.). However, not all the parameters needed for such a model were available to the author at the time of this research. As a result, an attempt was made to determine a more accurate accumulation rate and age-depth model using magnetic measurements to correlate the present core under investigation to a previously ^{210}Pb dated profile, which is discussed in the following section.

4.3.3 Magnetic susceptibility results

An existing ^{210}Pb dated core from Lake Gormire (GC3) using an alternative model suggests a sediment accumulation rate of 5.1 mm/year in the surface horizons (c. 1995AD), decreasing to 1.1 mm/year at a depth of 21 cm (c. 1890 AD) (Oldfield and Wake, pers. comm.). Since this core (GC3) had also been analysed for its magnetic susceptibility record, magnetic measurements from core GOR 1 should allow correlation between the two profiles and the application of the existing ^{210}Pb chronology to core GOR1 (see section 3.6.1). The magnetic characteristics of core GOR1 are shown in Figure 4.13 (courtesy of Prof. Frank Oldfield, Prof. John Dearing and Mr. Bob Jude at the University of Liverpool).

Figure 4.13 Magnetic characteristics of core GOR1 from Lake Gormire



The graph of bulk susceptibility (χlf 10^{-8}Am^{3}kg^{-1}) demonstrates a peak in values at a depth of 9 – 10 cm in GOR1. A peak in bulk susceptibility from core GC3 is recorded at a depth of c. 20 cm. Based on the assumption that the same event caused both peaks in bulk magnetic susceptibility (thus making the two spikes synchronous in time), the ^{210}Pb age-depth model from core GC3 records a date of 1899±26 years for this phenomenon (Oldfield and Wake, pers. comm.). This would suggest that for profile GOR 1, the top 10 cm of sediment accumulated over approximately the last 100 years. The ^{210}Pb age-depth model for GOR 1 using the "simple" model (see Figure 4.11) suggests a date of around 1925 AD for this same depth. It would therefore appear that the "simple" model provides a rough estimate of the age-depth relationship.

It is, however, encouraging that the average accumulation rate of GOR 1 based on the "simple" model (c. 1.3 mm/year) is of a similar order of magnitude to the accretion rate for sediments of depths between c. 14 cm to 21 cm calculated by the alternative model for core GC3. Unfortunately there are no more characteristic patterns in the magnetic record that can be used to reliably constrain the "simple" model used in core GOR 1. There is, however, a pollen horizon suitable for correlation. The cores demonstrate a significant peak in *Myriophyllum alterniflorum* pollen which has been ^{210}Pb dated to c. 1770 AD (Oldfield and Wake, pers. comm.). This again fits well with the "simple" model used in this research and provides an additional date for the GOR1 profile. Based on the assumptions that the top 10 cm reflects approximately the last 100 years, and sediment accumulation rates appear to stabilise at around 1.1 – 1.3 mm/year at a depth of c. 20 cm in core GC3, the 70 cm sediment record of core COR 1 would appear to date from c. 1300 AD.

4.4 Summary

An age-depth model based on AMS radiocarbon dates and pine rise data has been constructed for each of the peat profiles and TAL2. Fitting a linear regression model allows interpolation between the radiocarbon determinations in order to give an approximate date for specific levels of palynological or geochemical interest. The establishment of an historical tephra isochrone at Abbeyknockmoy Bog constrains the radiometric chronology and allows direct comparison with the documentary record. ^{210}Pb dating was used at Lake Gormire since this record was unsuitable for radiocarbon analysis.

Chapter 5 – Pollen Analytical Results

5.0 Introduction

This chapter describes the pollen analytical results from each profile investigated. The pollen taxa shown in Figures 5.1 to 5.7 (excluding Figure 5.6, the reasons for which are explained in Section 5.6) have been selected as being characteristic of a particular land use type and are organised into ecological groups to aid interpretation (see section 3.4.1.5 and Table 3.2). For every level counted, the sums of all pollen taxa in each of the ecological groups have been calculated to produce summary curves for every land use type. As discussed in Chapter 3, these totals include taxa that were excluded from the pollen sum, such as *Alnus* and Cyperaceae (see section 3.4.1.5), meaning that cumulative values may exceed 100%. Although these summary curves give an indication of the fluctuating importance of the different land use types over time, they cannot be used to quantitatively reconstruct the area of land involved in each land use category. Full pollen diagrams showing all the pollen taxa recorded from each profile can be found in Appendices 1 to 7. The description of pollen analytical results in this chapter will concentrate on the indicator species used in the ecologically grouped diagrams. To aid discussion and interpretation (see Chapter 7), the pollen analytical profiles have been divided into local pollen assemblage zones (LPAZ) (see section 3.4.1.5), with all zonation schemes beginning at the base of each record working upwards towards the surface.

5.1 Abbeyknockmoy Bog

The pollen analytical profile from Abbeyknockmoy Bog has been divided into four distinct local pollen assemblage zones (see Figures 5.1a and 5.1b). A description of each zone can be found in Table 5.1. The full palynological record is given in Appendix 1.

Table 5.1 Description of local pollen assemblage zones for AKM'99

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
AKM'99 1	100 – 67 c. cal. 0 – 700 AD	This zone is dominated by woodland pollen taxa (see Figure 5.1b), with *Corylus avellana* type being the dominant taxon, as well as low, but stable pollen frequency curves for the other tree species of *Betula*, *Quercus* and *Alnus* (see Figure 5.1a). Heathland pollen indicators increase in the latter third of this zone to produce a sustained peak across the zone boundary. The pastoral pollen indicators, largely consisting of *Poaceae* and *Plantago lanceolata*, exhibit very low frequencies during this zone, with a decline in values to reach a minimum at a depth of 84 cm, followed by a gradual rise in percentages. The taxa in the tall herbs/wet meadow category, dominated by Cyperaceae, exhibit a similar, although slightly later decline in values followed by a gradual increase. The *Plantago media/major* curve, the only taxon in the arable/disturbed/waste group throughout this zone, gradually rises towards the upper zone boundary. No arable indicators are recorded in this LPAZ.
AKM'99 2	67 - 24.5 c. cal. 700 – 1600 AD	This zone is characterised by the steady rise in pastoral pollen indicators, again largely attributable to the *Poaceae* and *Plantago lanceolata* taxa, although *Rumex* undiff. frequencies begin in AKM'99 2 and then develop into a continuous curve across the latter two thirds of the zone. Occurrences of *Lactuceae* undiff. pollen become more common across this phase. This zone is also marked by the first recordings of pollen taxa from the arable group. The continuous curve of arable weed taxa is mainly the result of the *Artemisia* type pollen record. Arable/disturbed/waste indicators demonstrate an unbroken record across this zone, with values peaking in the first half of AKM'99 2, a phenomenon which is largely attributable to the *Plantago media/major* pollen frequency curve. *Pteridium* values generally increase across the period, with the initial rise in pastoral indicators being accompanied by a peak in *Pteridium* at the beginning of this zone, whilst heathland indicators experience decline in the first half of this phase, followed by a gradual expansion in values throughout the second section. Woodland species appear relatively stable in the first part of AKM'99 2, followed by a gradual decline in cumulative values towards the zone boundary. The *Quercus* curve, however, demonstrates a different pattern, with low frequencies at the beginning of the zone being replaced by a period of maximum values in the latter half of the LPAZ, which is then followed by declining percentages towards the upper zone boundary. Occurrences of hedgerow taxa become more frequent across this zone.

AKM'99 3	24.5 - 13.5 c. cal. 1600 – 1800 AD	AKM'99 3 is distinguished by the rapid and significant increase in *Plantago lanceolata* frequencies which peak at 35% of total dry land pollen. This is accompanied by rises in the other pastoral indicators of *Poaceae*, *Rumex* undiff. and *Lactuceae* undiff. At the same time *Plantago media/major* type pollen, *Pteridium* and Cyperaceae values also demonstrate a similar peak in frequencies. The arable weeds curve, mainly through higher incidences of *Artemisia* type and *Sinapis* type pollen, and to a lesser extent the cultivars, also demonstrate increased values across this zone. It should be noted that a single grain of *Linum bienne* type pollen was registered in this period. Woodland values generally experience a rapid and sharp decline from the beginning of AKM'99 3, although *Pinus* pollen frequencies start to expand in the latter stage of the zone. Heathland values continue to rise, while incidences of hedgerow taxa become less frequent during this zone.
AHM'99 4	13.5 – 0 c. cal. 1800 – 1999 AD	This zone is characterised by high, relatively steady percentages of *Pinus* pollen, followed by a rapid increase in frequencies just below the surface of the profile, while the remaining tree species demonstrate very low frequencies for the remainder of the record. At the same time *Poaceae* values continue to record a rise in frequencies to reach a substantial subsurface peak of 50% of total dry land pollen, while *Plantago lanceolata* percentages experience gradual decline throughout this zone. *Pteridium* and tall herbs/wet meadow taxa also exhibit contracting frequencies across this zone. Meanwhile the arable weeds curve undergoes a swift and significant drop in values during AKM'99 4 and the arable indicators curve becomes discontinuous for the first time since AKM'99 2. Incidences of hedgerow taxa do, however, become more common in this zone, with a maximum in values occurring at a depth of 5 cm.

5.2 Tregaron Southeast Bog

The palynological record from Tregaron Southeast Bog has been divided into five separate local pollen assemblage zones (see Figures 5.2a and 5.2b). A description of each zone is given in Table 5.2 and the full pollen analytical profile can be found in Appendix 2.

Figure 5.1a Ecological grouping of selected pollen taxa from Abbeyknockmoy Bog (AKM'99)

Figure 5.1b Summary curves of ecological groups from Abbeyknockmoy Bog (AKM'99)

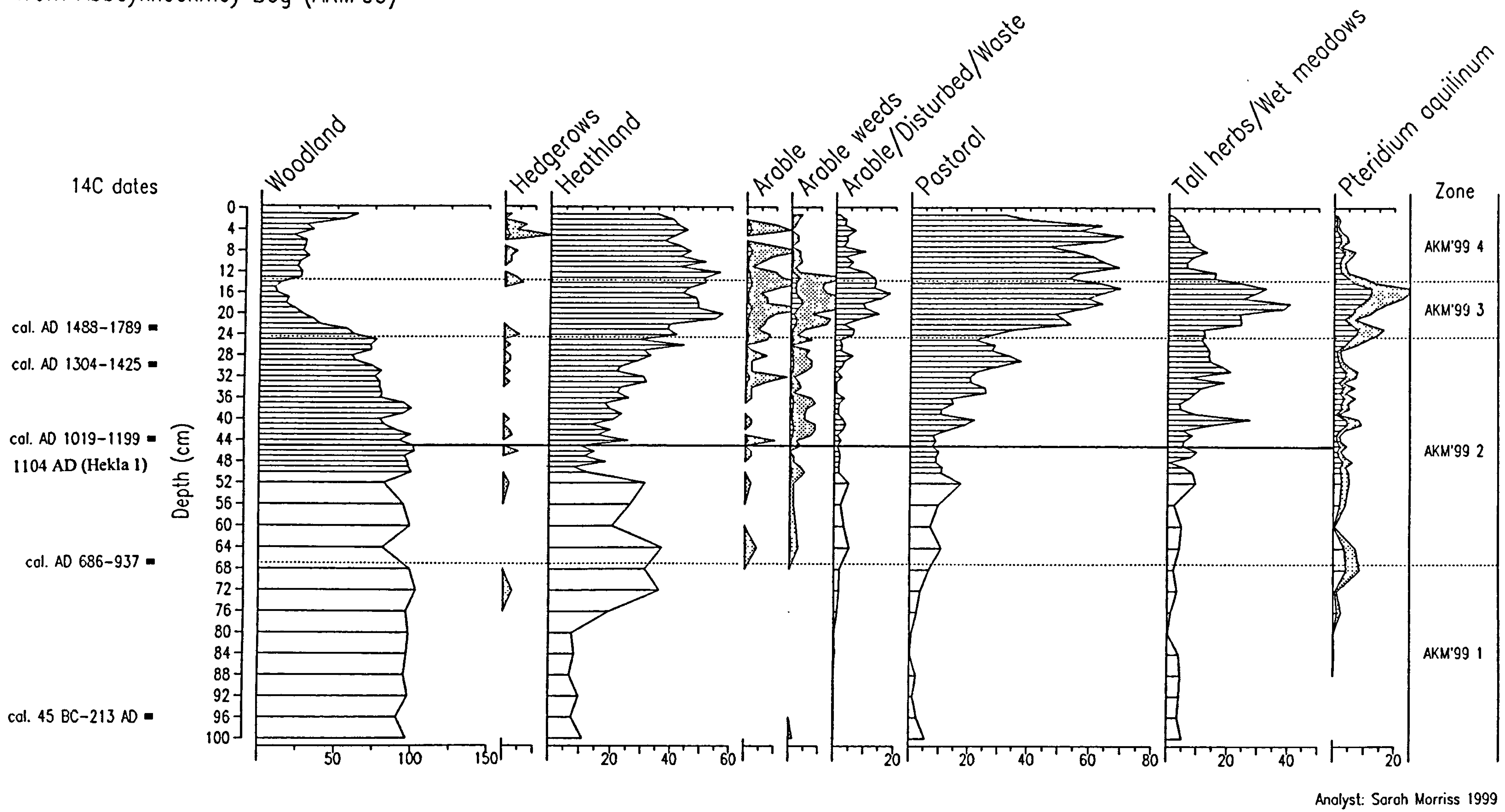


Figure 5.2a Ecological grouping of selected pollen taxa from Tregaron Southeast Bog (TRE'98)

Figure 5.2b Summary curves of ecological groups from Tregaron Southeast Bog (TRE'98)

Table 5.2 Description of local pollen assemblage zones for TRE'98

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
TRE'98 1	100 - 69.5 c. cal. 550 – 100 BC	It can be seen from Figure 5.2b that this zone is dominated by woodland taxa, the principal constituent of which is *Corylus avellana* type pollen. The three other main tree taxa in this zone include *Betula*, *Quercus* and *Alnus*, all of which demonstrate relatively uniform curves across TRE'98 1 (Figure 5.2a). Pastoral indicators, dominated by *Poaceae*, exhibit a gradual increase in values across the zone. The combined arable/disturbed/waste indicators produce an unbroken curve across this phase, although frequencies remain relatively low. Incidences of arable and arable weed pollen taxa are rather infrequent, while values of tall herbs/wet meadow taxa and *Pteridium* spores remain low.
TRE'98 2	69.5 – 44.5 c. cal. 100 BC – 400 AD	This zone is characterised by a rapid rise in pastoral indicators, with *Poaceae* recording a substantial increase in frequencies by the end of the zone. *Plantago lanceolata* pollen values demonstrate a phase of steady expansion, followed by a levelling out in frequencies in the middle of the zone. There is then a sharp trough in the grasses curve, although after this event frequencies are re-established to their former levels, prior to a gradual decline towards the zone boundary. The *Rumex* undiff. curve is continuous across this phase and there are also more consistent recordings of *Rumex acetosella* type and *Lactuceae* undiff. type pollen for the majority of the zone. Arable/disturbed/ waste indicators experience a phase of increased values compared to the previous zone, while frequencies of cultivars and arable weeds also expand throughout this phase. This is accompanied by a synchronous decline in values of *Corylus avellana* type pollen, although the curves of the other woodland species continue to remain relatively even across TRE'98 2. The second half of this zone experiences a rapid and sustained peak in Cyperaceae values, which ends shortly before the next zone boundary. *Pteridium* values rise to peak in the middle of zone TRE'98 2, which is then followed by decline. Heathland indicators generally increase during the zone, although a recession in values is recorded in the middle of the phase.
TRE'98 3	44.5 – 21.5 c. cal. 400 – 1200 AD	TRE'98 3 is distinguished by the rapid decline in pastoral indicators, which is particularly reflected by the *Poaceae* curve. For this taxon, declining values towards the middle of the zone are followed by a relatively stable curve for the remainder of the period, although frequencies continue to be greater than those recorded in the first LPAZ. The arable/disturbed/waste indicators decline slightly from the previous zone while arable weeds demonstrate a moderate

		rise in frequencies across TRE'98 3. The pollen of arable indicators is more infrequent in this zone when compared to the previous phase. *Pteridium* values also decline throughout this LPAZ, whereas the tall herbs/wet meadow category show some sharp fluctuations. Heathland taxa remain relatively high, while of the woodland taxa, *Corylus avellana* type in particular and to a lesser extent *Betula* and *Quercus*, respond by generally increased frequencies.
TRE'98 4	21.5 – 15.5 c. cal. 1200 – 1800 AD	This stratigraphically narrow zone demonstrates some high magnitude changes. Frequencies of *Corylus avellana* type pollen record a rapid decline, while *Quercus* and *Alnus* experience more gradual reductions in percentages. This is accompanied by a rapid and substantial increase in *Poaceae* pollen and a subsequent peak in *Plantago lanceolata* values. Cultivars also demonstrate an increase in frequencies across this period, while arable weed taxa record a "double peak" in this zone. Arable/disturbed/waste taxa peak at the beginning of the zone, followed by a gradual decline, although frequencies remain relatively high. The tall herbs/wet meadow category peaks early in the zone and then declines, while *Pteridium* values remain low. Heathland taxa peak in this phase.
TRE'98 5	15.5 – 0 c. cal. 1800 – 1998 AD	The main features of this zone include the high and stable frequencies of *Poaceae* pollen and the rise in *Pinus* pollen values to form a steady curve until reaching the surface. *Betula*, *Quercus*, *Fraxinus* and *Fagus* also demonstrate an increase in percentages across the majority of the zone. Values of pollen taxa in the arable and arable weed groups both demonstrate a general expansion in frequencies throughout this zone, with species such as Cereal type and *Sinapis* type producing continuous records. Frequencies of pollen taxa from the arable/disturbed/waste group demonstrate lower values, however, resulting in quantities more similar to those recorded in TRE'98 1. The tall herbs/wet meadow category exhibits low but steady percentages, while *Pteridium* values virtually disappear from this zone. Heathland taxa experience rapid decline at the beginning of the phase, to be followed by a period of lower but relatively stable frequencies. The incidence of pollen taxa from the hedgerow group becomes more frequent in this zone than in any earlier phase.

5.3 Tregaron West Bog

The palynological profile recorded from Tregaron West Bog has been divided into three distinct local pollen assemblage zones (see Figures 5.3a and 5.3b). An overview of each zone is given in Table 5.3 and the full pollen diagram can be found in Appendix 3.

Figure 5.3a Ecological grouping of selected taxa from Tregaron West Bog (TRWA 2000)

Figure 5.3b Summary curves of ecological groups from Tregaron West Bog (TRWA 2000)

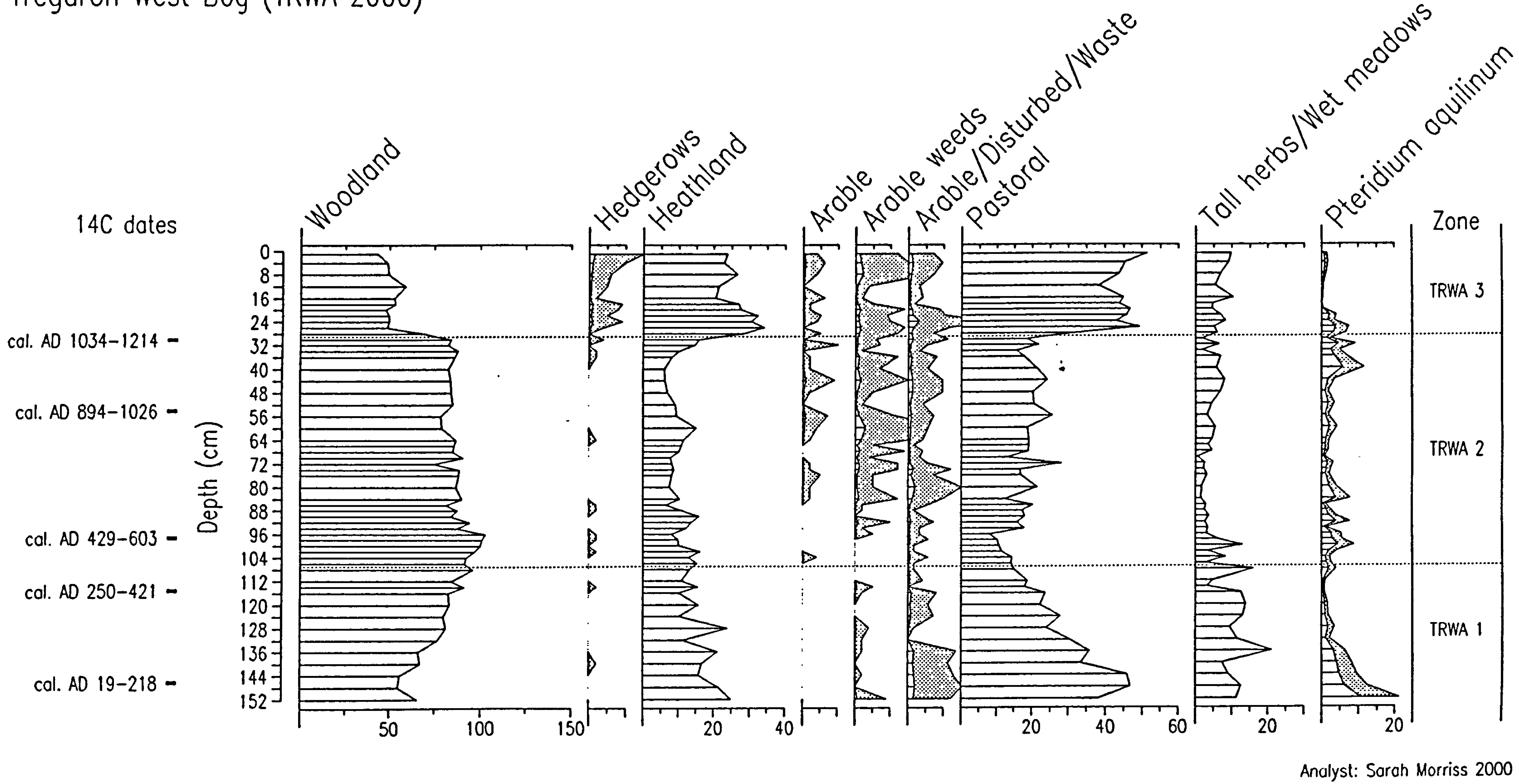


Table 5.3 Description of local pollen assemblage zones for TRWA 2000

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
TRWA 1	152 – 107 c. cal. 0 – 500 AD	This zone is marked by the decline in pastoral pollen indicators, with *Poaceae*, *Plantago lanceolata* and to a lesser extent *Rumex* undiff. and *Lactuceae* undiff. demonstrating similar patterns. The *Pteridium* curve also falls throughout TRWA 1 (see Figure 5.3a). Over the same period, the woodland taxa of *Corylus avellana* type, *Quercus* and *Betula* gradually increase towards the upper zone boundary, although *Alnus* values remain relatively constant. The pollen taxa of the combined arable/disturbed/waste group begin this zone with a stable and relatively high curve, which then declines in the second half of the phase. A discontinuous arable weeds curve, largely as a result of *Artemisia* type values, is recorded across the zone, although it is interesting to note that no arable taxa were registered. Both the heathland and tall herbs/wet meadow curves fluctuate around generally high values in this first LPAZ.
TRWA 2	107 – 29 c. cal. 500 – 1100 AD	The composite woodland taxa curve records high values and remains relatively uniform across this zone (see Figure 5.3b), with *Corylus avellana* type remaining the dominant taxa, although there are also important contributions from *Betula*, *Quercus* and *Alnus*. Pastoral indicators increase very gradually in the first half of the zone, followed by a levelling out of values for the remainder of the period. *Poaceae* and *Plantago lanceolata* continue to be the major constituents in the pastoral group, although *Rumex* undiff. and *Lactuceae* undiff. produce almost unbroken curves across this phase. Arable taxa are recorded for the first time in the profile, with the curve becoming continuous by the latter section of the zone. Arable weed taxa are virtually continuous during TRWA 2, with *Artemisia* type being the most abundant taxa recorded. The arable/disturbed/waste category generally produces greater frequencies throughout this LPAZ. *Pteridium* values and tall herbs/wet meadow taxa both decline towards the middle of the zone, followed by marginal increases in frequencies towards the upper zone boundary. Heathland taxa remain relatively stable, while incidences of hedgerow taxa are sparse.
TRWA 3	29 – 0 c. cal. 1100 – 2000 AD	This zone is characterised by a significant increase in *Poaceae* pollen which evens out at around 40% of total dry land pollen recorded. This is accompanied by a substantial rise in *Pinus* pollen frequencies, while *Corylus avellana* type pollen values decline rapidly to very low levels for the remainder of the zone. The arable, arable weeds and arable/disturbed/waste groups exhibit relatively similar frequencies to the previous zone, although this phase is

		marked by a continuous curve of *Sinapis* type pollen for the first time in the profile. The occurrences of hedgerow taxa increase significantly in TRWA 3, while heathland values exhibit a largely sustained rise in frequencies. Tall herbs/wet meadow taxa demonstrate a gradual rise across this zone, although *Pteridium* values almost disappear in the middle of the LPAZ, followed by a marginal expansion in frequencies towards the surface.

5.4 Shaw Moss

The palynological record from Shaw Moss has been divided into five distinct LPAZ's (see Figures 5.4a and 5.4b). A brief description of each zone can be found in Table 5.4. The top section of the diagram (0-36 cm), which encompasses the contiguous 0.5 cm interval counts, has been expanded in Figures 5.4c and 5.4d to show the results of the close sampling in more detail. The full pollen analytical record can be found in Appendix 4.

Figure 5.4a Ecological grouping of selected pollen taxa from Shaw Moss (SAW2)

Figure 5.4b Summary curves of ecological groups from Shaw Moss (SAW2)

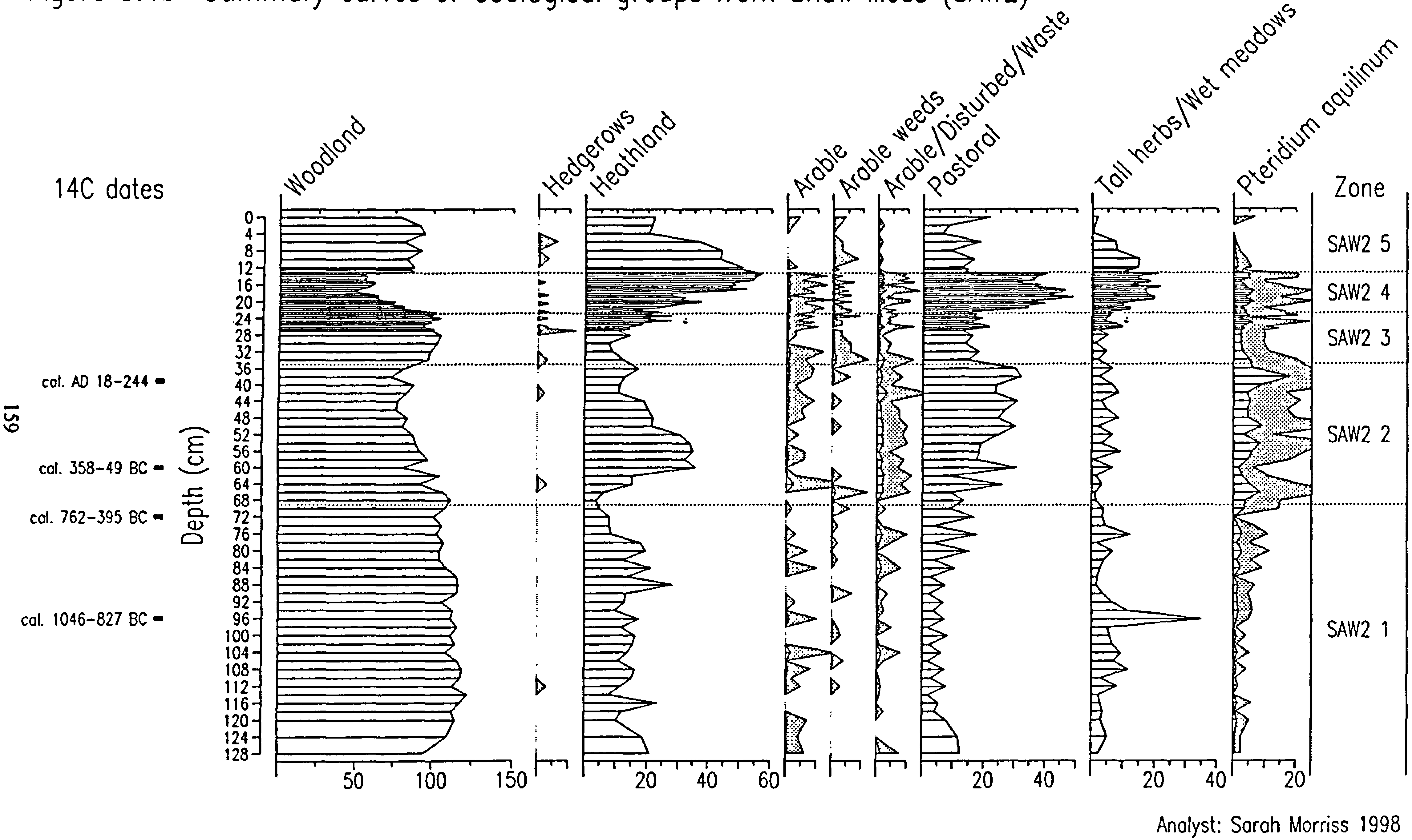


Table 5.4 Description of local pollen assemblage zones for SAW2

Local Pollen Assemblage Zone	**Depth (cm) and approx. age**	**Main characteristics**
SAW2 1	128 – 69 c. cal. 1600 – 400 BC	This zone is dominated by woodland taxa (Figure 5.4b), with *Corylus*, *Alnus*, *Quercus* and *Betula* being the dominant species (Figure 5.4a). The peak in *Betula* pollen values at the beginning of the zone is followed by a maximum of *Quercus* frequencies in the middle of SAW2 1. The *Ulmus* curve also peaks in the centre of the zone at a depth of 96 cm which is then followed by decline. Pastoral pollen indicators increase gradually towards the top of the zone, with low but continuous curves of both *Poaceae* and *Plantago lanceolata*. There are sporadic occurrences of Cereal type pollen, accompanied by higher incidences of *Cannabis sativa* type and *Artemisia* type pollen.
SAW2 2	69 – 35 c. cal. 400 BC – 200 AD	This zone is marked by the sustained increase in *Poaceae* pollen values and the generally greater magnitude of *Plantago lanceolata* pollen frequencies, as well as greater occurrences of all the *Rumex* species and *Lactuceae* undiff. *Pteridium* values largely increase across the zone, peaking just below the zone boundary with SAW2 3. The Cereal type curve is virtually continuous throughout SAW2 2, although occurrences of *Cannabis sativa* type pollen are less frequent than in the previous zone. The pollen of the arable/disturbed/waste category (largely dominated by *Plantago media/major* type) produce a low, but relatively stable, continuous curve across the zone for the first time. The woodland pollen taxa generally exhibit a decline across this zone, with *Ulmus* values becoming discontinuous for the first time in the profile, although *Quercus* frequencies demonstrate a peak in the first half of SAW2 2. The middle of this zone is also characterised by a sharp peak in heathland totals, although they decline relatively rapidly towards the top of SAW2 2.
SAW2 3	35 - 22.75 c. cal. 200 – 1800 AD	In addition to a drop in pastoral pollen indicators, SAW2 3 is characterised by declines in arable, arable weed and arable/disturbed/waste pollen taxa, while woodland taxa generally demonstrate increases in values. Recordings of hedgerow species start to become more common towards the end of this zone. *Pinus* pollen frequencies are just beginning to increase above background levels by the latter part of SAW2 3, although *Ulmus* values remain very low.
SAW2 4	22.75 - 13.25 c. cal. 1800 – 1900 AD	This zone is marked by the rapid increase in *Pinus* pollen values, although the profile would appear to indicate a "3 stage" pine rise, with the preliminary increase in frequencies at 25 cm followed by a second at 18 cm and a final and sustained rise at 13 cm (Figure 5.4c). This zone is

		also characterised by a rapid and sustained peak in pastoral pollen indicators (Figure 5.4d) which is dominated by increased values of *Poaceae* pollen. Arable pollen indicators generally increase, with the occurrence of a grain of *Fagopyrum esculentum*, while the combined woodland taxa (excluding *Pinus*) demonstrate significant declines, especially in the *Alnus* and *Corylus* curves. Again there are greater occurrences of hedgerow pollen taxa. The pollen indicators of heathland environments generally rise across this zone, while the tall herbs/wet meadows category (dominated by Cyperaceae) increase in the early part of the zone to form a generally stable and sustained expansion in values.
SAW2 5	13.25 – 0 c. cal. 1900 – 1997 AD	Zone SAW2 5 is dominated by very high frequencies of *Pinus* pollen and large percentages of *Betula* pollen. Pastoral pollen indicators drop to similar levels recorded from zone SAW2 3, while values of arable and arable/disturbed/waste pollen taxa are significantly reduced. The tall herb/wet meadow pollen, heathland taxa and *Pteridium* all experience declines throughout the majority of this zone.

5.5 Lake Gormire

The pollen analytical record from Lake Gormire has been divided into three local pollen assemblage zones (see Figures 5.5a and 5.5b). A description of each zone is given in Table 5.5 and the full pollen diagram can be found in Appendix 5. *Myriophyllum alterniflorum* has been included in Figures 5.5a and 5.5b since the significant peak in frequencies at the end of zone GOR1 2 provides a means of correlating this record to a previously ^{210}Pb dated core which also demonstrates this feature, thus providing an additional date for the profile (see Chapter 4). Furthermore, it is suggested that the peak in *Myriophyllum alterniflorum*, when combined with certain other dry land taxa, may indicate a change in land use in the lake's catchment, such as increased acid grassland, rather than just an internal lake signal and is discussed in detail in Chapter 7. It must be noted that this taxon is not included in the pollen sum.

Figure 5.4c Ecological grouping of selected pollen taxa from Shaw Moss (SAW2): 0 – 36cm

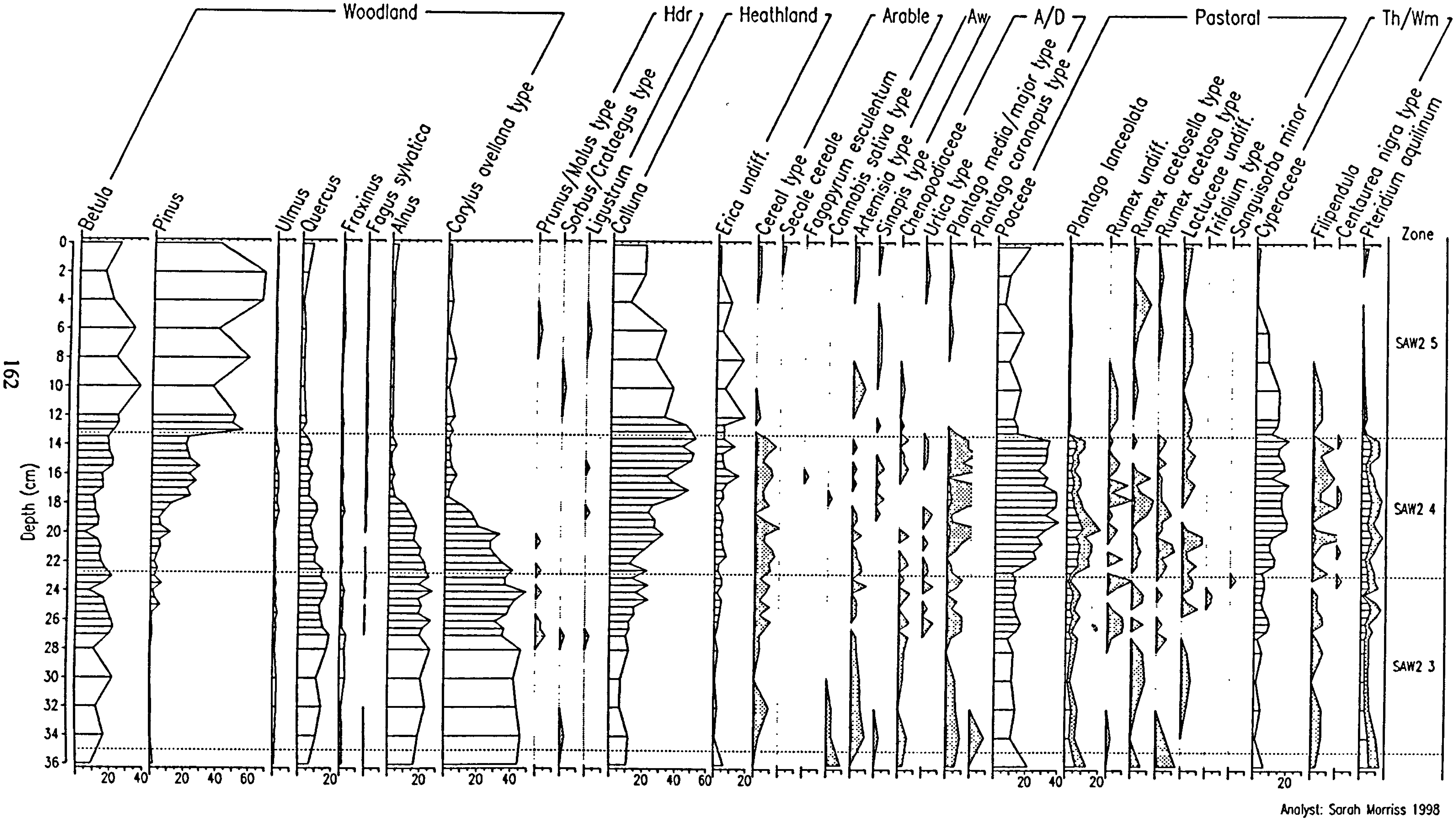


Figure 5.4d Summary curves of ecological groups from Shaw Moss (SAW2): 0 – 36cm

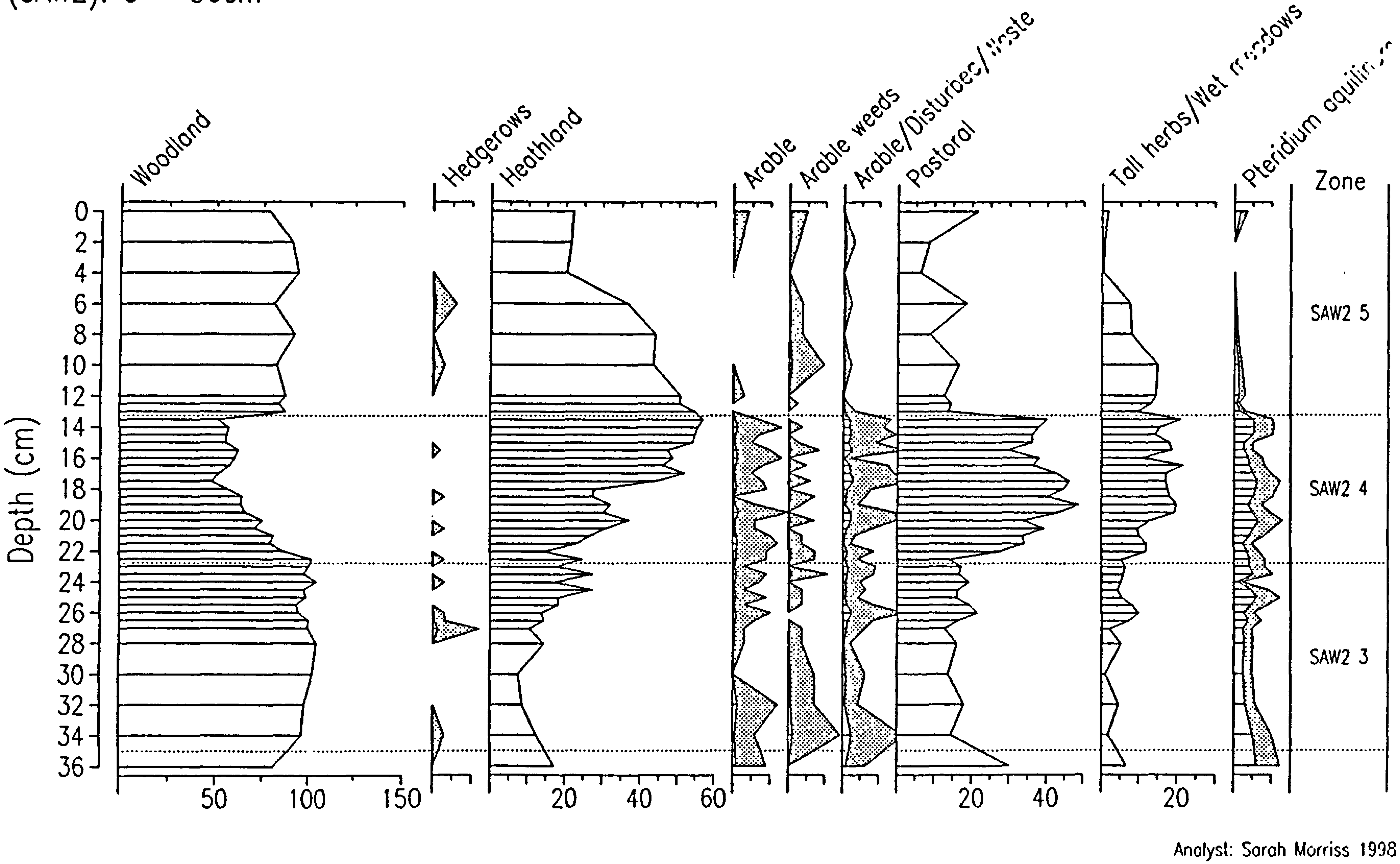


Figure 5.5a Ecological grouping of selected pollen taxa from Lake Gormire (GOR1)

Figure 5.5b Summary curves of ecological groups from Lake Gormire (GOR1)

Table 5.5 Description of local pollen assemblage zones for GOR1

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
GOR1 1	70 - 39.5 c. 1300 – 1600 AD	This zone is dominated by the gradually declining woodland taxa of *Corylus avellana* type, *Alnus*, *Quercus* and to a lesser extent *Betula* (Figures 5.5a and 5.5b). Another important feature of this zone is the steady rise in pastoral indicators, through the main taxa of *Poaceae* and *Plantago lanceolata* and the lower but continuous curves of *Lactuceae* undiff. and *Rumex* undiff. There are also greater incidences of *Sanguisorba minor* pollen in the latter part of this zone. At the same time, an unbroken and significant curve of arable indicators is recorded throughout this zone, which gradually increases to peak in the second half of GOR1 1. This is the result of continuous frequencies for Cereal type, *Secale cereale* and *Cannabis sativa* type pollen, with the *Cannabis* curve peaking in the latter section of the zone. Arable weeds display a virtually continuous curve, with *Artemisia* type and *Centaurea cyanus* type being the main constituents. The curves of the arable/disturbed/waste, heathland and tall herbs/wet meadow categories demonstrate largely stable frequencies across the zone. *Pteridium* and *Myriophyllum alterniflorum* values remain constant but low for the duration of the zone. Occurrences of hedgerow taxa are also common in this zone.
GOR1 2	39.5 - 24.5 c. 1600 – 1770 AD	This zone is distinguished by the rapid and substantial rise in *Myriophyllum alterniflorum* values, which peak at the upper zone boundary with frequencies of 31%. Although zone boundaries are not usually based on aquatic species, in this case this taxon may represent an external signal from land use changes in the lake's catchment when interpreted with the other taxa of *Pteridium* and Cyperaceae, such as an increase in acid grassland (see Chapter 7). This feature also provides an additional date for the profile as a result of correlation with a previously ^{210}Pb dated core. Meanwhile pastoral indicators continue to rise throughout this zone, but while *Poaceae* and *Plantago lanceolata* values remain relatively steady or experience a very gradual rise respectively, *Lactuceae* undiff. frequencies virtually double in the second part of the zone to create a sustained peak in percentages. The cultivars generally display an even curve throughout this zone, although frequencies tend to be lower than those recorded in the previous phase. This is partially a result of declining *Cannabis sativa* type percentages, which break into a discontinuous record across this zone. The arable weeds roughly maintain their frequencies in the first half of this zone, although experience a decline in values towards the upper zone boundary. It is interesting to

		note that the *Centaurea cyanus* type pollen curve is absent from this zone, apart from a few occurrences at the very beginning of GOR1 2. The arable/disturbed/waste group remains largely constant across this zone, while tall herbs/wet meadow taxa demonstrate a small increase and *Pteridium* values experience a rise which is sustained for the majority of the phase. Both woodland and hedgerow taxa exhibit continued declines in GOR1 2, with *Quercus* suffering from the sharpest drop in values. Heathland taxa increase marginally in the second half of the LPAZ.
GOR1 3	24.5 – 0 c. 1770 – 1999 AD	One of the features of this zone is the gradual rise in *Pinus* pollen towards the top of GOR1 3 and an accompanying peak in *Betula* pollen in the top section of this phase. This zone is also marked by the continued rise in pastoral indicators, which level out by the middle of the period and then experience decline. Occurrences of *Trifolium* type pollen become more frequent in the early-to-mid section of the zone. The *Myriophyllum alterniflorum* curve declines relatively smoothly over this zone towards the surface of the profile. Arable weeds and *Pteridium* experience a gradual decline throughout this period, while the arable indicator curve becomes slightly more subdued compared to the previous zone. Hedgerow taxa demonstrate an increase in values in the latter part of this zone, which is largely the result of the *Rubus* type pollen record.

5.6 Talkin Tarn (TAL1)

The pollen analytical record from Talkin Tarn (TAL1) has been divided into three local pollen assemblage zones (see Figure 5.6). A description of each zone can be found in Table 5.6. Since the radiocarbon dates indicate that the base of this profile is of Lateglacial / Early Holocene origin (cal. 12,346 – 11,700 BP) (see Chapter 4), it was considered inappropriate to ecologically group the pollen taxa according to land use type and thus only a summary pollen diagram of the main taxa recorded is presented here. A full palynological profile can be found in Appendix 6. Description and discussion (see Chapter 7) of this profile are relatively brief since this timeframe is somewhat outside the chronological range of this project and is thus not relevant when considering the research questions posed in Chapter 1. It should be noted that AMS dates on this profile are quoted as calibrated radiocarbon years BP rather than calibrated years AD/BC.

Figure 5.6 Summary pollen diagram from Talkin Tarn (TAL 1)

Table 5.6 Description of local pollen assemblage zones for TAL1

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
TAL1 1	75 – 67 Lateglacial: c. cal. 12,023 BP at 70.5 cm	This zone is distinguished by the substantial quantities of *Artemisia* type pollen recorded, which peak at 35% of total dry land pollen and dominate this zone. This is accompanied by large frequencies of *Poaceae*, Cyperaceae and *Rumex* undiff. pollen, as well as the only zone in the profile to contain a significant amount of *Thalictrum* pollen. There are also low but continuous curves of *Caryophyllaceae* undiff., *Silene dioica* type, *Filipendula* and *Anthemis* type pollen. At the same time *Corylus avellana* type and *Calluna* pollen frequencies remain subdued, although *Salix* values are quite important in this zone. The main tree species recorded in this zone are *Betula* and *Pinus*, although traces of *Ulmus*, *Quercus*, *Fraxinus*, *Fagus* and *Alnus* pollen are registered.
TAL1 2	67 – 53	This zone is characterised by the rapid decline of *Artemisia* type pollen, as well as sharp reductions in Cyperaceae, *Rumex* undiff., *Caryophyllaceae* undiff. and *Filipendula* pollen frequencies, to almost trace levels. The *Poaceae* curve also experiences decline but then stabilises to produce a period of low but uniform values until the end of the zone. At the same time there is a dramatic increase in *Corylus avellana* type pollen, which is accompanied by a rise in *Betula*, *Quercus*, *Ulmus* and *Alnus* pollen. The *Corylus avellana* type curve, however, experiences a decline in frequencies prior to the upper zone boundary. *Pinus* values remain low but steady throughout this LPAZ. This zone marks the beginning of continuous curves for both *Plantago lanceolata* and *Pteridium*.
TAL1 3	53 – 0 c. cal. 3,842 BP at 46.5 cm to 2000 AD	The beginning of this zone is marked by the increase in frequencies of *Quercus* pollen, which is then followed by a gradual drop in values towards the surface. A similar trend of slow and steady decline with decreasing stratigraphical depth is demonstrated by the *Corylus avellana* type, *Alnus* and *Betula* curves. At the same time the *Pinus* and *Poaceae* curves exhibit an inverse pattern of gradually increasing values towards the top of the profile. *Fagus* values also expand slowly towards the surface, while *Ulmus*, *Calluna* and *Salix* remain relatively even. There are a much greater variety of herbs in this zone, as well as almost continuous curves for the first time of Cereal type, *Plantago media/major* type and *Lactuceae* undiff. pollen. *Rumex* undiff. values start to take off in the latter two thirds of this zone, while *Plantago lanceolata* frequencies are relatively stable across TAL1 3, except for a trough in values at 16 cm. *Sinapis* type, *Galium* and *Ranunculus* type pollen also become more frequent by the second half of the zone.

5.7 Talkin Tarn (TAL2)

The palynological profile from Talkin Tarn (TAL2) has been divided into three distinct local pollen assemblage zones (see Figures 5.7a and 5.7b). A description of each zone is given in Table 5.7 and the full pollen diagram can be found in Appendix 7.

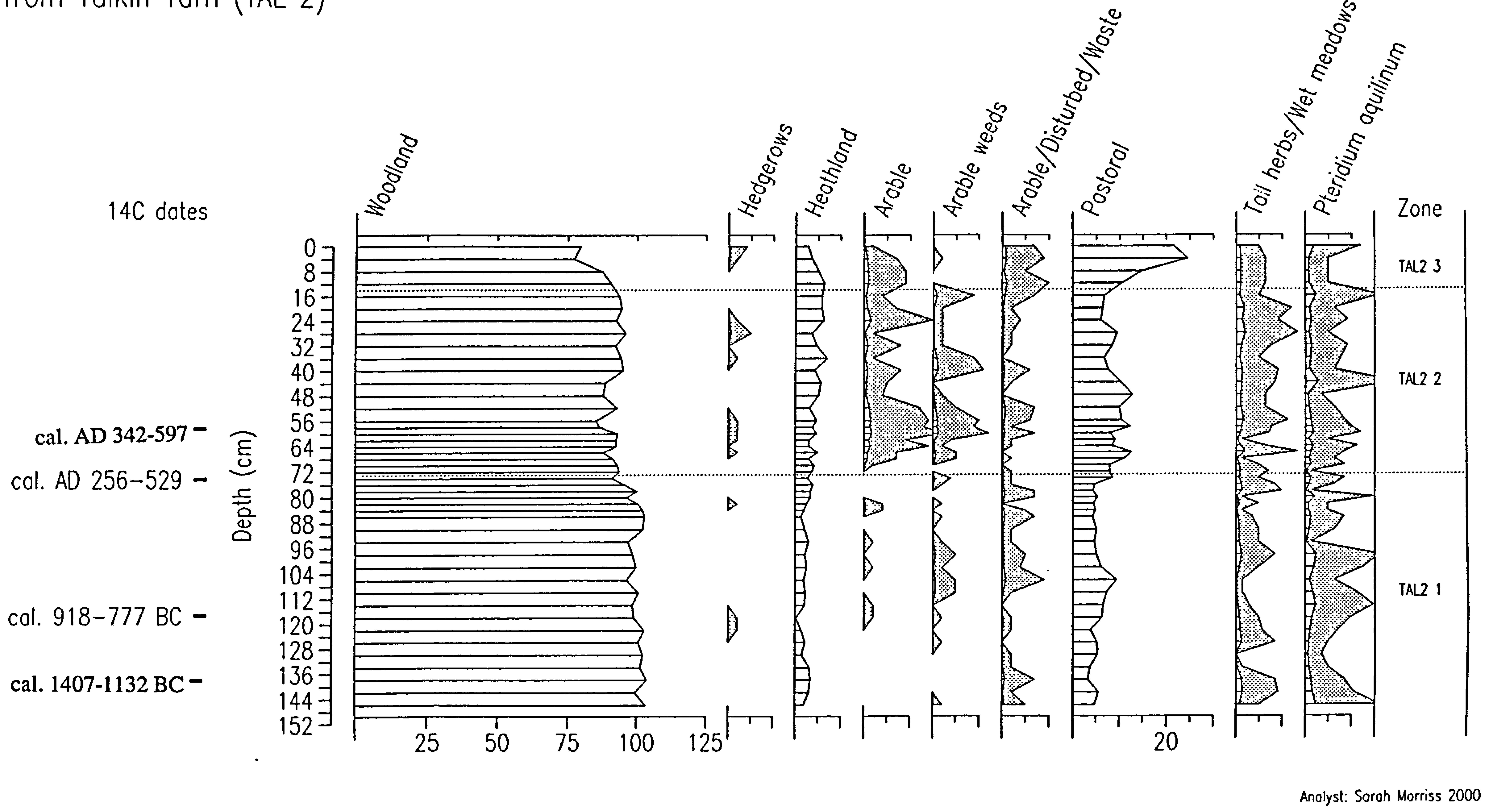
Table 5.7 Description of local pollen assemblage zones for TAL2

Local Pollen Assemblage Zone	Depth (cm) and approx. age	Main Characteristics
TAL2 1	146 – 73 c. cal. 1500 BC – 400 AD	This zone is dominated by the woodland pollen taxa of *Betula*, *Quercus* and *Corylus avellana* type, and to a lesser extent *Alnus* (see Figure 5.7a), which combine to produce a fairly uniform cumulative curve across the zone (see Figure 5.7b). Pastoral indicators rise to peak in the middle of the zone, which is followed by declining values until the upper zone boundary. In this ecological group, *Poaceae* values are supported by near continuous curves of *Plantago lanceolata* and *Rumex* undiff. frequencies. The arable/disturbed/waste taxa also produce a virtually unbroken curve throughout this zone, largely as a result of *Chenopodiaceae* values. Taxa from the arable and arable weeds groups demonstrate lower, more patchy frequencies with Cereal type and *Artemisia* type being the dominant taxa respectively. Occurrences of hedgerow taxa remain sparse during TAL2.. Heathland and tall herbs/wet meadow taxa are relatively subdued over this phase. The *Pteridium* curve experiences some fluctuations, although values generally remain low.
TAL2 2	73 – 14 c. cal. 400 – 1650 AD	This zone is characterised by a virtually continuous record of arable indicators, with *Secale cereale* pollen being recorded for the first time in the profile. This is accompanied by an almost unbroken curve of arable weeds with *Artemisia* type and *Sinapis* type being the main constituents. In terms of pastoral indicators, *Poaceae* frequencies peak in the first section of the zone, which is followed by a shorter-lived peak in both *Plantago lanceolata* and *Rumex* undiff. pollen in the middle of TAL2 2. The *Lactuceae* undiff. frequencies produce a virtually continuous curve across this zone. The combined pastoral indicators then decline towards the upper zone boundary. At the same time, heathland indicators demonstrate a very gradual increase across the zone, while woodland values suffer a marginal decline. Tall herbs/wet meadow taxa

		exhibit slightly greater frequencies sustained over the latter two thirds of the LPAZ, while *Pteridium* values continue to fluctuate. Incidences of hedgerow taxa become marginally more common during this period.
TAL2 3	14 – 0 c. cal. 1650 – 2000 AD	The surface zone is distinguished by a significant rise in *Pinus* pollen values largely at the expense of the other main woodland taxa, although *Fagus* frequencies also increase towards the end of this zone. There is a substantial rise in *Poaceae* values. Arable indicators remain relatively consistent across this zone, while values of arable weeds drop dramatically. This is accompanied by an increase in arable/disturbed/waste taxa. Heathland indicators decline in TAL2 3 and hedgerow taxa become more sparse than in the previous zone. The tall herbs/wet meadow category experiences a drop in frequencies in this final zone while *Pteridium* values continue to fluctuate.

Figure 5.7a Ecological grouping of selected pollen taxa from Talkin Tarn (TAL 2)

Figure 5.7b Summary curves of ecological groups from Talkin Tarn (TAL 2)



Chapter 6 – Geochemical and Charcoal Results

6.0 Introduction

The first section of this chapter describes the geochemical results recorded from three of the peat profiles investigated. As discussed in Section 3.4.2, Silicon and Titanium have been identified as good indicators of soil erosion, through activities such as forest clearance and farming, thus making these elements a useful proxy for reconstructing human impact on the environment. The geochemical curves are displayed adjacent to their respective pollen diagrams to allow direct correlation with the pollen analytical results. Since Si can, however, be contained in certain plants and diatoms, Ti analyses have also been undertaken, courtesy of Dr. A. Hölzer, because this element is not found in these sources. It is therefore argued that synchronous peaks in both Si and Ti are the result of increased soil erosion rather than contamination by plants or diatoms (see Chapter 3). The Si curves register concentrations that are several orders of magnitude greater than the Ti curves. This is due to the fact that concentrations of Si contained in mineral soils, which are subsequently eroded into bogs, can range between 10 – 30%, whereas concentrations of Ti register only 0.1 – 1% (Allen, 1974). (This should be compared against the background levels of Si and Ti found in peat sediments, which range between 0.2 – 2% and 0.01 – 0.08% respectively (Allen, 1974)).

The second section of this chapter illustrates the charcoal concentrations recorded from Talkin Tarn (TAL2), which are also displayed next to the pollen data to allow direct comparison of results. (A discussion of charcoal as a proxy for reconstructing past human activity can be found in Section 3.4.4). Finally, the results of using magnetic susceptibility studies for identifying horizons of increased charcoal concentrations at Lake Gormire are discussed. It should be noted that the local pollen assemblage zones referred to here correspond to those defined in the previous chapter.

6.1 Abbeyknockmoy Bog

The Si and Ti results from Abbeyknockmoy Bog are displayed in Figures 6.1a and 6.1b. Concentrations of Si range from 463 to 13,805 ppm (parts per million) and Ti from 21.4 to 197.4 ppm. There is a striking similarity in the shape of both the Si and Ti curves from

Abbeyknockmoy Bog, which would suggest that the synchronous peaks are the result of inputs to the bog surface by soil erosion rather than by plant or diatom contamination.

Both geochemical curves begin the profile by registering low frequencies, although there is a sharp peak in Si frequencies at a depth of 88 cm which is mirrored by a rather more gradual peak in the Ti curve. After this event, both curves register a generally increasing trend in concentrations towards the upper zone boundary. This generally corresponds well with the pollen analytical results which also suggest little human activity in the first half of this zone. This is then followed by a gradual rise in pastoral indicators in the second section of AKM'99 1, a trend which mirrors the geochemical signal. The only discrepancy between the geochemical record and the pollen data would appear to be the aforementioned peak in Si and Ti values at 88 cm. There is nothing in the pollen profile that explains this peak, although it must be remembered that due to the production and dispersal characteristics of taxa such as Cereal type pollen, the lack of arable indicators recorded in the diagram does not automatically mean that there was an absence of cultivation in the local area at this time. However, the lack of associated arable weeds would appear to support this view, thus leaving the cause of the peak in Si and Ti in doubt. Since both geochemical proxies record increases at this depth, it is unlikely that this event is the result of Si contamination by plant phytoliths or diatoms. It does, however, appear to coincide with the very beginning of the *Pteridium* record.

At the beginning of zone AKM'99 2 there is a peak in Ti values followed by a small decline to relatively stable levels that are generally consistently higher than those recorded in the previous zone. This correlates well with the palynological record which demonstrates significant quantities of arable and arable weed indicators for the first time in the profile together with a continued increase in pastoral type pollen. This Ti peak is also concurrent with a decline in *Corylus avellana* type pollen, perhaps indicating some clearance of scrub for agricultural purposes. It is interesting to note, however, that Si values start this zone with a phase of slightly higher frequencies, but then this is replaced by declining values until a peak at 51 cm and it is only in the second half of the zone that Si concentrations experience a gradually increasing trend. The Si peak at 51 cm coincides with a peak in *Plantago lanceolata* pollen, although greater frequencies of Cyperaceae pollen are also recorded at this depth. It is possible that the peaks in Si and Ti in the early part of this zone indicate a phase of substantial change in the local environment with clearance of scrub being accompanied by increased arable and pastoral activity on a level that had not previously been experienced in the preceding c. 800 years. Once this new farming regime had been introduced in cal. AD 686 – 937, the stabilisation of the geochemical proxies may indicate a period of sustained agricultural activity. These geochemical results indicate that small rises in the percentages of indicator species to above background levels in the pollen diagram are sufficient to be registered in the Si and Ti curves, thus meaning that even slight increases in the pollen record may indeed have been the result of significant land use change in the local environment.

The shapes of the two geochemical curves look virtually identical throughout zone AKM'99 3. Both demonstrate an almost synchronous peak in values followed by a small decline at the beginning of the zone, only for concentrations to rise sharply to reach a maximum of Si and Ti values, which decline rapidly at the end of the zone. Although there is a peak in Cyperaceae during this zone, the increased Ti frequencies would suggest that the geochemical indicators are responding to soil erosion rather than phytoliths contained within certain plants (Hölzer and Hölzer, 1998). Furthermore, the peak in Cyperaceae frequencies actually occurs in between the two peaks of the geochemical proxies. This correlates very well with the pollen diagram where the first peak coincides with a rapid decline in woodland indicators, peaks in the pastoral indicators of *Poaceae* and *Plantago lanceolata* and increased arable and arable weed taxa. The Si and Ti maxima then occur virtually synchronously with the low point in the woodland curve, indicating the largest extent of cleared land and also correlate with peaks in *Plantago lanceolata*, Cereal type and *Artemisia* pollen. Both the geochemical and pollen data therefore suggest an increase in forest clearance and farming activity.

The final zone, AKM'99 4, is characterised by a decline in both Si and Ti concentrations, although frequencies remain relatively high when compared to the remainder of the profile. This again supports the pollen analytical data, which demonstrate slightly lower levels of arable and arable weed taxa although pastoral indicators continue to fluctuate around high levels until the very end of the zone. It is interesting to note that in this case, the declining Si and Ti concentrations are coupled with increasing *Poaceae* values but declining *Plantago lanceolata* frequencies. Indeed, Hölzer and Hölzer (1998) comment on the strong correlation between Si and Ti and *Plantago lanceolata*. The Si and Ti curves across this uppermost zone would also appear to demonstrate an almost inverse trend to the woodland pollen taxa, which by this stage in the profile is dominated by

Figure 6.1a Geochemical results from Abbeyknockmoy Bog (AKM'99)

Figure 6.1b Summary curves of ecological groups and geochemical results from Abbeyknockmoy Bog (AKM'99)

Pinus. One possible explanation for this is that such reforestation though the planting of pine and other exotics, had the opposite effect on the Si and Ti curves by reducing soil erosion and hence Si and Ti input to the bog surface. In addition, a more heavily wooded landscape may also obstruct the transportation of dust particles thus having the effect of inhibiting dispersion and ultimately reducing deposition.

Overall, the Si and Ti curves for Abbeyknockmoy Bog complement each other very well, with the major peaks in concentration occurring virtually synchronously, thus suggesting that these proxies are responding to a soil erosion signal. Furthermore, the geochemical curves correspond very well with the pollen evidence for past anthropogenic activity, especially when compared with the Cereal, *Artemisia* type, *Plantago lanceolata*, *Poaceae* and combined woodland pollen taxa. It is recognised, however, that there are difficulties in determining the source of the soil erosion, for example whether it be a response to deforestation or agricultural activity. To this end, the pollen data is necessary to help elucidate the different causal factors for the fluctuations in Si and Ti.

6.2 Tregaron Southeast Bog

The Si and Ti results from Tregaron Southeast Bog are displayed in Figures 6.2a and 6.2b. Concentrations of Si range from 553 to 35,885 ppm and Ti from 23 to 264.7 ppm. Again there is a strong similarity in the shape of both the Si and Ti curves from Tregaron Southeast Bog, which also implies that the geochemical curves are registering a soil erosion signal rather than fluctuations in phytoliths or diatom concentrations.

Both the Si and Ti curves record low concentrations during the first half of zone TRE'98 1, which gradually increase towards the upper zone boundary. The pollen evidence demonstrates a similar picture of subdued human activity which is beginning to increase slowly in the latter part of the zone. This activity would appear to be largely pastoral in nature, with *Poaceae* and *Plantago lanceolata* being the main taxa involved, and is accompanied by a gradual decline in woodland pollen frequencies.

The beginning of zone TRE'98 2 is marked by a small pulse in both Si and Ti concentrations followed by a phase of significantly higher geochemical concentrations which begins at a depth of c. 63 cm. Although this coincides with a period of increased Cyperaceae frequencies the significant amounts of Ti indicate that this is a period of marked increase in soil erosion rather than plant contamination. Again this correlates strongly with the pollen analytical record, which registers a substantial increase in pastoral indicators, mainly through the *Poaceae*, *Plantago lanceolata* and to a lesser extent the *Lactuceae* undiff. pollen, and significantly greater frequencies of arable and arable weed taxa as well as larger percentages of arable/disturbed/waste pollen. This period of greater Si and Ti concentrations and increased farming activity also coincides with continued decline of the woodland pollen taxa.

It is interesting to note that both the Si and Ti curves record three distinct peaks in concentration across this phase, the first two of which are concurrent and the last being recorded slightly later in the Ti profile. Although the combined pastoral curve does indicate an increase in frequencies in a pattern of three "steps", these peaks do not correspond stratigraphically with the peaks recorded by the geochemical curves. Furthermore, in both the Si and Ti curves, the middle peak registers the largest concentrations, which is not the case with the pastoral graph. There does not appear to be a similar pattern registered in any of the individual pollen taxa or in the summary ecological group curves. This may suggest that the Si and Ti proxies are very sensitive even to small scale, short-lived episodes of increased soil erosion, and can thus detect more subtle changes in farming activity and deforestation than the pollen analytical data. Therefore a more detailed record of human activity can be obtained by combining the techniques of pollen and geochemical analysis. The end of this zone registers the beginning of a fall in both Si and Ti concentrations, which occurs at the same time as the start of declines in pastoral, arable and arable/disturbed/waste pollen frequencies.

The next zone, TRE'98 3, demonstrates the continued decline of Si and Ti values which reach their lowest concentrations in this period at a depth of 34 cm and 36 cm respectively. As well as correlating to the continued decline in pastoral pollen frequencies and decreasing arable taxa percentages, this phase is accompanied by an increase in woodland pollen taxa. This again suggests that the expansion of trees and scrub results in decreased soil erosion and hence reduced deposition of Si and Ti. Si and Ti concentrations then begin to expand across the second half this zone. Since the cumulative woodland frequencies appear to be relatively stable during this phase, it would suggest that little clearance activity was taking place at this time and hence soil erosion through farming activity must be producing the geochemical signal for this part of the

Figure 6.2a Geochemical results from Tregaron Southeast Bog (TRE'98)

Figure 6.2b Summary curves of ecological groups and geochemical results from Tregaron Southeast Bog (TRE'98)

Analyst: Sarah Morriss 1998

record. The pollen data record largely stabilised frequencies of pastoral indicators and slightly increasing arable percentages during the remainder of this zone.

The Si and Ti curves then register rapid, significant peaks in concentrations at a depth of 16 cm and 18 cm respectively in zone TRE'98 4. This is matched by a period of sharp decline in the woodland taxa, especially in the *Corylus avellana* type curve, suggesting a phase of woodland clearance, and increases in pastoral, arable and arable/disturbed/waste taxa, indicating a general increase in agricultural activity and deforestation.

The final zone, TRE'98 5, registers declines in both the geochemical curves. Unfortunately the top few centimetres of the sequence could not be analysed for Si and Ti content due to insufficient sample material. It would appear to indicate a similar trend to that recorded from Abbeyknockmoy Bog, where reforestation through the planting of pine and other exotics results in declining Si and Ti concentrations. It must be noted, however, that pastoral, arable and arable weed frequencies remain high, indicating that agriculture continued to have a significant impact on the environment, despite reduced quantities of Si and Ti.

In summary, the Si and Ti curves from Tregaron Southeast Bog display very similar characteristics to each other and also correlate closely with the pollen analytical evidence for land use change.

6.3 Shaw Moss

The Si and Ti results from Shaw Moss can be seen in Figures 6.3a to 6.3d. Concentrations of Si range from 605 to 47,008 ppm and Ti from 34.1 to 504.5 ppm. Again the two geochemical curves demonstrate very similar trends. It must be noted that the Ti profile from Shaw Moss only extends as far as 104 cm down the profile since priority was given to analysing the upper section of more recent human impact in greater detail.

The beginning of the profile demonstrates a small pulse in Si values which is then followed by a period of low, relatively stable concentrations until a sharp peak in Si at a depth of 95 cm. The Ti record begins shortly before this peak but does not register a concurrent event of a similar magnitude. The Si curve then increases very gradually towards the upper zone boundary while the Ti profile increases to peak at 80 cm which is followed by a gradual decline to relatively stable levels by the end of this zone. The pollen analytical data correlate well with the geochemical evidence as the beginning of the diagram records a phase of increased arable and pastoral frequencies which then decline, but while pastoral taxa gradually increase throughout the zone, the arable indicators curve becomes discontinuous. Woodland pollen taxa record a slight decline in frequencies in the latter part of this zone. In this instance, the peak in Si concentrations at 95 cm is not synchronous with a similar Ti event but there is a sharp "spike" in Cyperaceae pollen at this level, which suggests that this phenomenon may be the result of phytoliths, which form between and within plant cells (Loeta Tyree, 1994), rather than soil erosion.

Zone SAW2 2 is marked by an early, synchronous peak in both Si and Ti concentrations, followed by a quite significant decline, after which both curves demonstrate a substantial but steady increase in values until the zone boundary where both curves experience a concurrent, sharp trough in concentrations. This corresponds well to the pollen evidence which indicates a phase of woodland clearance, increased pastoral taxa, significant amounts of arable/disturbed/waste pollen and an almost continuous curve of arable taxa. It is interesting that this record from Shaw Moss demonstrates a similar pattern to Abbeyknockmoy Bog where an initial pulse in Si and Ti concentrations is followed by decline and then resumed expansion of the geochemical proxies, while the pollen indicators of human activity do not exhibit the short period of decline and continue to increase in a more steady fashion. Again this may be interpreted as a substantial increase in farming activities and forest clearance from the previous zone which causes significant change in the local environment resulting in large quantities of soil erosion and hence causing the peak in Si and Ti concentrations. After this initial phase of activity, it may be that soil erosion decreases as the new farming patterns become established, resulting in the continued expansion of pastoral and arable pollen indicators while Si and Ti concentrations then increase as the land is worked and agriculture sustained for a long period of time. The trough in Si and Ti values at the top of this zone corresponds with increasing woodland frequencies and a decline in pastoral indicators.

Zone SAW2 3 demonstrates a rapid increase in Si values and a slightly more gradual rise in Ti concentrations (see Figures 6.3c and 6.3d). Indeed the Si curve fluctuates to a much greater extent than the Ti curve over this zone, although some of this may be a function of the different sampling intervals. The pollen record fits reasonably well with the geochemical proxies across this zone. Pastoral indicators remain relatively steady across SAW2 3, although there is a peak in pastoral frequencies, largely due to the *Poaceae* curve, which coincide with a Si peak at 26 cm. This Si peak also occurs at the same time as a peak in the arable/disturbed/waste category. In general, the arable and arable weed taxa do not increase across the zone as might be expected from the Si and Ti curves. Since both geochemical curves indicate an increase in concentrations during SAW2 3 yet woodland taxa remain relatively stable indicating little forest clearance, it might suggest an increase in the intensity of agricultural activity on the existing area of land. It is interesting that the pollen indicators for activity do not increase at the same rate as the Si and Ti curves in this zone, suggesting that this farming event may not have been detected by the palynological data alone, thus indicating the importance of a multi-proxy approach to land use reconstructions.

The Si and Ti curves continue to rise until the middle of zone SAW2 4. This corresponds strongly with the palynological record where pastoral indicators also peak in the centre of the zone and arable, arable weeds and arable/disturbed/waste taxa become more abundant. The rise in Si and Ti concentrations also accompanies a decline in the woodland pollen curve which reaches its lowest point in the middle of this zone. The second half of the zone is characterised by declining Si and Ti concentrations, which corresponds with an increase in woodland pollen taxa, largely as a result of the *Pinus* curve, again demonstrating the inverse relationship between geochemical inputs and reforestation. At the same time pastoral indicators decline slightly while the arable, arable weeds and arable/disturbed/waste taxa continue to remain relatively steady.

Both the Si and Ti curves decline to stable but low levels in the final zone of the profile, while woodland taxa exhibit an increase in values which is sustained across SAW2 5, again largely as the result of the expanding *Pinus* frequencies. At the same time pastoral indicators drop to demonstrate lower percentages throughout this zone, while frequencies of both arable and arable/disturbed/waste taxa are greatly reduced.

In summary, there is a strong correlation between the Si and Ti curves for Shaw Moss suggesting that the signal is largely one of soil erosion, which also corresponds closely with the pollen analytical record for human activity.

Figure 6.3a Geochemical results from Shaw Moss (SAW 2)

Figure 6.3b Summary curves of ecological groups and geochemical results from Shaw Moss (SAW 2)

Figure 6.3c Geochemical results from Shaw Moss (SAW 2): 0–36cm

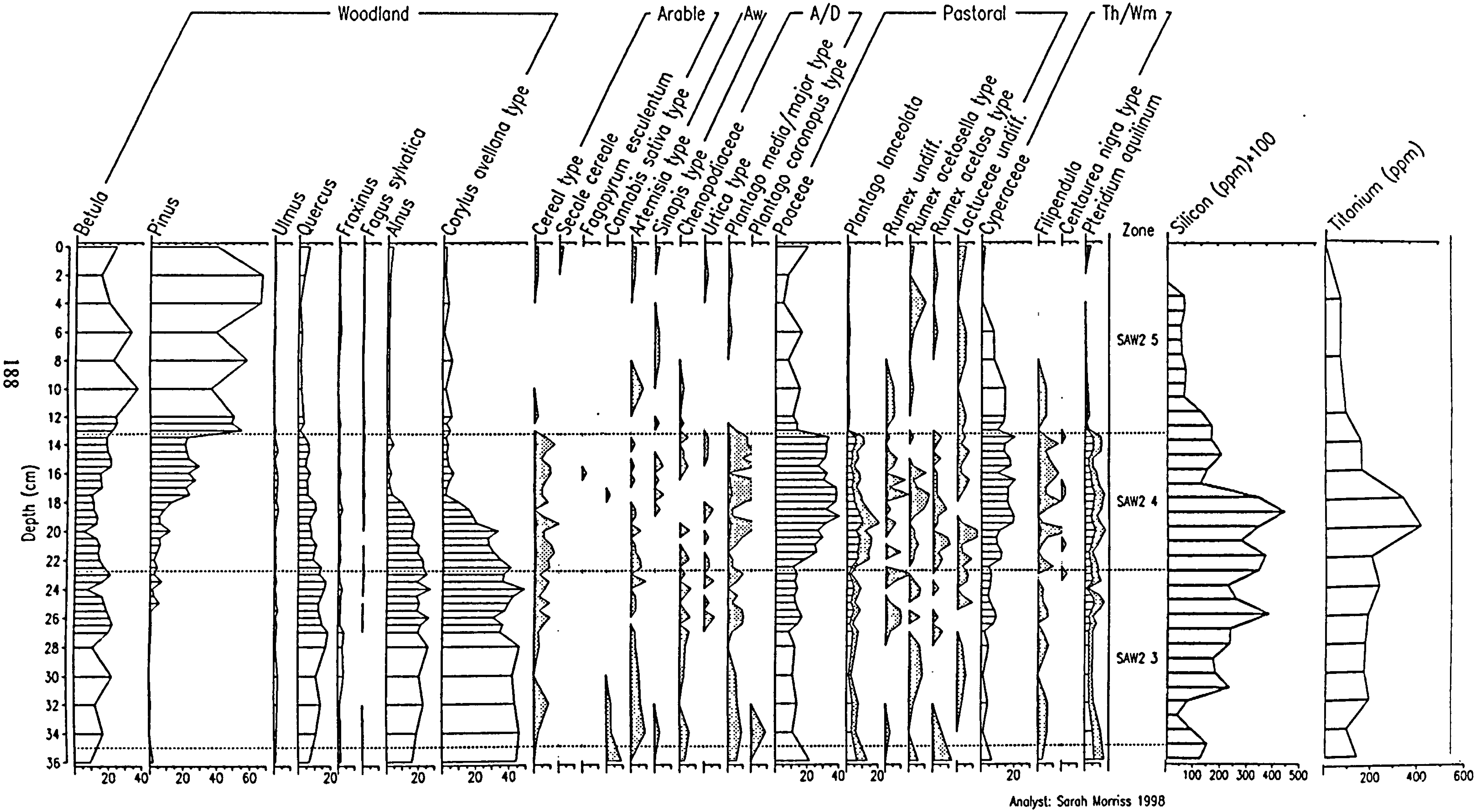


Figure 6.3d Summary curves of ecological groups and geochemical results from Shaw Moss (SAW 2): 0–36cm

Analyst: Sarah Morriss 1998

6.4 Charcoal results

As explained in Chapter 3, charcoal concentrations were counted during routine pollen preparation for Talkin Tarn (TAL2) and an attempt was made to use the magnetic measurements of bulk susceptibility and saturated isothermal remanent magnetisation (SIRM) to provide a history of charcoal input to the sediment core from Lake Gormire (GOR1).

6.4.1 Talkin Tarn (TAL2)

The charcoal concentrations recorded from Talkin Tarn (TAL2) are shown in Figures 6.4a and 6.4b. Charcoal concentrations range between 647 and 35,597. The results indicate that the beginning of the profile is characterised by low levels of charcoal fragments, which rise in the second half of zone TAL2 1 to produce a phase of increased, relatively stable inputs. This is followed by decline towards the upper zone boundary. The pollen evidence across this zone indicates relatively stable frequencies of total woodland taxa, although *Corylus avellana* type pollen expands in the latter section of the phase, while pastoral indicators increase towards the centre of TAL2 1 and then decline to relatively stable percentages for the remainder of the zone. This is accompanied by an increase in arable, arable weeds and arable/disturbed/waste taxa in the latter part of the zone.

Charcoal concentrations experience a sharp peak at a depth of 56 cm which is then followed by relatively low levels until concentrations demonstrate a rapid increase at the end of zone TAL2 2. The peak in concentrations of charcoal appears to occur just after a peak in cultivation, as demonstrated by significant, but short-lived increases in both the arable and arable weeds taxa. Pastoral indicators rise gradually towards the middle of the zone and then demonstrate a decline in frequencies. After the peak in charcoal values, the arable and arable weeds pollen curves experience declines. Woodland taxa exhibit a small decrease in percentages in the first half of the zone which levels out across the remainder of TAL2 2. The rapid peak in charcoal concentrations at the end of TAL2 2 corresponds with the beginning of a decline in woodland frequencies, reduced pastoral pollen values and increasing arable and arable/disturbed/waste taxa.

The final zone demonstrates a sharp increase in charcoal concentrations which coincides with a general decline in woodland taxa, although *Pinus* values expand across TAL2 3, a

Figure 6.4a Charcoal counts from Talkin Tarn (TAL 2)

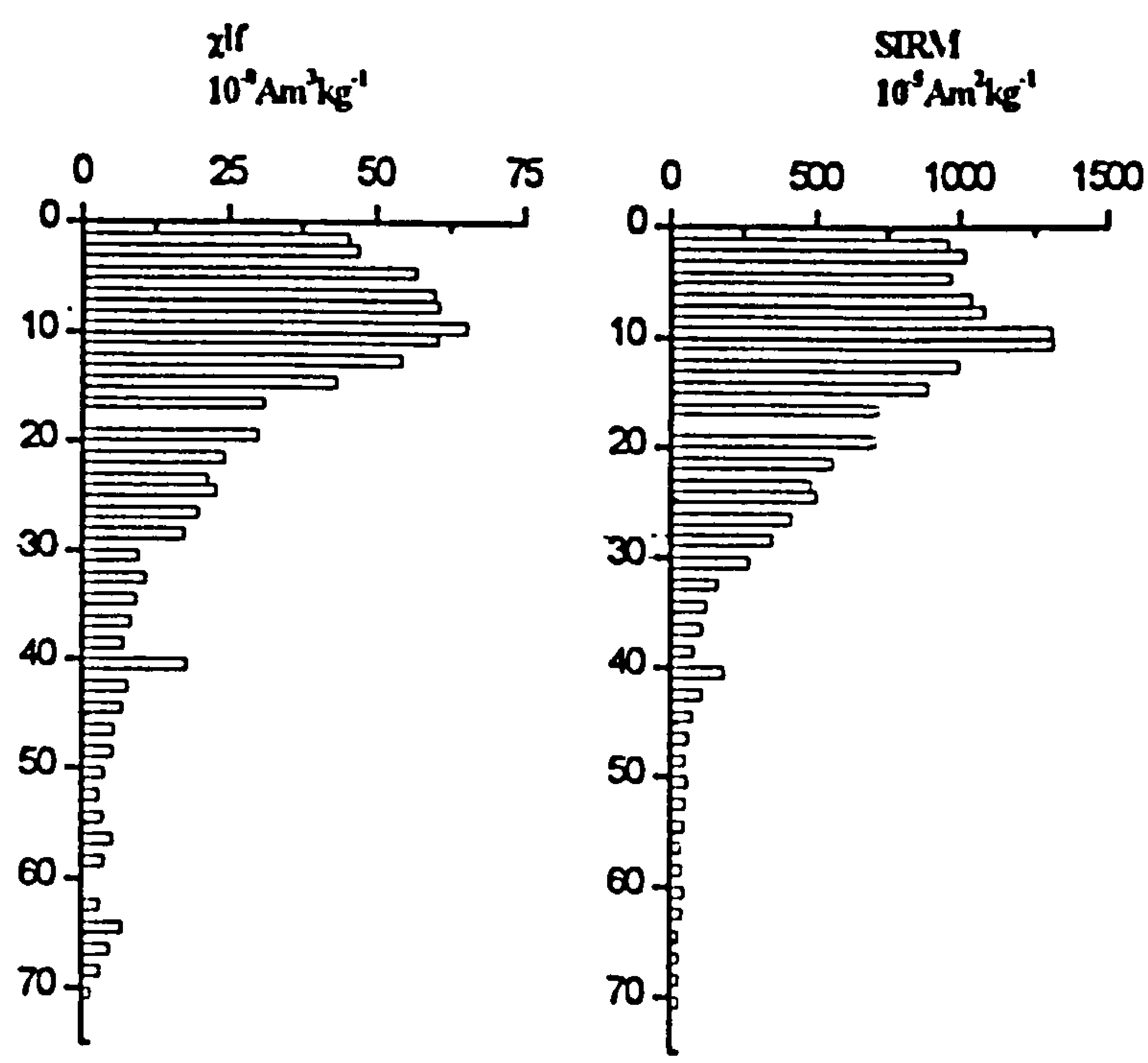
Figure 6.4b Summary curves of ecological groups and charcoal counts from Talkin Tarn (TAL 2)

rapid and substantial peak in pastoral indicators and greater percentages of both arable and arable/disturbed/waste pollen taxa.

6.4.2 Lake Gormire (magnetic results)

The full magnetic results from core GOR1 have already been presented in Figure 4.13 and therefore only a summary diagram is provided below (see Figure 6.5). Both the curves of magnetic susceptibility (χ) and saturated isothermal remanent magnetisation (SIRM) indicate a small peak in values at a depth of 40 cm. Above this depth is a gradual increase in values with both magnetic measurements reaching a maximum in concentrations at a depth of 9 – 10 cm, which is followed by decline towards the surface. However, it is not possible to tell from these data alone whether these features are the result of increased input of magnetically enhanced oxides through the burning of soils during fire events in the catchment or the outcome of another process. Indeed, Rummery (1983, p57) notes that in lake sediments "there is difficulty in differentiating between fire formed SIRM peaks and those formed by large inputs of primary magnetic minerals from the substrate". Thus it would appear that magnetic measurements of this type alone may provide inconclusive results which "should be used to complement rather than replace other more time-consuming techniques for identifying fire records" (Rummery, 1983 p57). As a result, it has not been possible to reconstruct a fossil charcoal record from GOR1.

Figure 6.5 Bulk susceptibility and SIRM from core GOR1 (Source: Jude, pers. comm.)



Chapter 7 – Interpretation and Discussion

7.0 Introduction

This chapter seeks to integrate the palynological and geochemical evidence for past human impact with the historical record, within an AMS, ^{210}Pb or tephra-based chronological framework. Sites are interpreted individually and also discussed with reference to relevant existing palaeoecological studies. Those sites with neighbouring profiles (such as from the Tregaron raised bog complex) or with multiple records (e.g. Talkin Tarn) are assessed in terms of their pollen analytical replicability. This is followed by a comparison of regional Cistercian monastic impact and regional Iron Age/Roman impact on the surrounding landscapes. The correlation between the pollen analytical and geochemical records is considered, as well as comparison of these two proxies for reconstructing past anthropogenic activity with documentary evidence. The final sections discuss the problems involved with the interpretation of these palaeoenvironmental records and consider the difficulties associated with correlating radiometric chronologies to historical timescales.

7.1 Abbeyknockmoy Bog (AKM'99)

Since Abbeyknockmoy Bog is a large peat deposit in a relatively open landscape environment (see Section 3.2.1 for a description of the site), pollen input into the raised mire is likely to be dominated by the regional component of pollen deposition, with much smaller contributions from the extra-local and local categories (Jacobson and Bradshaw, 1981). This means that human activity can be reconstructed for a fairly broad spatial scale. This site, lying approximately 11 km southeast of Tuam in County Galway, is situated in the western section of a large lowland area known as the Central Plain. This western portion is called the Plain of Connaught, where the underlying geology of limestone is covered by scattered patches of peat interspersed with fertile tracts of drift soil (Fitzgerald, 1925), of which shallow brown earths are the leading soil type in the area today (Mitchell and Ryan, 1997). Fitzgerald (1925) records Co. Galway as receiving 40 – 60 inches of rainfall a year, yet the extensive areas of bog are the result of impeded drainage rather than excessive precipitation. This environmental setting must be borne in mind when interpreting the palaeoenvironmental records from core AKM'99. A review of previous research into human impact in Ireland can be found in Section 2.3.7.

The pollen analytical evidence from zone AKM'99 1 (see Figures 5.1a and 5.1b) suggests that the surrounding vegetation was dominated by scrubby woodland at the beginning of the profile in c. cal. 45 BC – 213 AD, consisting mainly of *Corylus* with lower levels of *Alnus*, *Quercus*, *Betula*, *Ulmus* and *Fraxinus*. The herb pollen taxa indicate extremely low levels of human activity in the first half of this zone to c. cal. 450 AD using the age-depth model in Chapter 4, with farming almost exclusively pastoral in nature. The expansion of *Calluna* and *Erica* pollen could reflect growing areas of heathland, although caution must be expressed since these species may also grow on the surface of the mire. The Ti curve does exhibit, however, a peak in concentrations in the first half of this zone (see Figures 6.1a and 6.1b), suggesting perhaps that the pollen record may be underestimating the level of activity, although at the same time the Si curve generally remains low. This episode of subdued anthropogenic activity and subsequent woodland regeneration appears to correspond with the end of Mitchell's (1976) "Damage-phase".

This is followed by a gradual rise in pastoral indicators, arable/disturbed/waste taxa and *Pteridium* frequencies in the second half of the zone, which is accompanied by a substantial decline in *Ulmus* values and reductions in *Fraxinus* and *Corylus avellana* type pollen percentages. This suggests a phase of scrubby woodland clearance to make way for increased farming activity, which is again dominated by pastoral practices. This is supported by the geochemical curves which indicate an increase in concentrations in the second half of this zone from c. cal. 450 AD. Such secondary declines in elm pollen after a phase of woodland regeneration in the first millennium AD have also been recorded by Mitchell (1965) at Littleton Bog in Tipperary, Watts (1985) at Redbog in Co. Louth and O'Connell *et al.* (1988) at Connemara National Park. This correlates well with McCracken's (1971) work, which states that *Ulmus* was virtually eliminated from Ireland by the 7th century AD, partly due to disease and partly as a result of the practice of feeding tethered cattle on its foliage. This appears to mark the beginning of Mitchell's (1976 p135) "Destruction-phase" where "elm and ash are swept away with a thoroughness from which they never recover ..... in which more advanced farming ultimately destroys the woodlands".

When interpreting the landscape history of Ireland, it must be remembered that this country "was never part of the Roman Empire and that, apart from some influence on the eastern coastal region, Roman Britain and its subsequent collapse appear to have had little effect on developments in Ireland generally" (O'Connell, 1994 p50).

A common feature in Irish pollen diagrams is a lull in farming activity on a scale comparable to that of the late Neolithic (Aalen, 1983), resulting in woodland regeneration between the relatively intensive agricultural practices of the Bronze Age peoples and the impact of the Early Christian settlers (Mitchell, 1976). This Iron Age regression in agricultural activity was recorded at Redbog (Mitchell, 1976; Watts, 1985) and can also be seen in pollen diagrams from Limerick, Tipperary, Meath, Antrim, Offaly and Tyrone (Mitchell, 1956; 1965); in profiles from southwest Ireland (Lynch, 1981); in northern Mayo (O'Connell, 1990) and at Connemara (Molloy and O'Connell, 1991). From such pollen profiles the lull was recorded to have lasted from c. 200 BC to c. 300 AD, when farming activities were subsequently resumed and expanded rapidly with a dramatic increase in arable agriculture (Mitchell, 1976; Mitchell and Ryan, 1997). Mitchell (1976 p162) suggests that this Iron Age depression in agriculture was the "culmination of a long-continuing and widespread exhaustion of the soil, rather than a drastic social upheaval brought about by military conquest". Alternatively, Barber *et al.* (in prep.) derived a proxy climate record for Abbeyknockmoy from the detrended correspondence analysis of plant macrofossils which indicates that the lull in human activity corresponds with a phase of wetter climatic conditions. The regression in agriculture at this time may therefore be the result of a deteriorating climate rather than soil exhaustion. It seems reasonable to suggest that the record from AKM'99 begins in the middle of this woodland regeneration period, which is then followed by renewed farming activity in the Early Christian period.

Mitchell (1976 p134) states "it does seem that the major agricultural episodes can be traced throughout Ireland, and are essentially synchronous", yet the end of the lull period from this profile at Abbeyknockmoy Bog would appear to be somewhat later than c. 300 AD. It must be noted, however, that this apparently "synchronous" date was based on some pollen profiles that had no calibrated radiocarbon chronologies, but instead relied on palynological correlations to previously dated records. At Abbeyknockmoy, the pollen curves of pastoral indicators such as *Poaceae* and *Plantago lanceolata*, the arable/disturbed/waste taxon *Plantago media/major* and spores of *Pteridium* experience a gradual rise in frequencies from c. cal. 450 AD, although arable and arable weeds taxa do not exhibit a rise in percentages until the beginning of zone AKM'99 2 at cal. 686 – 937 AD. Such "late" dates for the renewal of farming activity have also been registered from Connemara National Park at c. cal. 653 AD (O'Connell *et al.*, 1988), the Burren in Co. Clare at cal. 580 AD (Jelicic and O'Connell, 1992) and Derryinver Hill in the Renvyle Peninsula, Co. Galway, where woodland regeneration spans the interval 1650 to 1350 BP (Molloy and O'Connell, 1993). Thus it would appear that the date of the resurgence of farming recorded from AKM'99 in the Early Christian period is not dissimilar to other profiles from the western region of Ireland, but generally later than in other parts of the country. However, the lack of calibrated radiocarbon dates for some profiles makes it difficult to assume a synchronous date for this event across Ireland.

Zone AKM'99 2 is marked by the continued expansion in pastoral farming activities and the presence of arable agriculture of any significance for the first time in the profile beginning at cal. 686 – 937 AD. The first occurrences of arable indicators are registered at the same time as declines in *Corylus avellana* type pollen and *Quercus* frequencies, again suggesting the possible clearance of scrub, although it is interesting to note that *Betula* and *Alnus* values increase in the first half of this zone, which may reflect some invasion into the recently cleared areas. This is accompanied by a peak in Ti concentrations followed by stable but significant levels for the majority of the zone. This activity is thought to be the result of rising local populations in the Early Christian period. Indeed, the majority of ringforts and crannógs in Ireland were occupied and probably constructed during a 300 year period from the 7th to 9th centuries AD (Stout, 1997). Furthermore, over 45,000 Early Christian archaeological sites have been discovered in Ireland, which "contrasts with the virtual absence of secular settlement for all prehistoric and historic periods prior to the 17th century" (Stout, 2000 p92).

Mitchell (1976) attributes the dramatic increase in arable agriculture in c. 300 AD to the introduction of the coulter-plough to Ireland. The next advancement in arable farming was the adoption of the mouldboard plough in the 7th or 8th century AD (Mitchell and Ryan, 1997). Mitchell (1976) believes that a general rise in *Artemisia* pollen from c. 600 AD is the result of this technological innovation, since this species grows when competition from other weeds is reduced. At AKM'99 the *Artemisia* curve becomes constant for the first time in c. cal. 686 – 937 AD, suggesting that the growth in arable agriculture in this area may well have been a response to the introduction of the mouldboard plough.

Ireland was then subject to Viking influences after c. 800 AD, although their impact on the landscape was likely to have been small and the native farmsteads continued to operate on a basis of subsistence farming (Mitchell, 1976). This phase of continuity can be seen from the palaeoecological evidence. This was then supplanted by Anglo-Norman influences in the 12th century (Edwards, 1985), their invasion creating a rapid increase in population (van Geel and Middeldorp, 1988). The Anglo-Norman demand for wealth and power revolved around intensive farming activities in order to provide a surplus and resulted in the development of an embryonic feudal system in the 12th century (Mitchell, 1976), although Ireland largely remained a patchwork of separate kingdoms at this time (Stalley, 1987). There were a small number of Anglo-Norman boroughs in Co. Galway and one market, which indicates the agricultural potential of the county since the Anglo-Norman invaders were only interested in the better quality lands (Mitchell and Ryan, 1997). Again the pollen evidence demonstrates the continuation of a mixed farming economy, as pastoral indicators generally increase between cal. 686 – 937 AD and cal. 1019 – 1199 AD, arable/disturbed/waste taxa record higher percentages in the first two thirds of this period, and cultivars and arable weeds remain relatively constant.

Due to the "unorthodox" nature of the Celtic religion (established in the 7th century AD), foreign churchmen decided that by the 12th century the Irish church should be organised on a basis similar to that found in the rest of Europe, and thus Cistercian monks were introduced to Ireland (Stalley, 1987). Since Cistercian communities were prepared to accept land that had not previously been cultivated there was little resistance from local rulers. Furthermore "the presence of a group of intelligent, hard-working farmers in the neighbourhood could set an example to the local population and provide a focus of economic as well as religious development" (Stalley, 1987 p14). The Cistercian monastery of Abbeyknockmoy was established in 1190 AD (Stalley, 1987) on a site virtually adjacent to the Bog and given tracts of land from local patrons (see Plate 7.1).

Using the known tephra isochrone of 1104 AD at a depth of 45 cm (see Section 4.2.1.2), the average peat accumulation rate of 21.3 y/cm from the age-depth model (Figures 4.1 and 4.9) and the assumption of a constant growth rate, 1190 AD occurs at a depth of approximately 41 cm in the profile. Cistercian monks were renowned for their agricultural skills involving land clearance, drainage, cultivation and animal rearing (Stalley, 1987). The palynological evidence indicates the continued clearance of scrub and a steady decline in *Alnus* pollen from about this time, perhaps indicating that some wetland areas were reclaimed for agricultural purposes. This is accompanied by a substantial increase in pastoral indicators, largely through *Poaceae*, *Plantago lanceolata* and to a lesser extent *Rumex* species, a peak in *Artemisia* and a slightly later peak in arable indicators with Cereal type pollen being accompanied by *Secale cereale* and occurrences of *Cannabis sativa* type pollen. Si and Ti concentrations generally expand over this period as well. It is impossible to quantify how much of this intensification in agricultural activity was directly attributable to monastic influences, although this expansion was likely to have been aided by an ameliorating climate in the 13th century as demonstrated by surface wetness reconstructions from Abbeyknockmoy Bog (Barber *et al.*, in prep.). Agriculture and trade generally flourished in the 13th century with most monasteries beginning to acquire feudal rights and privileges such as tithes and the rights to hold fairs (Stalley, 1987).

Plate 7.1 The Cistercian Abbey of Abbeyknockmoy, Co. Galway

It is interesting to note that the *Quercus* pollen curve demonstrates a short period of relatively substantial, fluctuating frequencies beginning at a depth of 47 cm in the profile while other woodland taxa experience decline, especially that of the *Betula* curve. Again using the tephra isochrone of 1104 AD and the average peat accumulation rate calculated from the age-depth model, this depth equates to a date of around c. cal. 1060 AD. *Quercus* percentages then begin to decline at 36 cm which results in an extrapolated date of c. cal. 1340's AD. This may simply be a feature of the relative nature of percentage pollen diagrams or alternatively may reflect a period of managed woodland where oak could have been pollarded to prevent animals eating the regrowth or coppiced to provide crops of timber and underwood (c.f. Rackham, 1988). Indeed Göransson (1986) notes that coppice wood stems are fertile at a younger age than non-coppiced trees resulting in higher pollen production from young coppice woods, while Iversen (referenced from Malmros, 1986) explains a marked rise in hazel pollen at Sørborg Sø in Denmark during the Neolithic as evidence of coppice management. Furthermore, Chambers (1983a) suggests that the marked fluctuations in *Corylus* pollen from Cefn Gwernffrwd in Wales are indicative of repeated clearance and regeneration possibly suggesting coppicing.

The Anglo-Norman occupation of Ireland was dealt a series of severe blows in the mid-14th century from which it never recovered (Mitchell and Ryan, 1997) leading to an Irish resurgence. Invasion by Edward Bruce between 1315 and 1318 AD was followed by climatic deterioration, poor harvests and ultimately the Black Death in 1348-9 AD which resulted in political instability and economic decline in Ireland (Stalley, 1987). This may provide a possible explanation for the decline in *Quercus* percentages and increase in *Betula* frequencies in c. cal. 1340's AD as woodland management was abandoned allowing birch to colonise previously coppiced woods. There is a trough in Ti concentrations around this level, which also occurs at the end of a short phase of decreased pastoral indicators.

Both the pollen and geochemical records for human activity indicate an increase in mixed farming after this period with pastoral taxa exhibiting a peak in activity at cal. 1304 – 1425 AD. This is followed by a short period of agricultural contraction with some scrub regeneration at the upper zone boundary of AKM'99 2. The Cistercian monastery was virtually just a landlord by this stage and at the Dissolution in the 16th century, Abbeyknockmoy was valued at around £78.10.0 (a middle-ranking monastery in terms of wealth), with its lands reverting to the king or important local families (Stalley, 1987).

The next zone, AKM'99 3, demonstrates a period of rapid and substantial change in the surrounding landscape. Scrub and any remaining woodland was cleared on a scale never previously registered in the pollen diagram beginning in the c. cal. mid-16th century until the c. cal. late 18th century. A similarly sharp and significant decline in *Corylus* pollen was recorded from Littleton Bog in the same period by Mitchell (1965). Documentary evidence from Arthur Young writing in 1780 (quoted from Mitchell, 1965 p131) supports the palynological data: "the greater part of the country exhibits a naked, bleak, dreary view for want of wood, which has been destroyed for a century past with the most thoughtless prodigality, and is still cut and wasted"; with specific comments about Co. Galway: ".... is perfectly free from woods, and even trees, except about gentlemen's houses" (from Mitchell, 1976 p203).

The continued decline in *Alnus* pollen suggests the possibility of further drainage of wetlands for agricultural use. Indeed Arthur Young, writing in the eighteenth century, comments on the bog reclamation techniques employed by Robert French in the neighbouring parish of Monivea (Harvey, 1996). This is accompanied by a dramatic and substantial increase in pastoral farming activity, the beginning of which is dated to cal. 1488 – 1789 AD, with frequencies of *Plantago lanceolata* reaching almost 40% of total dry land pollen towards the end of the zone in the c. cal. early 18th century. This is thought to reflect a real expansion of pastureland since experiments by Sagar and Harper (1964) proved that *Plantago* spp. could not grow on *Sphagnum* bogs. There is also a peak in tall herb/wet meadow taxa at this time, largely through the Cyperaceae curve, which may also indicate increased grazing activity. This is concurrent with significant increases in *Poaceae* pollen, while higher frequencies of *Rumex* spp. and *Lactuceae* pollen are also recorded, as well as occurrences of *Trifolium* type pollen. *Pteridium* values reach their maximum in this zone, possibly as a result of increased grazing (c.f. Oldfield, 1963). It is interesting that the heathland taxa demonstrate a very similar pattern to that of pastoral indicators suggesting that this may be a real expansion of heath rather than a local mire surface signal.

The arable, arable weeds and arable/disturbed/waste taxa also exhibit substantial rises in percentages across AKM'99 3. Cereals appear to be the dominant cultivars although *Cannabis sativa* type and *Linum bienne* type pollen are also registered. The occurrence of a grain of *Linum* pollen is considered in further detail in a following section. In terms of arable weeds, *Artemisia* is the dominant taxa, although this zone also contains a continuous *Sinapis* type curve for the first time in the pollen record. Arable/disturbed/waste taxa involve large amounts of *Plantago media/major* type pollen with smaller, but still significant contributions from *Plantago coronopus* type.

Thus the pollen evidence indicates a phase of increased mixed farming with pastoral agriculture remaining the dominant land use and arable farming playing a secondary role in the rural economy of the c. cal. 16th to 18th centuries, a landscape history similar to that described by the historical record (Harvey, 1996). The geochemical curves also indicate a rapid and significant increase in farming activity across this zone, although this is divided into two distinct phases by a period of reduced activity with much lower Si and Ti concentrations. The trough in geochemical values appears to be virtually synchronous with a short-lived decline in *Plantago lanceolata* percentages in the c. cal. mid-17th century, which might possibly reflect inter-clan wars and revolts against English authority (Mitchell, 1976).

This correlates well with the historical record which documents that Tudor rule resulted in a new wave of English settlement in Ireland in the mid-16th century, and that the same areas of fertile land which had once attracted the Anglo-Normans were now given to the English (Mitchell, 1976). This led to commercial exploitation of the remaining woodlands, especially of oak as it was used for the manufacture of barrel staves, tanning, and was the preferred wood for providing charcoal for smelting in the 160 or so ironworks that were established all over Ireland in the 17th and 18th centuries (McCracken, 1971). This may account for the decline in *Quercus* pollen during this zone to largely background levels. Indeed by the 18th century wood was being imported into Ireland because local supplies were exhausted and could not meet the demand (McCracken, 1971). The shortage of wood was so severe that Parliament passed a number of Acts between 1689 and 1791 AD to either conserve the few remaining forests or to encourage or enforce planting (McCracken, 1971).

Tudor woodland clearances are also demonstrated in the pollen records from Shower and Leigh in Tipperary (Mitchell, 1956), Carbury Bog (van Geel and Middeldorp, 1988) and Derrycunihy Wood (Mitchell, 1988), although deforestation on such an extensive scale is not registered at Lios Lairthín Mór (Jelicic and O'Connell, 1992), Long Lough (Hall, 1990) and Lough Henney and Sluggan Bog (Hall, 1994).

The population of Ireland continued to grow rapidly in the 18th century and the expansion of agriculture evident from the pollen and geochemical results was developed mainly through wealthy landlords using labour from poor tenants. Documentary records covering eastern Galway in the 18th century note that the limestone soil provided excellent areas of pasture while the mild, wet climate allowed the pasturing of sheep and cattle out of doors all year round, and this provided a major source of income to the landlord in Co. Galway (Harvey, 1996). Indeed inner Connaught (consisting of the plains of Boyle, east Mayo and east Galway) became one of two core areas for cattle fattening in Ireland in the 18th century (Whelan, 2000). The Duke of Rutland stated in 1787 (from Harvey, 1996 p300) "The whole county is flat, but the land is good, and it produces greater quantities of cattle than any other county ..... [from Tuam and Loughrea] the country remains good all the way to Ballinasloe". This, therefore, is thought to account for the huge peak in *Plantago lanceolata* pollen and pastoral indicators in general in the c. cal. 18th century, although some tillage is also noted from historical records of this area (Whelan, 2000).

Landlords also encouraged further industries on their estates, particularly those connected to the linen industry, which began on a significant scale in Co. Galway in the 1750's (Harvey, 1996). One grain of *Linum bienne* type, which includes the cultivated variety of *Linum usitatissimum* (Scaife, pers. comm.), was recorded from a depth of 17 cm which can be extrapolated to a date of c. cal. early to mid-1700's AD from the age-depth model. From documentary sources it is known that Robert French, in the neighbouring parish of Monivea, provided flax for his tenants, started a spinning school in 1746, brought weavers to his estate in 1749 and constructed a mill, although the post-Napoleonic Wars depression sharply curtailed the fledgling industry in Galway, resulting in the concentration of activity in Ulster (Harvey, 1996). Due to its low pollen productivity and dispersal characteristics, even a single grain of flax in a pollen record can be significant (Hall, 1989). When it is combined with other indicators of arable agriculture, even small quantities of *Linum* pollen may suggest the possibility of flax being grown or processed in the area (Tolonen, 1978). Furthermore "few records exist of its pollen in fossil assemblages in Ireland" (Hall, 1990 p381), with occurrences being noted in the 17th and 18th centuries from Long Lough in Co. Down (Hall, 1990) and Carbury Bog in Co. Kildare (van Geel and Middeldorp, 1988).

The steep rise in landlord incomes from the mid-18th century onwards allowed not only estate improvement but also the building of country houses, of which Galway had a large number (Harvey, 1996). In the second half of the 18th century landscaped parks became important features of the demesne, so that by the 1770's more extensive stands of trees were planted and the 1800's are noted for their "rise of conifers and the dilution of native hardwoods by elm and beech, sycamore, chestnut and lime" (McCracken, 1971). Thus from the pollen diagram, the beginning of the rise in *Pinus* pollen at the end of zone AKM'99 3 is thought to reflect the c. 1770's AD, with the substantial increase in *Pinus* pollen to relatively steady levels at a depth of 13 cm, the start of the 19th century.

This significant increase in *Pinus* frequencies opens the final zone of the pollen profile, AKM'99 4, which corresponds to Mitchell's (1976) "Expansion-phase". The reintroduction of pine was accompanied by the planting of *Fagus*, a species not native to Ireland (Mitchell, 1965), as can be seen from the palynological record. The trace levels of *Fagus* pollen registered from earlier zones in the diagram are thus most likely to be the result of long-distance transport (O'Connell *et al.*, 1988). The planting of other exotics, including *Abies* and *Picea*, can be seen in the diagram in Appendix 1. During the period of the plantations, an increasing number of hedgerows were planted as field boundaries which were often colonised by ash (McCracken, 1971; Hall, 1989). The palynological data does indicate an increase in hedgerow taxa and *Fraxinus* frequencies over this zone which may reflect this phenomenon, although hedgerow species such as *Prunus* and *Crataegus* produce little pollen and are insect pollinated, thus making it difficult to detect these taxa in fossil pollen assemblages (Bradshaw, 1981).

It is interesting to note that both the Si and Ti curves enter a period of decline at the beginning of this zone in c. 1800 AD. This is accompanied by a decline in *Plantago lanceolata* values but an increase in *Poaceae* frequencies. There are also reductions in the amount of arable/disturbed/waste taxa, arable weeds and arable indicators recorded from this zone. This combination of geochemical and pollen evidence suggests a number of possible explanations. First, that the decline in Si and Ti concentrations reflects the *Plantago lanceolata* curve with pastoral activity actually declining in the surrounding area; secondly, that pastoral activity is continuing to expand, as may be suggested by the *Poaceae* curve, while the contraction of arable farming is reflected by the geochemical curves, hence implying that Si and Ti may be more responsive to arable rather than pastoral practices; or thirdly, that the decline in geochemical values is inversely related to reforestation with tree planting reducing soil erosion and thus limiting the quantity of dust particles available to reach the mire surface. In this instance, agricultural statistics dating back to 1925 (see Table 7.1) (Source: Agricultural Statistics, Central Statistics Office, Cork) indicate that pastureland continued to be the dominant agricultural land use in the area, with cereal, root and green crops forming a much smaller proportion of the mixed economy. This may suggest that the third explanation has resulted in the decline in Si and Ti concentrations.

The population of Ireland increased from 3,700,000 to 6,800,000 in the years between 1790 and 1821 AD (Neeson, 1991), which was facilitated by cultivation of the potato, a vegetable that was well suited to the conditions in Ireland and consequently became the staple diet for much of the population (Mitchell, 1976). The pressure of providing fuel for such a large number of people resulted in a largely treeless landscape with only the rich having woodlands inside their walled and protected demesnes. This may account for the predominance of pollen from planted trees such as *Pinus* and to a lesser extent *Fagus*, and the relative scarcity of other indigenous taxa. The failure of potato crops due to disease resulted in the Great Famine of 1845-51 AD, during which approximately 800,000 people died and twice as many emigrated leaving a population of only 4 million by 1930. This event does not appear to be obvious from the pollen diagram, especially since the pollen of potatoes (*Solanum tuberosum*) is rarely detectable from fossil assemblages due to the exceptionally poor dispersal ability of these grains (Hall, 1989; 1990b). Huang and O'Connell (1992), however, were able to correlate pollen and magnetic evidence for a contraction in agriculture from Ballydoo Lough in northeast Co. Galway with statistical records for reduced numbers of sheep and cattle and declines in the area of land under cultivation during the Great Famine period.

The final increase in *Pinus* pollen at the top of zone AKM'99 4 may be the result of a new impetus in planting which began in 1948 when the government adopted a State planting policy of 25,000 acres per annum (Mullay, 1992). The agricultural statistics displayed in Table 7.1 indicate the predominance of pastoral farming in the district electoral divisions of Abbey East and Abbey West from 1925 to 1991, with cultivation being of secondary importance, as reflected by the palynological evidence in the top few centimetres of the pollen diagram. It is interesting to note that although the numbers of cattle and sheep have generally increased over the years 1925 to 1991, the area under pasture has remained relatively stable, perhaps indicating an intensification in grazing pressures on the same acreage of land. The detailed nature of these statistics indicates that in terms of cereals, oats were the dominant crop with rather smaller amounts of wheat, barley and rye being grown. Root and green crops consisted of potatoes, turnips, mangels, fodder beet, sugar beet, kale and field cabbage.

Table 7.1 Agricultural statistics for the district electoral divisions of Abbey East and Abbey West from 1925 – 1991 (Source: Agricultural Statistics, Central Statistics Office, Cork)

Year	Total no. of cattle	Total no. of sheep	Cereals (acres)	Root and green crops (acres)	Pastures (acres)	Woods and plantations (acres)
1925	1134	2761	556.5	722.75	5763.5	Not recorded
1930	1195	5235	545	463	5379	110
1935	1468	4648	656	748	2862	79
1940	1095	4385	680	644	4627	80
1946	1324	3951	1012	843	3412	325
1951	1342	5238	645.5	520.5	3213	137
1960	1859	9496	758.5	637	4602.25	417
1965	2331	10570	659.5	480.25	4523	207
1970	3164	9173	539	427.75	4904.75	131
1975	4079	8197	409	275.25	5181.5	356
1980	4292	5526	358	279	5262	262
1991	4842	8250	213	40	4139	Not recorded

In summary, the pollen analytical and geochemical data from Abbeyknockmoy Bog seem to correlate well with the landscape history described through documentary evidence (see Figure 7.1). The ability to constrain the AMS radiocarbon chronology through the tephra isochrone at 1104 AD is particularly useful, not least as a check on the age-depth model, but also because it allows direct comparison with the historical record and from it the ability to establish, with much more certainty than from AMS dates alone, the foundation of the Cistercian monastery of Abbeyknockmoy in 1190 AD.

Figure 7.1 Schematic diagram of landscape history inferred from palaeoenvironmental evidence from Abbeyknockmoy Bog

Depth (cm)	Palaeoenvironmental Data	Historical Period	Date	
0, 10	Increase in pine pollen, high levels of pastoral activity, reduced arable farming and decline in Si and Ti concentrations.	Pine plantations	Pine rise c. 1800 AD	
20	Rapid deforestation and substantial increase in both arable and pastoral activity and sharp increase in Si and Ti concentrations.	c. 17th and 18th centuries	cal. 1488-1789 AD	
30	Continuation of mixed farming and increasing Si and Ti concentrations.	c. 15th and 16th centuries	cal. 1304-1425 AD	
40	Continued clearance of scrub and increase in agriculture, especially pastoral farming and rise in si and Ti concentrations.	Irish resurgence Abbeyknockmoy Abbey founded in 1190 AD Anglo-Norman period	cal. 1019-1199 AD Hekla I Tephra-1104 AD	Warmer and drier climate
50	Continuation of mixed farming.	Viking period		Colder and wetter climate
60	Rise in arable indicators and increase in Si and Ti concentrations.	Early Christian period continued	cal. 686-937 AD	
70	Rise in pastoral indicators and decline in elm pollen with increased concentrations of Si and Ti	Early Christian period		
80, 90, 100	Scrubby woodland with generally low concentrations of Si and Ti	Late Iron Age 'lull' in farming activity	cal. 45 BC-213 AD	

7.2 Tregaron Bog

In light of the radiocarbon results obtained from profiles TRE'98 and TRWA 2000, a brief overview of the existing literature regarding human impact in Wales in the Iron Age and first millennium AD is given in the following section. The review is not meant to be exhaustive but aims to explain the context of the current research. Further summaries are given in Dark and Dark (1997) and Dark (2000). A review of human impact over the second millennium AD can be found in Chapter 2.

7.2.1 Previous research into late Iron Age and Roman impact in Wales

This section has been divided into three parts in order to cover north Wales, mid-Wales and south Wales respectively, although Dark (2000 p66) notes that "there are very few pollen sequences from Wales with well-dated deposits spanning the Iron Age". Sites referred to in the text can be located on the map in Figure 7.2.

Beginning with north Wales, Mighall and Chambers (1995) present detailed radiocarbon dated pollen profiles from Bryn y Castell, Snowdonia. Their evidence indicates that a large proportion of local woodland was cleared during the late Bronze Age or early Iron Age, which was accompanied by indicators of both pastoral and arable activity. Iron-working at the hillfort of Bryn y Castell in the late Iron Age and Romano-British period is thought to have had a relatively minor impact on the remaining local woodlands, although there is pollen analytical evidence to suggest that agriculture was practised concurrently with iron-working. By the post-Roman period most local woodland had been removed, leaving an open landscape with large tracts of grass and peatland and the continuation of local arable and pastoral farming. From the end of the Medieval period onwards, the surrounding area appears to have been used largely for grazing purposes.

Undated pollen profiles from the western Rhinogau, Gwynedd (Walker and Taylor, 1976), indicate that some clearance took place during the Bronze Age, with continued deforestation and mixed farming occurring in the Iron Age. A maximum in human disturbance and agricultural activities has been tentatively correlated with Romano-British colonisation of the area during c. 200 to 500 AD. This was followed by a marked phase of woodland clearance which is thought to be Medieval in origin and is accompanied by an intensification in grazing pressures and continued arable cultivation. Grazing continued into the 16th century although there is no evidence for increased arable farming during the Napoleonic Wars.

Figure 7.2 Location of Welsh Iron Age/Romano-British sites mentioned in the text.

1. Bryn y Castell
2. Western Rhinogau
3. Llyn Padarn and LlynPeris (Llanberis Pass)
4. Erw-wen and Moel y Gerddi (Upland Ardudwy)
5. Llyn Cororion
6. Crawewellt
7. Carneddau
8. Borth Bog
9. Towy Valley
10. Elan Valley
11. Plynlimmon
12. Llyn Gynon
13. Blaen yr Esgair
14. Cefn Gwernffrwd
15. Tregaron Southeast Bog
16. Merthyr Tydfil
17. Cefn Ffordd
18. Brecon Beacons
19. Waun-Fignen-Felen
20. Llangorse Lake
21. Crymlyn Bog

Less detailed palynological records for this period in north Wales are provided by two lake cores at the lower end of the Llanberis Pass (Elner and Happey-Wood, 1980), which demonstrate rapid deforestation beginning around c. 2750 BP with clearance of the Llyn Padarn catchment appearing to be complete by 1900 BP. Major deforestation occurred in the early Bronze Age in Upland Ardudwy (Chambers and Price, 1988), with dramatic human impact on the landscape before the occupation of the later Bronze Age settlements of Erw-wen and Moel y Gerddi (Chambers *et al.*, 1988). There appears to be some woodland regeneration after this phase, possibly as a result of the abandonment of Moel y Gerddi. Renewed woodland decline is registered from the Roman period, although a short-lived increase in woodland may be reflected at c. 800 AD with continued decline in AP percentages from the c. mid-12th century onwards. The vegetation history from Llyn Cororion in lowland Gwynedd (Watkins, 1990) also indicates widespread forest clearance in the mid- to late Bronze Age, which is accompanied by both arable and pastoral activity. Deforestation continued with a peak in pastoral indicators at 1200 BP, which was followed by a subsequent major decline in tree and shrub pollen at 780 ±60 BP and the high percentages of *Cannabis* pollen recorded in the upper sections of the profile suggest that the lake may have been used for retting at this time. Evidence from another iron-working site at Crawcwellt, Gwynedd (Chambers and Lageard, 1993) demonstrates two episodes of marked human impact during the late Bronze Age and early Iron Age which ultimately resulted in a cleared, predominantly open moorland landscape. The subsequent abandonment of the site led to a recovery of woodland and scrub in the early historic period.

A series of pollen diagrams from Carneddau in upland mid-Wales (Walker, 1993) indicate a woodland clearance episode radiocarbon dated to the middle to late Bronze Age which was accompanied by a gradual increase in pollen indicative of pastoral farming. This is followed by a second clearance phase at the Bronze Age/Iron Age transition (c. 2500 BP), although the most extensive period of deforestation was registered from the Romano-British era of between cal. 30 AD and cal. 230 AD, which resulted in a largely open landscape that was mainly used for pastureland. Further agricultural activity was recorded in the Medieval period before the 15th century AD, followed by some scrub woodland regeneration in the post-Medieval period, which could possibly indicate abandonment of the area during the Little Ice Age. Renewed upland agriculture took place in the 18th century onwards, leading to the final clearance of any remaining woodland and scrub and the development of the present, open landscape of grass and heather moorland.

Moore (1968) and Moore and Chater (1969) present a series of pollen diagrams from sites in west-central Wales, although without radiocarbon dating all chronologies are inferred from palynological/historical correlations. A series of clearance and regeneration phases are attributed to Bronze Age activity, followed by more widespread clearances and greater agricultural activity throughout the Iron Age/Roman period. Following the Roman withdrawal from Wales in c. 400 AD, some regeneration is thought to have occurred as a result of tribal warfare leading to a return of shifting pastoralism. Renewed agricultural activity is linked to the establishment of Strata Florida Abbey in the 12th century AD. Similarly, evidence from Cefn Gwernffrwd (Chambers, 1982a) indicates relatively substantial woodland clearance in the Bronze Age with the possibility of some pastoral activity, followed by a short phase of *Corylus* scrub regeneration in the Iron Age and subsequent deforestation in the late Iron Age or Romano-British period. Alternatively, evidence from a previous core taken from Tregaron Southeast Bog (Turner, 1964b) suggests that extensive deforestation did not occur until the end of the Iron Age, with pastoral farming continuing through the Roman period.

Evidence from south Wales demonstrates the apparently selective clearance of *Quercus* from c. 3260 BP followed by a later phase of more severe forest clearance suggesting that a predominantly open upland environment was established by c. 3000 BP (Chambers, 1983b). A partial recovery of *Corylus* was finally cleared by c. 1155 BP. Further Bronze Age woodland clearances are recorded from Cefn Ffordd and a site in the Brecon Beacons (Chambers, 1982b), although at the latter site more extensive forest removal was experienced in the late Iron Age creating a largely open period by the Roman period. Again at Waun-Fignen-Felen (Smith and Cloutman, 1988) major human impact occurred in the Bronze Age with a strong agricultural phase being recorded in the late Bronze Age. This was followed by some woodland regeneration in the early Iron Age, although renewed woodland clearance took place in the late Iron Age and Romano-British periods, with a subsequent phase of regeneration in the post-Roman period. Further evidence of increased Roman agricultural activity was recorded from Llangorse Lake in the Brecon Beacons National Park (Jones *et al.*, 1985).

Palynological data from Crymlyn Bog (Dumayne-Peaty, 1998c) indicate that the surrounding landscape was heavily wooded during the Bronze and Iron Ages with limited evidence for human impact. Woodland clearance and agricultural activity appears to have increased in c. cal. 115 AD in the Romano-British period, with the presence of *Hordeum* suggesting an arable element to the local farming economy. This was followed by a brief phase of woodland regeneration and decline in human activity in the middle of the 4th century AD, although renewed small-scale clearances took place in the post-Roman period. An episode of significant woodland clearance is recorded between c. cal. 880 – 1080 AD with evidence for both pastoral and arable agriculture. This may have been the result of expanding local settlement due to the Norse invasions of South Wales.

In summary, many sites in Wales experienced some scale of woodland clearance in the Bronze Age, which was often accompanied by pastoral activity, although limited occurrences of Cereal type pollen may also indicate an element of arable farming. There is some evidence of partial regeneration of woodland in some profiles from mid and South Wales in the Iron Age (Dark, 2000), which is then followed by renewed forest destruction and increased farming activity in the late Iron Age and Romano-British periods. Some sites indicate the expansion of woodland in the Dark Age period following Roman withdrawal.

7.2.2 Southeast Bog (TRE'98)

According to Jacobson and Bradshaw's (1981) model of pollen source areas, a deposit the size of Tregaron Bog receives the majority of its pollen input from the regional component, with only minor contributions from the local and extra-local categories. Consequently, reconstructions of vegetation change and human impact on the landscape from this site are probably regional in nature. This relatively open site lies between 400 and 800 feet OD (Bowen, 1994) and the dominant soil types in the vicinity of the bog complex today consist of Brown earths, which are particularly suitable for livestock farming, wetter Stagnogley soils and Brown podzolic soils which are currently used extensively for forestry (Rudeforth, 1994).

At the base of the profile, zone TRE'98 1 (see Figures 5.2a and 5.2b) indicates that the surrounding landscape was dominated by hazel scrub woodland with elements of *Betula*, *Quercus* and *Alnus* in the late Iron Age. Both the pollen and geochemical evidence (see Figures 6.2a and 6.2b) demonstrate very subdued levels of farming activity, which appear to have been biased towards pastoral practices. There are isolated occurrences of Cereal type pollen and arable weeds during this period which may imply that some small-scale cultivation was taking place in the catchment at this time. Indeed, one grain of *Secale* *cereale* (rye) was recovered from the top of this zone at a depth of 71 cm which can be extrapolated to a date of c. cal. 100 – 150 BC from the age-depth model (see Figure 4.2). This would appear to suggest a pre-Roman origin for this grain, perhaps providing further evidence for the antiquity of rye cultivation in the British Isles (c.f. Chambers, 1989). *Secale cereale* pollen has been recorded from Bronze Age deposits in Britain (Chambers and Jones, 1984; Behre, 1992), although there is still debate as to the status of this taxon in prehistoric times in terms of whether it was purposefully being cultivated as a crop or formed part of the weed flora for other cereals (Behre, 1992).

It is interesting to note that clearance of scrub does not appear to begin in this profile until cal. 202 BC – 2 AD at the start of zone TRE'98 2, with *Corylus avellana* type frequencies dropping rapidly from around 60% to approximately 30% of total dry land pollen. This date is somewhat later than that recorded by Turner (1964b) from a previous core taken from the Southeast Bog, which dated a period of significant deforestation to c. 400 BC, although Taylor (1973) records woodland clearance in the Ystwyth Forest and from the lower slopes of the Ystwyth Valley at the slightly late date of c. 3rd century BC. Turner (1964b; 1965) argues that this clearance episode was a response to a warmer and drier climate after c. 450 BC which allowed a recovery in both agriculture and population after the previous phase of poor climatic conditions and consequently pushed farming back into more marginal zones again.

This deforestation episode in zone TRE'98 2 is accompanied by a rapid increase in pastoral indicators, mainly demonstrated through the *Poaceae* and *Plantago lanceolata* pollen curves, although there are also greater values of *Rumex* spp. and the beginning of an almost continuous curve of *Lactuceae* undiff. pollen. Indeed the *Poaceae* curve peaks at approximately 45% of total dry land pollen near the top of this zone, a value which qualifies as "extensive clearance" using the definition of Dumayne (1992, Dumayne-Peaty, 1998b). At the same time, occurrences of Cereal type pollen are recorded, as well as increased frequencies of arable weeds and higher percentages of arable/disturbed/waste taxa. This is supported by the beginnings of a rise in Ti and Si concentrations. It would therefore seem reasonable to suggest that small-scale arable agriculture was taking place in the region at this time, while pastoral practices remained the dominant farming activity. The radiocarbon date of cal. 202 BC – 2 AD suggests that this phase of clearance and farming began in the pre-Roman late Iron Age, although the uncertainties associated with broad radiocarbon age ranges are acknowledged. This date does, however, correlate well with archaeological evidence that Cardiganshire was a "heavily settled landscape dominated by settlements of overwhelmingly defended character" (Davies and Hogg, 1994 p219) by the end of the Iron Age and the remains of an Iron Age hillfort have been identified at Tregaron (Hogg, 1994). Furthermore, these palaeoenvironmental data may begin to provide some of the evidence that Davies and Hogg (1994, p230) claim is lacking: "Despite the overwhelmingly negative palynological evidence it is inherently likely that there was always an arable component in the [Iron Age] economy".

The geochemical curves, especially that of Ti, demonstrate a rapid and substantial increase in human activity at a depth of 62 cm in the second half of zone TRE'98 2, which can be extrapolated to a date of c. cal. 75 AD. This rise in Si and Ti concentrations corresponds with a phase of almost continuous arable indicators, consisting of Cereal type, *Secale cereale* and *Cannabis sativa* type pollen, which is accompanied by higher incidences of *Artemisia* pollen and greater percentages of arable/disturbed/waste taxa. Hicks (1971) also noted the possible cultivation of *Cannabis* in Roman times from pollen profiles in Derbyshire, although in Norfolk, hemp cultivation did not become common until Anglo-Saxon times (Godwin, 1967a). Pastoral indicators such as *Poaceae*, *Plantago lanceolata* and *Pteridium* (Oldfield, 1963) continue to increase. The extrapolated date of c. cal. 75 AD for the beginning of this phase of increased arable and pastoral farming activity suggests that it is Romano-British rather than late Iron Age in origin, although again caution must be expressed when trying to correlate radiocarbon timescales to the historical record (Baillie, 1991; Dumayne *et al.*, 1995). It is interesting to note the marked response of the of Si and Ti records to this period of greater human impact, since an increase in activity of such a scale and intensity is not immediately obvious from the palynological evidence alone. Furthermore, both the Si and Ti curves indicate three peaks in activity which are not replicated by the pollen data. Both the pollen and geochemical curves indicate that this phase of mixed farming appears to enter a period of decline from c. cal. 350 AD. Thus this episode of increased agriculture appears to correlate well with the known period of ameliorating climatic conditions from c. 150 BC to c. 400 AD (Lamb, 1981).

The extrapolated dates of c. cal. 75 – 350 AD for this period of increased mixed farming make very interesting comparison to the archaeological and historical records. The Roman conquest of Wales was completed in 74 – 77 AD resulting in the establishment of a series of military installations in Ceredigion in order to meet strategic requirements

(Davies, 1994). The remains of the Roman auxiliary fort of Bremia have been located south of Tregaron Bog at Llanio (Davies, 1962) (see Figure 7.3), which was built in the 70's AD to hold 500 soldiers (Nash-Williams, 1969). These forts were usually positioned with respect to both defensive needs, for example the axial North-South military road crossed the River Teifi here and with a view to supervising concentrations of local populations (Davies, 1994). Hanson and Macinnes (1991) argue that Roman forts were also sited with regard to the local availability of agricultural produce with which to supply the soldiers. The pollen and geochemical records, however, appear to suggest that although some evidence of cultivation is registered, it seems to have been a very small-scale activity at this time in this part of Wales. Nevertheless this idea of a pre-Roman local population would appear to be evident from the pollen diagram since scrub clearance and farming activity are recorded from the late Iron Age.

Roman forts often had a civilian village (*vicus*) outside the military buildings, and archaeological excavations have recovered the remains of such a settlement at Llanio (Davies, 1994). There is much debate in the literature, however, as to whether Roman forts such as this actually stimulated local agricultural production in supplying provisions to the soldiers, or merely "fossilised" or "stagnated" existing farming activities (Jones, 1989, 1991; Hanson and Macinnes, 1991; Davies, 1994). At this point it is important to make the distinction between stimulation in terms of innovation and new methods of crop production and stimulation in the sense of the expansion or intensification of current arable agricultural practices. The palaeoenvironmental data presented here offer no contribution towards Roman agricultural innovation, however some comment may be given on the timing and nature of increased farming activity in this area.

The radiocarbon dated palynological and geochemical records presented here suggest that some clearance and farming activity took place in the late Iron Age, although it is tempting to assign the significant expansion in arable cultivation to the date of c. cal. 70's AD, which does correspond to the known Roman occupation of the area in terms of the fort and *vicus* at Llanio. This may suggest that the presence of the Roman military stimulated local production to produce an agricultural surplus (Hicks, 1971; Bartley *et al.*, 1976; Dark and Dark, 2000). This appears to differ somewhat from some of the existing literature. For example Jones (1991, p26) states "as far as we can tell from the better dated pollen diagrams, imperial expansion follows the major wave of agricultural expansion, rather than vice versa but such expansion continues in various parts of the

Figure 7.3 **Location of the Roman auxiliary fort (Bremia) at Llanio in relation to Tregaron Bog (Source: Ordnance Survey Landranger Series, Sheet No. 146, 1:50,000)**

country during the Roman period". Furthermore, Jones (1989, p134) argues "....in parts of the frontier zones at all stages, the Roman presence would appear to halt or even reverse intensification of arable production". Davies (1994) suggests that the settlements around the forts were abandoned soon after the military establishments were decommissioned, which in this case was no later than 130 AD according to Davies (1994) or 170 AD according to Nash-Williams (1969), implying that agriculture would also have suffered. However, this phase of increased agricultural activity appears to continue until c. cal. 350 AD, approximately two centuries after the abandonment of the fort at Llanio. In addition, Hanson and Macinnes (1991) note that increasing arable farming may be the result of an ameliorating climate rather than stimulation from some form of Roman presence. As a result of the uncertainties associated with radiocarbon chronologies, it may be pertinent to be "more circumspect as to cultural origin" (Manning *et al.*, 1997 p176) for this apparent intensification of arable cultivation.

This period of landscape history at Tregaron would therefore appear to be somewhat contentious. The age ranges produced by radiocarbon dates make correlation to such critical historical dates particularly problematical (Baillie, 1991; Dumayne *et al.*, 1995). Similar problems were experienced in the Hadrian's Wall frontier zone in northern England where there is some debate as to the extent of Iron Age versus Roman impact in the vicinity of and adjacent to the Wall (e.g. Dumayne and Barber, 1994; McCarthy, 1995; Manning *et al.*, 1997; Dumayne-Peaty, 1998b). The hypothesis of a Roman stimulus to agricultural intensification, especially in terms of arable farming, is neatly summarised by Davies (1994, p289): "This is an issue whose parameters continue to be highly speculative, and will remain so until palaeoenvironmental data pertaining to the nature of pre-Roman and Romano-British food-production has been obtained from settlement sites in the vicinity of military establishments". The results presented here do, however, agree with the accumulated evidence that suggests "an overall pattern for later Roman Britain of an unprecedented level of exploitation of all available land including soils only marginally appropriate for agriculture" (Jones, 1996, p207).

Zone TRE'98 3 exhibits a substantial decline in pastoral pollen frequencies, notably *Poaceae*, *Plantago lanceolata*, *Rumex acetosella* type, *Lactuceae* undiff. and *Pteridium*, as well as reduced quantities of arable pollen taxa to relatively stable levels for the later part of this zone. This is accompanied by scrubby woodland regeneration, with increases in *Corylus avellana* type pollen, and to a lesser extent expansion of the *Quercus* and

Betula curves. At the same time both the Si and Ti records experience decreasing concentrations, with a low point of human activity evident in the middle of this zone. This decline in human activity appears to begin from c. cal. 350 AD, with the trough in geochemical values dating from cal. 347 – 544 AD. The end of the more intensive agricultural episode thus appears to coincide with both the withdrawal of the Romans in c. 400 AD and a deteriorating climate (Lamb, 1981), which is likely to have had a more significant impact on the already marginal uplands (Applebaum, 1958). In terms of agriculture, a fall in yearly average temperatures of even 1°C dramatically reduces the growing season, while wetter than usual summers can seriously damage harvest yields (Jones, 1996).

Turner's (1964b) results from Tregaron suggest, however, the continuation of pastoral farming from the Roman withdrawal until the c. 12th century AD, but with only c. 12 cm of peat accumulating between 473 – 1182 AD, the resolution makes this difficult to asses in great detail. Moore (1968) and Moore and Chater (1969) also identified a phase of regeneration in their pollen diagrams from central Wales and attributed it to increased tribal warfare and a return to shifting pastoralism during the Dark Ages after Roman withdrawal, although these profiles lack an independent chronology. Such results would appear to differ from evidence from northern England, where farming continued to at least the 6th century AD implying a measure of political stability after the Roman withdrawal (Turner, 1979), but support Turner's (1981 p71) later conclusion that "the majority of pollen diagrams indicate a regenerated forest and a lower proportion of arable and pasture land ......Some show no change and only a very small proportion indicate a higher level of activity than in the Iron Age", although this view is contested by Bell (1989).

The socio-economic structure of Ceredigion in the centuries following the Roman withdrawal up to c. the 11th century AD is still disputed by historians (Dodgshon, 1994). Opinion is split between the continuation of an essentially tribally based society who practised a semi-nomadic, pastoral style economy and the organisation of society into clan-groups who had a significant arable sector to their economy with the landscape being made up of permanent fields and farms. The pollen evidence from this profile indicates some possible land abandonment and woodland regeneration suggesting perhaps the former outcome, especially since the 5th to 7th centuries were characterised by highly disturbed conditions in Ceredigion as the local people fought off Irish invaders (Kirby, 1994).

Subdued agricultural activity appears to have continued for the remainder of this zone, although the Si and Ti curves do begin to rise towards the upper zone boundary. The 9th and 10th centuries in Ceredigion were also characterised by instability and fighting since the county changed hands many times as the kingdoms of both Gwynedd to the north and Dyfed to the south fought for possession of the land each claimed was theirs (Kirby, 1994). By this time the peat accumulation rate drops to approximately 41.7 y/cm, reducing the resolution of the pollen analytical data and making it more difficult to correlate with the historical record. Possible reasons for this phenomenon are discussed in Chapter 4. This was followed by the coming of the Normans in the 11th century who "ravaged" Ceredigion and Dyfed in 1073 and 1074 AD (Kirby, 1994 p337).

The next zone, TRE'98 4, sees renewed arable and pastoral activity accompanied by further removal of scrub woodland, which is particularly evident from the *Corylus avellana* type, *Alnus* and *Betula* curves. The Si and Ti records register this increase in agricultural activity by recording maximum concentrations in this zone. This peak in activity has been radiocarbon dated to cal. 1128 – 1284 AD and marks the next major phase of human impact on the environment in this region; that of the Cistercian monks at Strata Florida Abbey in the 12th century (see Plates 7.2 and 7.3). This phase has also been recorded by Turner (1964b), Moore (1968) and Moore and Chater (1969). Evidence from Lamb (1981) indicates that an episode of ameliorating climate ("the Medieval warm period") occurred between c. 980 to 1300 AD, which correlates well with the increased agricultural activity registered from both the palynological and geochemical records in this zone.

The Cistercian Abbey of Strata Florida was established in 1164 AD. It has been well documented that land endowments were made to the Abbey by the local lords and wealthy families in the 12th century and Strata Florida probably received "lands which had either never been previously exploited or had been exploited in the past and gone out of cultivation and reverted to scrub by the 12th century" (Cowley, 1977 p71). This may account for the reduced levels of agriculture demonstrated by the pollen and geochemical records from the previous zone of TRE'98 3. Consequently, it was "necessary for the monks to face up to the immediate task of developing these territories" (Jones Pierce, 1950 p19), the result of which appear to be identifiable from the pollen and geochemical records.

Plates 7.2 and 7.3 The Cistercian Abbey of Strata Florida, Ceredigion

The Cistercians organised their estates into "granges" and by the end of the 13th century Strata Florida operated 23 granges (Cowley, 1977), the distribution of which can be seen in Figure 7.4. The lands in the vicinity of the Abbey, such as Pennardd, Mevenydd and Blaenaeron, were known to have had a mixed agrarian economy with arable cultivation on the lower lying slopes and pastoral farming in the uplands (Jones Pierce, 1950). The monks were also known to have had rights to common pasture (O'Sullivan, 1947). Approximately two thirds of the Abbey's income was derived from pastoral farming and around one third from arable cultivation in 1291 (see Figure 7.5). Indeed, at the beginning of the 13th century Gerald of Wales records that Strata Florida "was in process of time enriched far more abundantly with oxen, studs of horses, herds of cattle and flocks of sheep and the riches they produced, than all the houses of the same order throughout Wales" (in Cowley, 1977 p83). Such a mixed grange economy biased towards pastoral farming may be evident from the pollen diagram in zone TRE'98 4.

However, the peat accumulation rate calculated for this profile from Tregaron Southeast Bog then appears to drop even more dramatically with approximately 600 years worth of peat forming in only around 4 cm since the large quantities of *Pinus* pollen imply that the overlying sediments date from the c. 1800's AD at a depth of approximately 17 cm in the profile. As explained in Chapter 4, the pollen profile does not appear to indicate a hiatus in peat development, but reasons for such a reduction in accumulation rates remain unknown (see Section 4.1.3.3). This means that no interpretation of the palynological and geochemical records can be made between the late 13th and 19th century.

The surface zone, TRE'98 5, exhibits a rise in *Pinus* pollen which is thought to represent the pine plantations established in the area from the c. 19th century onwards. This is accompanied by increased frequencies of hedgerow taxa across this zone. Estate maps of the late 18th century show that 200 years ago lowland Cardiganshire had something like two thirds of its present hedging (Chater, 1994). The palynological evidence also implies a short-lived peak in both pastoral and arable activity at the beginning of this phase. Similar features have been recognised in other pollen diagrams from this area (e.g. Moore, 1968; Moore and Chater, 1969; Moore, 1994), which have been attributed to the "plough-up" campaigns of the Napoleonic Wars in the early 19th century when high grain prices and favourable climatic conditions resulted in renewed cereal cultivation in more marginal, upland areas (Thomas, 1963 in Moore and Chater, 1969). Depression followed peace in 1815 AD, which may be indicated by the slight decrease in pastoral indicators

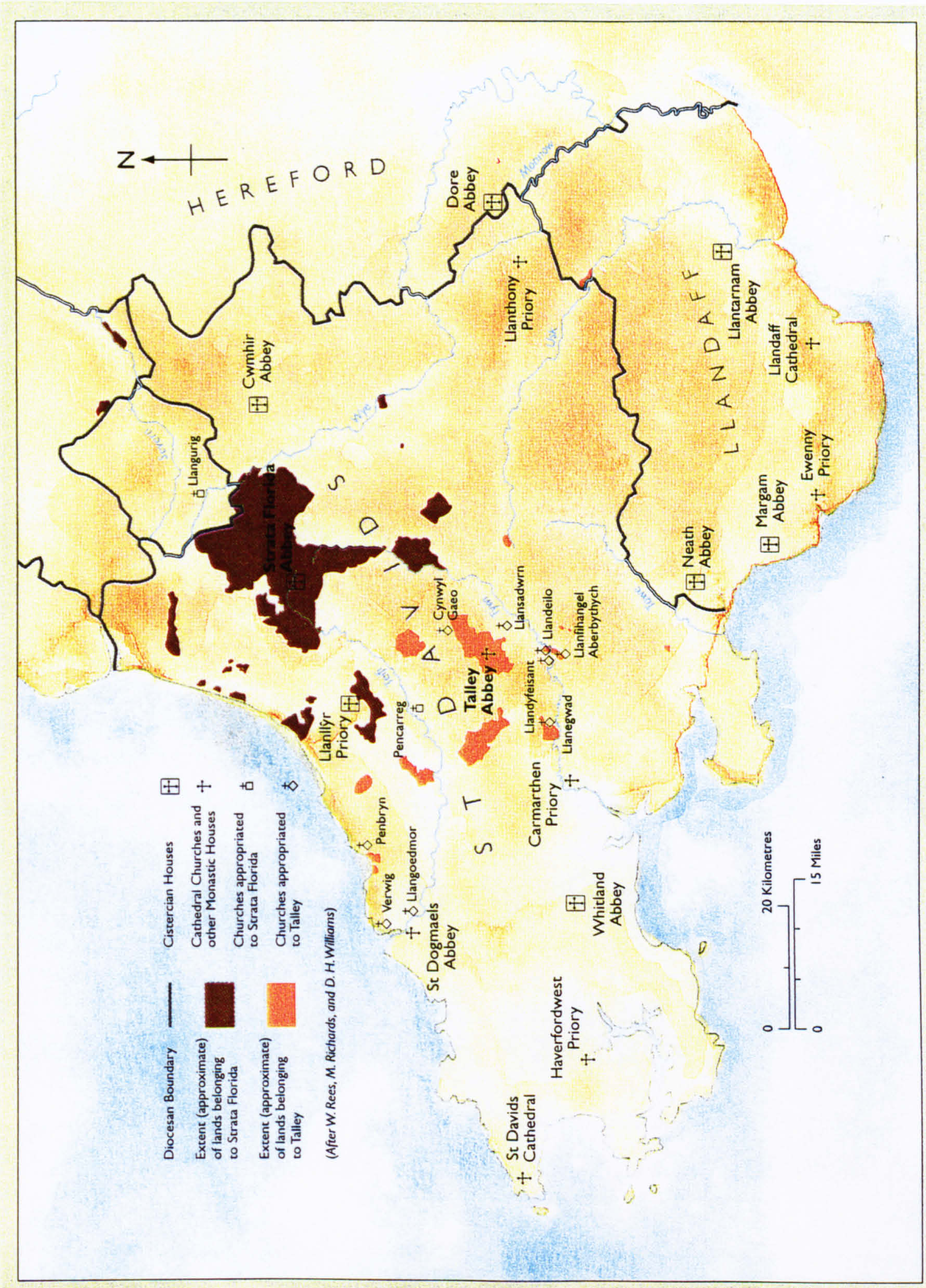


Figure 7.4 Lands belonging to Strata Florida Abbey (from Robinson and Platt, 1998, 2nd edition p21)

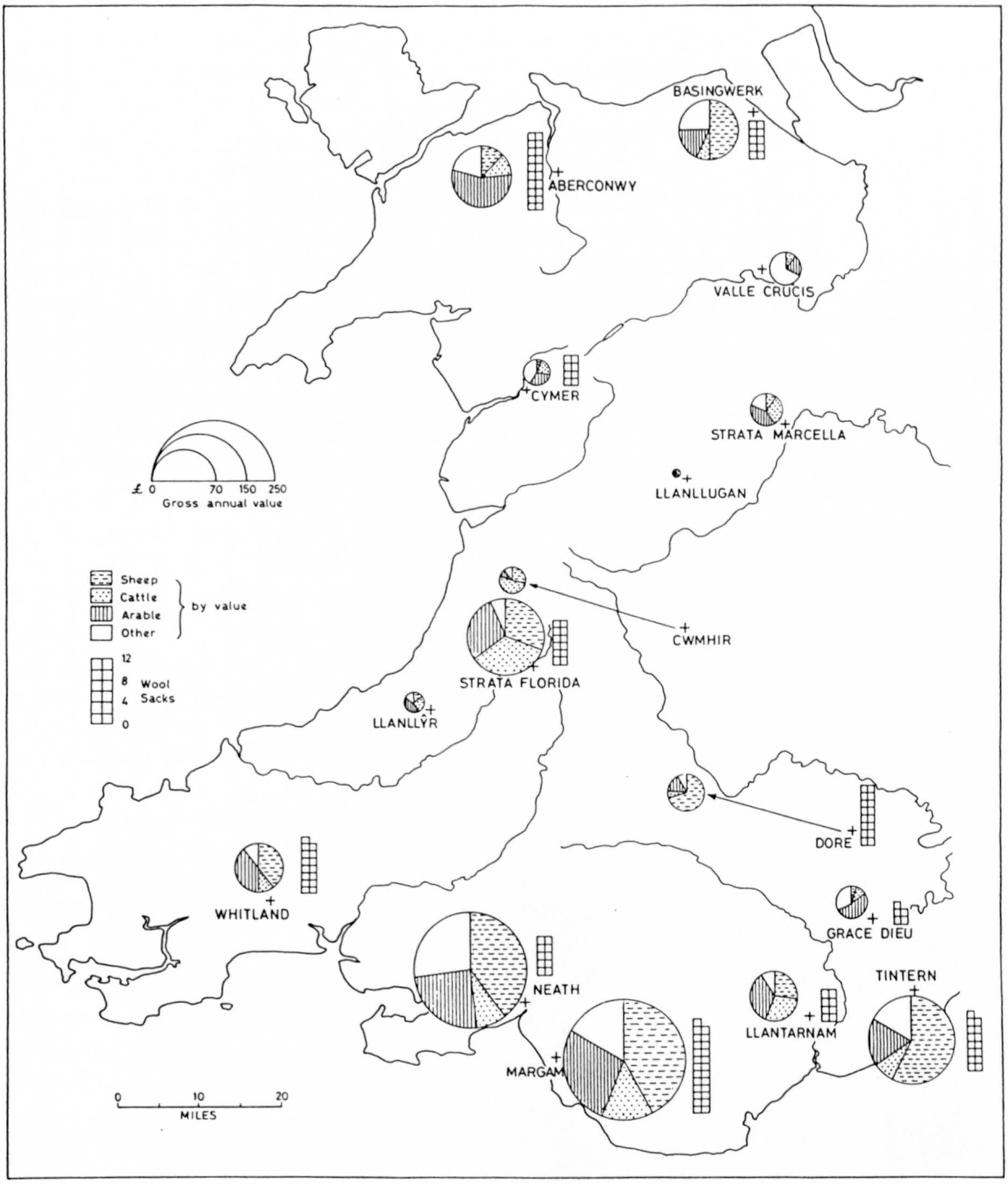


Figure 7.5 **The economic value of Strata Florida Abbey in 1291 AD (from Williams, 1990 p104)**

and woodland regeneration registered over the remainder of the zone, as depopulation through emigration resulted in land abandonment (Moore and Chater, 1969), although arable indicators remain relatively steady. Indeed, oats and rye were both widely cultivated in Ceredigion during the 18th and 19th centuries (Moore-Colyer, 1998). It is interesting to note that the Si and Ti curves demonstrate the beginnings of decline across this zone, although a lack of material meant that analyses could not be continued up to the surface. This phenomenon is similar to that in the AKM'99 profile and also appears to suggest a dominant, inverse relationship between increasing reforestation and declining geochemical input to the mire surface, despite continuing agriculture in the local area.

The main palynological and geochemical trends and their corresponding historical periods are summarised in Figure 7.6. This evidence would appear to support the view that the native landscape of this area of Wales probably developed directly from that of the late Iron Age, with the major landscape change connected to the formation of a network of Roman military establishments (Dark and Dark, 1997). The pollen analytical data do indicate an element of continuity in landscape evolution over this transition period, since there is evidence for agricultural activity by the end of the Iron Age, prior to Roman occupation, although the Roman presence does appear to have resulted in an intensification of farming practices that continued after the abandonment of the fort and *vicus* at Llanio. There does, however, appear to be a regeneration phase after Roman withdrawal with more subdued agricultural activity in the Dark Ages, although this may in part be a response to deteriorating climatic conditions in an already marginal landscape. The next major influence on landscape history and land use change comes from the Cistercian activity related to Strata Florida Abbey which left a significant impact on the pollen and geochemical records. This is followed by the 19th and 20th century records of possible increased agriculture during the Napoleonic Wars followed by pine plantations and general woodland regeneration. Again the geochemical records add to the interpretation of the pollen analytical data in light of local historical evidence.

Figure 7.6 Schematic diagram of landscape history Inferred from palaeoenvironmental evidence from Tregaron Southeast Bog

Depth (cm)	Palaeoenvironmental Data	Historical Period	Date	Climate
0–15	Increase in pine pollen and woodland regeneration. Continuation of mixed farming. Declining Si and Ti concentrations. Possible increase in agricultural activity.	Pine plantations Napoleonic war?	c. 1800 AD Pine rise	
15–22	Increase in mixed agriculture and woodland clearance. Peak in Si and Ti concentrations.	Monastic influence Strata Florida Abbey founded in 1164 AD	cal. 1128-1284 AD	Warmer and drier climate (Medieval warm period)
22–43	Woodland regeneration and decline in pastoral and arable activity. Decreased concentrations of Si and Ti concentrations.	(Arrival of Normans) Dark Ages	cal. 347-544 AD	Colder and wetter climate
43–61	Continued scrub clearance and increase in arable and pastoral activity. Substantial rise in Si and Ti concentrations.	Roman withdrawal c.400 AD Roman period	cal. 86-327 AD	Warmer and drier climate
61–100	Beginning of scrub woodland clearance Increase in pastoral activity and evidence of some arable cultivation. Rise in Si and Ti concentrations.. Scrubby woodland with generally low concentrations of si and Ti.	Iron Age	cal. 202 BC-2 AD	

Figure 7.7 Schematic diagram of landscape history inferred from palynological evidence from Tregaron West Bog

Depth (cm)	Palynological Data	Historical Period	Date	Climate
0–25	Rise in Pine pollen and continuation of mixed farming.	Pine plantations	c. 1800 AD Pine	
25–32	Increase in mixed agriculture and clearance episode.	Monastic influence	cal. 1034-1214 AD	Warmer and drier climate (Medieval warm period)
32–88	High but stable levels of scrub woodland, gradual rise in pastoral farming and increase in arable cultivation.	Arrival of Normans Viking invasions	cal. 894-1026 AD	Colder and wetter climate
88–113	Some regeneration of scrub, decline in pastoral activity, and subdued arable farming.	Dark Ages	cal. 429- 603 AD	
113–150	Declining pastoral activity with some scrub regeneration.	Roman withdrawal c.400 AD Roman period	cal. 250-421AD cal. 19-218 AD	Warmer and drier climate

7.2.3 West Bog (TRWA 2000)

The profile recovered from Tregaron West Bog is thought to have the same pollen source area as that from the Southeast Bog, therefore allowing landscape history reconstruction on a similar spatial scale (see Section 7.2.2). Unfortunately no geochemical records are available for this profile. It was hoped that this site would cover the "missing" c. 600 years from the Southeast profile. However the radiocarbon dates indicate that peat growth rates also dropped dramatically at this site from the c. 12th – 13th centuries AD which are then overlain by relatively modern deposits (see Chapter 4). Since this record covers approximately the same timescale as the previous profile from Tregaron, this discussion is kept relatively brief.

The profile begins the c. cal. 2nd century AD, dating it to the period of Roman occupation. Zone TRWA 1 appears to suggest declining pastoral activity and the regeneration of scrubby woodland during the Roman period. No Cereal type taxa are recorded from this zone although there is an almost continuous curve of *Artemisia* type pollen indicating that some cultivation may have been taking place in the catchment. It is in a situation such as this that the geochemical evidence may provide invaluable information.

Zone TRWA 2 dates from c. cal. 400 AD and implies that after Roman withdrawal there was a brief phase of increased woodland regeneration, although low levels of pastoral activity and one grain of Cereal type pollen are registered in this phase. It is interesting to note that an almost continuous arable pollen curve is recorded from the c. cal. 7th century AD as well as greater frequencies of arable weeds and arable/disturbed/waste taxa, which is accompanied by a marginal increase in pastoral indicators although scrubby woodland remains relatively high across this period. This would appear to indicate that mixed farming continued alongside some scrub expansion. This correlates well with evidence from the Welsh Laws which document that a transhumant pastoral economy was traditional of the Welsh peasantry prior to the establishment of the monasteries (Bowen, 1950).

This seems to continue until the c. cal. 12th and 13th centuries when zone TRWA 3 indicates a rapid increase in pastoral taxa and higher frequencies of arable weeds and arable/disturbed/waste percentages, which imply a period of expanding mixed farming that is most likely to be associated with the establishment of Strata Florida Abbey in the

12th century. Again this is overlain by relatively modern sediments with *Pinus* pollen dominating the woodland taxa, although mixed farming appears to continue to the present day. The main phases of landscape history are summarised in Figure 7.7.

7.2.4 Pollen replicability from neighbouring sites

The two profiles from Tregaron raised mire complex appear to indicate some degree of similarity in terms of broad landscape history trends inferred from the pollen analytical evidence although there are some differences. Both imply an element of Roman impact upon the local environment, although this would appear to be more marked from the Southeast Bog profile. This is followed by a common period of some form of agricultural decline and associated scrub woodland regeneration in the Dark Age period. One of the largest differences is that the profile from the West Bog indicates a phase of increased arable, and to a lesser extent pastoral, activity from the c. cal. 7th century to cal. 1034 – 1214 AD while this is not so obvious from the Southeast Bog record, not least because of the reduction in peat accumulation rates across this period at this latter site.

Both sites reflect the impact of the establishment of the Cistercian Abbey of Strata Florida in the 12th century and the pine plantations of the approximately last two centuries. The *Corylus avellana* type curve from the Southeast Bog seems to be more responsive to local human activity than that from the West Bog. This may possibly be explained through more persistent scrubby woodland fringing the borders of the West mire which may not have been cleared until a much later date and effectively acted as a either a filter to the regional pollen rain or as a source of large quantities of extra-local pollen (c.f. Rosen and Dumayne-Peaty, 2001). Further difficulties may arise from the fact that the profiles have been analysed at different sampling resolutions. A similar study involving comparison of three cores from two adjacent mires in Cumbria and their inferred vegetation histories was undertaken by Dumayne-Peaty and Barber (1998), who concluded that "the similarities in the three pollen profiles ....are probably due to the deposition of regional pollen rain, but the differences imply that local land-use change and extra-local pollen rain can play an important role" (Dumayne-Peaty and Barber, 1998 p162).

7.3 Shaw Moss

Due to the radiocarbon results obtained from SAW2, a brief summary of the existing literature regarding human impact in northwestern England in the Iron Age and first millennium AD is given in the following section. Again this overview is not meant to be exhaustive but aims to explain the context of the present research. More detailed reviews are given in Pennington (1970), Dark and Dark (1997) and Dark (2000). A review of existing literature covering the same timeframe for the Hadrian's Wall zone of northern England is given in Section 7.5.1 with reference to the interpretation and discussion of results from Talkin Tarn. A summary of previous research into human impact over the last 1,000 years is given in Chapter 2.

7.3.1 Previous research into Iron Age and Roman impact in northwestern England

Palynological evidence from Extwistle Moor, Lancashire (Bartley and Chambers, 1992) indicates a possible minor upland clearance episode in the late Bronze Age or early Iron Age, with a more marked woodland deforestation phase in the Roman period. (The sites mentioned in the text can be located on the map in Figure 7.8). A similar sequence of human activity was recorded from the Central Rossendale area of Lancashire (Tallis and McGuire, 1972) with some clearance inferred from the Bronze Age, which was followed by a prolonged clearance phase at higher altitudes in the Iron Age/Roman period, although dense forests persisted in the lowlands until the start of the Roman period.

The record from Fenton Cottage (Wells *et al.*, 1997) indicates that the Over Wyre region of Lancashire was abandoned during the early to mid Iron Age, a similar scenario to that recorded from the Morecambe Bay area where major woodland regeneration is recorded from the mires of south Cumbria from c. cal. 1000 BC (Wells, 1991). This is followed by a phase of extensive arable and pastoral farming which began in the late Iron Age at c. cal. 380 BC – cal. 90 AD at Fenton Cottage and continued through the period of Roman occupation, and indeed up to the present day apart from two brief periods of woodland regeneration prior to cal. 1047 – 1280 AD. Similar clearance in the late Iron Age, prior to the Roman invasion, occurred at the Forest of Bowland (Mackay and Tallis, 1994) which continued into the Romano-British period with evidence of both arable and pastoral farming. Renewed woodland deforestation and increased agriculture then took place at

Figure 7.8 Location of Iron Age/Romano-British sites from Northwest England mentioned in the text.

1. Extwistle Moor
2. Central Rossendale
3. Fenton Cottage
4. Forest of Bowland
5. White Moss
6. Lyth Valley
7. Urswick Tarn
8. Ellerside Moss
9. Rusland Moss
10. Helsington Moss

the end of the 4th century and first half of the 5th century AD, which was subsequently followed by regeneration and reduced agricultural activity from c. cal. 472 – 700 AD. Gradual clearance then took place until the 12th century demonstrating the relatively limited impact of the Vikings in this area.

In the southern Lake District, Wimble *et al.* (2000) studied Foulshaw Moss and Helsington Moss in the Lyth Valley and White Moss in the Duddon Estuary. Evidence from these sites suggests some woodland regeneration at the end of the Bronze Age followed by a marked recession in activity during the early Iron Age, which correlates with the data from Fenton Cottage and the Morecambe Bay area, as well as little evidence for disturbance during this period at Urswick Tarn and Ellerside Moss (Oldfield and Statham, 1963). Extensive woodland clearance then took place at White Moss in the late Iron Age between cal. BC 796 – 398 and cal. BC 710 – 202, although the initiation of deforestation at the Lyth Valley sites took place at the slightly later date of cal. BC 351 – 60 AD. This clearance phase intensified over the remainder of the Iron Age and continued into Romano-British times and was associated with pastoral and arable agriculture.

Pennington (1965) identified a similar phase of human activity from a number of sites in the Lake District, which she attributed to the "Brigantian" occupation in the early centuries of the first millennium AD and were "clearly responsible for the permanent deforestation of these parts" (Pennington, 1970 p72). A similar clearance phase was radiocarbon dated to 436 ± 100 years AD at Helsington Moss (Smith, 1959; Godwin and Willis, 1960). Pennington (1965) noted further clearance and agricultural expansion in Viking times, although White Moss registers some regeneration towards the middle to the Roman period, while the Lyth Valley sites record woodland regrowth around a century later. Resumption of woodland clearance at these latter sites begins around c. cal. 600 – 900 AD and may reflect Gaelic-Norse expansion in the area. Similarly, little evidence of activity was recorded from Rusland Moss between the late Roman period and possible Gaelic-Norse clearances of the 9th and 10th centuries AD (Dickinson, 1975). This is followed by a phase of marked regeneration from the Duddon Estuary and Lyth Valley sites at approximately 1000 AD, which may be a result of the "Harrying of the North" in which many areas were laid waste (Oldfield, 1963), although this is contested by some researchers (e.g. Wells *et al.*, 1997; Wimble *et al.*, 2000).

In summary, small-scale forest clearance associated with mainly pastoral activity appears to be characteristic of the Bronze Age in northwestern England, with a number of sites, especially those from south Cumbria, then suggesting a phase of land abandonment and reduced human activity in the mid Iron Age. Renewed woodland clearance associated with mixed farming economies began in the late Iron Age, which generally seems to continue throughout the period of Roman occupation. After Roman withdrawal there seems to be some variation in vegetation histories, with a number of sites recording woodland regeneration while others suggest the continuation of human activity. This would appear to be dependent on individual local histories.

7.3.2 Shaw Moss (SAW2)

Since Shaw Moss is a relatively small peat deposit, pollen input to the mire surface is likely to be dominated by the local and extra-local components of pollen deposition, thus the palynological record should be sensitive to human activity within several hundred metres of the site (Jacobson and Bradshaw, 1981; Jackson, 1997).

The pollen analytical evidence from zone SAW2 1 (see Figures 5.4a and 5.4b) suggests that the surrounding vegetation was dominated by scrubby woodland at the beginning of the profile in c. cal. 1500 BC (see Figure 4.4), consisting mainly of *Corylus*, *Alnus*, *Quercus* and *Betula* and to a lesser extent *Ulmus*. The herb pollen taxa and Si and Ti curves (see Figures 6.3a and 6.3b) indicate low levels of human activity during this zone, with pastoral farming appearing to be accompanied by some small-scale arable cultivation, as demonstrated by the Cereal type and *Artemisia* curves. This may indicate breaks in the woodland canopy that were temporarily cleared for cultivation or grazing (c.f. Dumayne and Barber, 1994). This correlates well with the pollen data from the Lyth Valley and Duddon Estuary sites, in which cereal cultivation also appears to be taking place in the mid to late Bronze Age (Wimble *et al.*, 2000). This also reflects the archaeological evidence which has identified a number of structures in the south and southwest of Cumbria thought to date from the period (Pennington, 1970).

It is interesting to note, however, the fairly frequent occurrences of *Cannabis sativa* type pollen recorded across this zone, which do not appear to feature in other pollen diagrams from the region at this time. This would appear to be either a very early phase of cultivation, since Godwin (1967b p49) notes "there is little firm evidence ..... for the cultivation of hemp in western Europe before the birth of Christ, but some indication of it from north-west England". Although Bartley *et al.* (1976) record the possibly earliest known cultivation of *Cannabis* in Britain from Thorpe Bulmer on the East Durham Plateau at c. 114 BC, while a single occurrence of *Cannabis* was also registered from Hutton Henry during the early Bronze Age. Or alternatively this may reflect *Humulus* growing naturally in the area as part of the local herb flora, with the possible mid-identification resulting from difficulties in distinguishing the two taxa from their pollen grains alone (c.f. Whittington and Edwards, 1987). The low concentrations of Si and Ti may imply the latter explanation since a cultivation episode is likely to be registered more significantly by the geochemical records.

Zone SAW2 2 indicates a phase of woodland clearance that begins in the late Bronze Age/early Iron Age at cal. 762 – 395 BC, with declines in the *Corylus avellana* type and *Alnus* curves, although *Quercus* values experience a rise in percentages. There would also appear to be a "secondary" elm decline at this date, possibly reflecting the practice of feeding tethered cattle on its foliage.

This is accompanied by a phase of increased pastoral activity, as indicated by the rise in *Poaceae*, *Plantago lanceolata*, *Rumex* spp., *Lactuceae* undiff. pollen and *Pteridium* spores, while the peak in *Calluna* could imply an expansion in heathland as a result of increased grazing, although it may be a signal from the mire surface. The almost continuous Cereal type pollen curve also suggests that more arable cultivation took place in the surrounding area. Both the Si and Ti curves indicate a peak at the beginning of this zone which coincides with the take-off of this more marked agricultural phase at c. cal. 762 – 395 BC. This is followed by a distinct decline in the Si and Ti concentrations at cal. 358 – 49 BC in the mid to late Iron Age. The pollen record does not, however, indicate an obvious reduction in human activity around this time, although there is a slight increase in *Quercus* values. This would appear to differ from the vegetation history recorded from the other sites in the area, which suggest an earlier recession in human activity in the late Bronze Age/early Iron Age (Wells, 1991; Wells *et al.*, 1997; Wimble *et al.*, 2000). This event does indicate the potential of combining the palynological record with geochemical data to give a more detailed reconstruction of past anthropogenic activity which may not always be achieved through pollen analysis alone.

This is followed by a rapid increase in Si and Ti concentrations across the remainder of the zone, while pastoral indicators continue to increase steadily and arable frequencies become more stable in a landscape that is gradually becoming more extensively cleared of scrub woodland. This phase of mixed agriculture dates from c. cal. 100 BC, which would imply a pre-Roman late Iron Age origin, that continued into Romano-British times after the Romans entered this area sometime after 71 AD (Rollinson, 1978), with a peak in Ti values at cal. 18 – 244 AD. This is a similar history to that inferred from other south Cumbria mires (e.g. Wimble *et al.*, 2000), as well as from sites in Lancashire (Mackay and Tallis, 1994; Wells *et al.*, 1997) and Derbyshire (Hicks, 1971). The palynological record from Bolton Fell Moss (Barber, 1981) in north Cumbria also demonstrates a similar history of human impact, although this area of Cumbria is considered in greater detail in Section 7.5.1 in relation to the results obtained from Talkin Tarn. Such agricultural expansion may have been facilitated by a shift from colder/wetter conditions in the early Iron Age to a milder climate from c. 150 BC, with temperatures continuing to rise in the Roman period until c. 400 AD (Lamb, 1981).

This phase of agricultural activity ends rather abruptly according to the Si and Ti curves, which both record a short-lived trough in concentrations at a depth of 34 cm at the beginning of zone SAW2 3. This is accompanied by a rapid drop in pastoral pollen indicators and a decline in arable/disturbed/waste taxa although arable indicators continue to exhibit steady frequencies and arable weeds actually increase. At the same time there is a regeneration in woodland taxa with increases in *Betula*, *Quercus* and *Alnus*, and to a lesser extent *Corylus avellana* type and even a small rise in *Ulmus* frequencies. This woodland expansion phase appears to date from c. cal. 250 AD. Such regeneration may imply a phase of land abandonment, although the date for this event from this profile would appear to be a century or so later than that recorded from other sites in the Duddon Estuary, but is more similar to those registered from sites in the Lyth Valley region (Wimble *et al.*, 2000). This pollen analytical and geochemical event may reflect the disturbed political and economic conditions that persisted in this region during the 3rd century AD (Shotter, 1988).

Unfortunately it is not possible to interpret the pollen and geochemical records for the remainder of this zone until the top few centimetres of SAW2 3, since the increase in *Pinus* pollen at this point implies that the overlying peats date from the last few centuries. Furthermore, the peak in *Cannabis* pollen dated to c. 1750 AD from other sites in the Lake

District (e.g. Oldfield, 1963, 1969; Gedye, 1998) is not apparent in this profile, again suggesting that the resumption of peat growth occurred after this date. However, the remote location of Shaw Moss may partly account for the apparent lack of local *Cannabis* cultivation. Thus approximately 1500 years of peat accumulation appear to be "missing". The pollen curves do not indicate an obvious hiatus in the peat profile and reasons for the dramatic decline in mire growth rates are discussed in Chapter 4.

Hughes (1965 p234) notes that "by the close of the eighteenth century 'planting' had become a feature of every well-managed estate in northern England", and thus it is suggested that the initial increase in *Pinus* pollen at the top of zone SAW2 3 may date from the mid to late 1700's AD (see Figures 5.4c and 5.4d). This is accompanied by relatively high frequencies of *Corylus avellana* type, *Alnus* and *Quercus* pollen. Such high percentages of these taxa may be explained through the presence of the local iron industry. The introduction of blast furnaces to the area from 1711 AD, coupled with increased demand for iron, required large quantities of charcoal that were supplied by the local coppice woods (Marshall, 1958). Although iron smelting had taken place on a much smaller scale in the nearby parish of Millom since the 17th century, a charcoal blast furnace was established at Duddon Bridge in 1736, just to the north of Shaw Moss (Lowe, 1988). "These furnaces used up vast quantities of coppice woodland, for each furnace produced between 10 and 15 tons of cast iron per week, requiring on average one acre of coppice per ton of iron" (Lowe, 1988 p117). Thus the high, fluctuating frequencies of *Corylus*, *Alnus* and *Quercus* pollen evident from this palynological profile may represent the presence of local coppice woods that were being used to provide charcoal at this time (c.f. Dewar and Godwin, 1963).

In terms of agriculture, Cumbria still practised a relatively primitive farming economy until the late 18th century (Barber, 1981). Advances in agricultural techniques and practices were largely stimulated by the enclosure movement from as late as the end of the 1700's onwards. This may account for the low levels of pastoral activity and the beginnings of an increase in arable indicators at the end of zone SAW2 3, as well as increased occurrences of hedgerow taxa possibly as a result of the planting of hedges to provide field boundaries. This was the beginning of the era of "agricultural improvement" and Hutchinson, writing in 1794 – 1797 (p529) suggested that the coastal estate at Millom would benefit greatly "by fencing and planting, it would in a great measure prevent those vast volumes of dry sand, being snatched up by tempests, which overwhelm the adjacent fields, and impoverish the soil. By experience, it has been proved, that such sands as those of Millum, when kept from the washing of the sea, soon gain a surface fit for vegetation, by the effects of summer suns and winter frosts; and under a peculiar mode of husbandry, are brought to afford delicious pasturage". Unfortunately it is not known whether such improvements were embarked upon.

The beginning of zone SAW2 4 records the continuation of a very gradual increase in *Pinus* frequencies, which may correlate with references to "Lord Muncaster's extensive and thriving plantations near Ravenglass" (Bailey and Culley, 1805 p234). This is supported by a fairly rapid decline in *Corylus avellana* type and *Alnus* pollen percentages and a more gradual reduction in *Quercus* values towards the middle of the zone. At the same time there is a marked increase in pastoral indicators, which is accompanied by an almost continuous curve of Cereal type pollen and rises in arable/disturbed/waste taxa. Si and Ti concentrations (see Figures 6.3c and 6.3d) also rise to peak in the middle of this zone. This zone is thought to date from around the beginning of the 19th century with the Napoleonic Wars (c. 1800 – 1815) providing a stimulus for increased agricultural production and a further wave of enclosure since "inflated grain prices encouraged farmers to increase the acreage under the plough" (Winchester, 1988 p94). Furthermore, the traditional wooden plough became obsolete in Cumbria in the early 19th century as a result of the introduction of iron ploughs, which made arable agriculture more efficient (Rollinson, 1978). Oldfield (1963) attributes the decline in *Artemisia* pollen to the new deep-ploughing techniques, although this taxon appears to remain present in the local environment after 1800 AD according to this profile. This may indicate that such a plough was not used in the immediate vicinity of Shaw Moss. Marshall (1958) states, however, that mixed farming still continued in Cumbria during this period, with sheep particularly being grazed in the uplands, which may explain the rise in pastoral pollen indicators across this zone in the pollen diagram.

By the 19th century AD, charcoal was not only used in the iron furnaces but was also necessary for the production of gunpowder (Marshall, 1958), while the iron working industry expanded significantly at Millom in the 1860's AD. Both these factors probably resulted in an increased demand for charcoal and may explain the significant decline in *Corylus*, *Alnus* and *Quercus* frequencies across this zone, perhaps reflecting the exhaustion of local coppice woods as demand for charcoal became too high. Marshall (1958 p60) also states that "the market for birch wood remained a lively one, and the latter was used for making parts of cart wheels and was also very useful in the cotton manufacture", which may account for the decline in *Betula* percentages in the first part of SAW2 4. After the most promising and productive land had been enclosed, attention was turned to the more marginal heaths and wetlands, with enclosure of such lands often resulting in the draining of bogs. This was known to have occurred in the Duddon Estuary and may be another factor that contributed to the decline of *Alnus*.

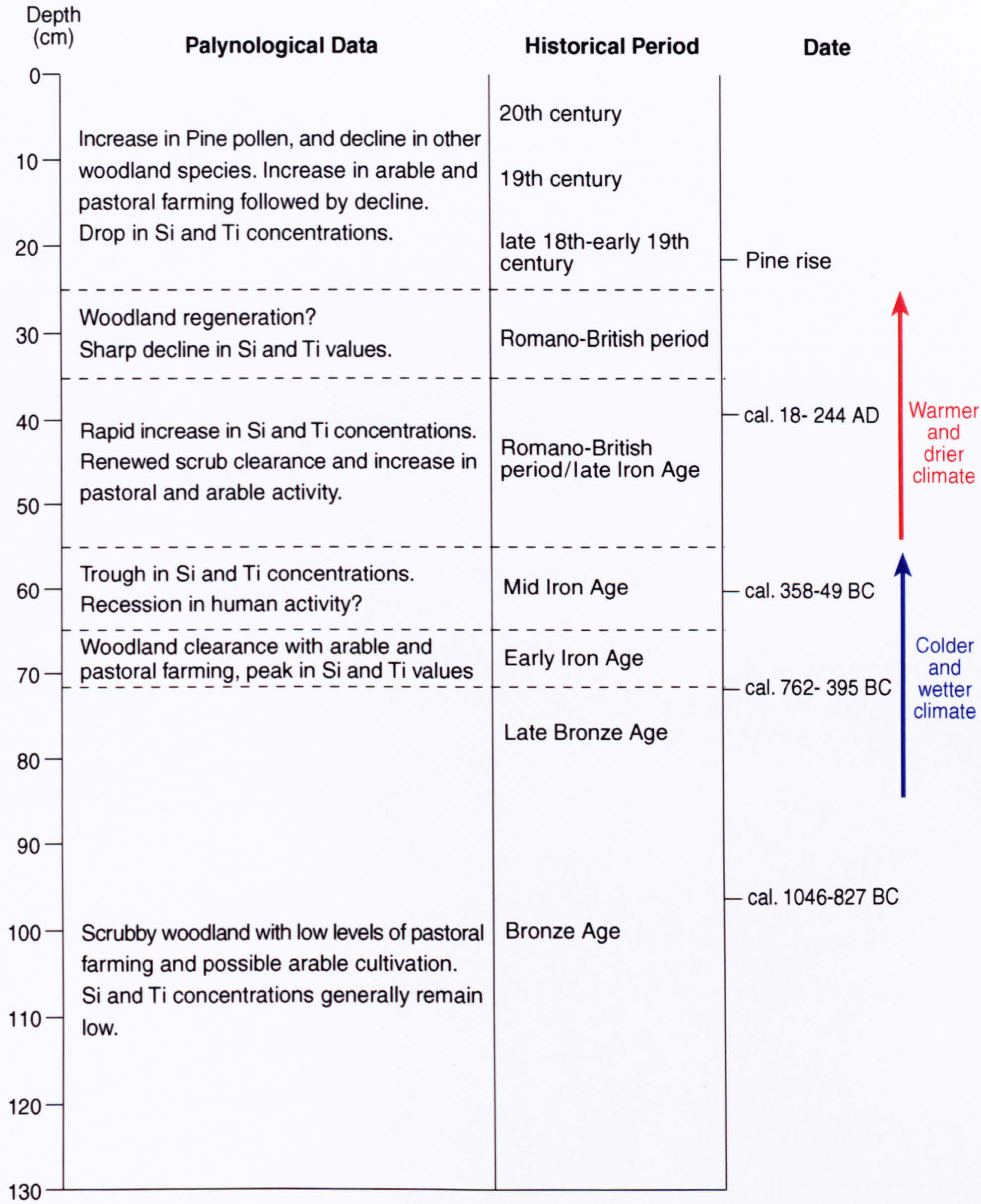
The continued exploitation of Cumbria's woodlands for industrial needs and agricultural improvements resulted in the further establishment of evergreen plantations in order to meet the local demand for charcoal and timber. This land use change was facilitated by the enclosure acts of the mid-19th century which allowed large blocks of fell pasture to be bought and sold (Winchester, 1988) and is thought to reflect the sharp increase in *Pinus* values in the middle of zone SAW2 4. By the late 19th and early 20th century, charcoal was replaced by coke which resulted in a decline in the value of coppice woodland, whilst the greater financial return from evergreen plantations may partially explain the continued increase in *Pinus* pollen (Satchell, 1989).

Such increases in forested land are again accompanied by decreasing Si and Ti concentrations, although there is still pollen analytical evidence for the continuation of arable and pastoral farming. Historical records also indicate the continuation of a mixed farming system, for example a description by Whellan (1860 p402) stated " the southern part of the parish is in general fertile, but a large proportion of the north consists of wastes and pasture grounds. Extensive pastures are found in Thwaites Chapelry, as also that of Ulpha, which in addition contains extensive woodlands". Relatively extensive woodlands and plantations are indicated to the north of Shaw Moss by the OS map of 1860 (Ordnance Survey 1st edition 1860, Sheet No. LXXXVIII). Corn mills are also indicated on this map in the neighbouring village of Arnaby, possibly providing further evidence for arable cultivation in the local area. The occurrence of a single grain of *Fagopyrum esculentum* (buckwheat) is recorded in this zone, which although is relatively uncommon now, was previously widely cultivated (Stace, 1991).

The final zone, SAW2 5, demonstrates the final rapid increase in *Pinus* pollen which peaks at around 67% of total dry land pollen towards the end of this zone. This is accompanied by an increase in *Betula* frequencies although other woodland taxa remain at virtually background levels. Such high *Pinus* pollen percentages are thought to represent the continuation of pine plantations during the 20th century as the result of Forestry Commission activities. Indeed by 1980, conifers made up 72% of Cumbria's woodland (Bunce, 1989). At the same time arable, arable weeds and arable/disturbed/waste taxa, as well as pastoral indicators decline across this zone. This may imply some land abandonment which might allow the colonisation of disused areas by birch and hence may account for the increase in *Betula* frequencies, although *Betula* was also planted by the Forestry Commission to soften the visual impact of the pine plantations. In addition, some grazing land was known to have been converted into forest plantations by the Forestry Commission in the 20th century. Si and Ti concentrations continue to decline, which in this instance may reflect a combination of both declining agricultural activity and extensive reforestation. (The lack of sufficient sample material meant that Si and Ti analyses could not be continued to the surface). The 20th century also saw the decline and closure of the local iron working and gunpowder industries.

In summary, subdued Bronze Age activity dominated by pastoral farming was followed by a phase of increased woodland clearance in the late Bronze Age/early Iron Age, with evidence for a mixed farming economy (see Figure 7.9). The Si and Ti records suggest a phase of decreased human activity in the mid to late Iron Age, although other sites in the area register a recession in agriculture during the earlier period of the late Bronze Age/early Iron Age. Renewed woodland clearance accompanied by a phase of mixed farming is suggested from the pre-Roman late Iron Age which continues into the Romano-British period, with woodland regeneration then being recorded from c. cal. 250 AD. The massive reduction in peat accumulation rates means that the overlying sediments are relatively modern in origin. The initial rise in *Pinus* pollen is thought to date from the late 1700's AD, with continued expansion of *Pinus* frequencies reflecting the growth of pine plantations to the present day, while other tree species declined as a result of exploitation for industrial or agricultural purposes. The rise in arable and pastoral indicators at the beginning of the 19th century may be a response to the Napoleonic Wars, which is subsequently followed by decline. Again the geochemical evidence provides additional information which supplements and extends the pollen data for reconstructing vegetation histories and past anthropogenic activity, ultimately allowing more detailed correlation to the historical record.

Figure 7.9 Schematic diagram of landscape history inferred from palaeoenvironmental evidence from Shaw Moss



7.4 Lake Gormire

Lake Gormire lies below the western edge of the great scarp of the North York Moors (see Section 3.2.4), its situation summarised by Marshall (1788 in Waites, 1997 p11) as "at the top a barren heath; at the foot the Vale of York and the fertile plains of Cleveland". The lack of permanent inflow streams to Lake Gormire means that there is little input of pollen from the streamborne component (Blackham *et al.*, 1981). Pollen deposition is therefore dominated by aerial inputs and overland flow from the catchment (Peck, 1973). Furthermore, the absence of outflow streams means that no pollen is exported from the lake. Despite the relatively small surface area of the lake, Jackson (1990) demonstrated that regional pollen contributions from the canopy were still significant. Thus the vegetation history recorded from this site is likely to be sensitive to local to regional scale disturbances. Using the approximate chronology and sedimentation rate established in Chapter 4, the base of the profile at 70 cm is thought to date from the c. 14^{th} century AD, with around 10 cm of sediment accumulating in approximately 100 years for the lower sections of the profile. The ^{210}Pb dates indicate that the sediment accumulation rate increases towards the upper part of the profile (see Chapter 4). A review of previous research into human impact in the northeast of England over the last 1,000 years is given in Chapter 2.

Zone GOR1 1 (see Figure 5.5a and 5.5b) demonstrates a gradual clearance in scrub woodland with *Corylus* and *Betula* appearing to be the main taxa removed. The other main woodland contributors, *Quercus* and *Alnus*, remain relatively steady across this zone. Arable indicators reach their maximum during zone GOR1 1, with evidence for the possible local cultivation of Cereal types, *Secale cereale* and *Cannabis sativa* type. This zone also displays almost continuous curves for the arable weeds taxa of *Sinapis* type, *Artemisia* type and *Centaurea cyanus* type. The combination of evidence for cereal cultivation and the *Centaurea cyanus* type curve (cornflower) may be of particular significance since "The cornflower ......was one of the most characteristic weeds of traditionally-farmed cornfields (and waste places too) from the middle ages onwards up to the last few decades, when it has almost entirely disappeared from the British Isles as a cornfield weed" (Greig, 1991 p97). This is also accompanied by a steadily increasing curve of pastoral indicators, through taxa such as *Poaceae*, *Plantago lanceolata*, *Lactuceae* undiff. and *Rumex* spp., implying that a mixed agrarian economy was being practised over this zone.

Assuming that a basal date for the profile in the c. 1300's AD is correct, this would place the beginning of the record in the middle of the monastic period in Yorkshire. A number of Cistercian Abbeys were established in the vicinity of Lake Gormire in the 12^{th} century AD, including Rievaulx, Byland, Fountains and Jervaulx (see Plates 7.4 to 7.7). These Abbeys held significant areas of land, and it has been estimated that there were some 120 Cistercian granges in Yorkshire, three quarters of which were in existence before 1200 AD, plus other unconsolidated land holdings (Donkin, 1964). Indeed, the largest concentration of Cistercian-controlled arable land in c. 1300 AD lay between Fountains, Jervaulx and Byland in the northern Vale of York and in the foothills to the east and west (Donkin, 1964) (see Figure 7.10). Furthermore, crop cultivation took place along the north and south margins of the Vale of Pickering, as well as on reclaimed marshland in the Vale of Pickering itself, largely by the monks of Rievaulx Abbey (Waites, 1997). Such extensive arable agriculture would appear to be demonstrated by the pollen record in zone GOR1 1.

As mentioned earlier, however, the pollen evidence suggests a mixed farming economy and the importance of pastoralism must not be underestimated (Hey, 1986). Analysis of the documentary evidence indicates that Cistercian sheep pasture was common, particularly on the limestone slopes north of the Vale of Pickering and the western margin of the North York Moors (Waites, 1997). Indeed, at the end of the 13^{th} century the Abbeys of Rievaulx and Byland were estimated to have owned around 10,000 and 7,000 sheep respectively. In addition, Fletcher (1919 p72) notes that "from Salley on the west of Yorkshire to Meaux on the east, the Cistercian properties were thick with sheep".

Monastic activity on the North York Moors has also been recorded by Atherden (1976) at Fen Bogs, where a phase of intensive agricultural activity was registered, and Jones (1976) at Seamer Carrs, which suggested a period of increased pastoral activities in the 13^{th} and 14^{th} centuries AD. Similarly, pollen evidence from North Gill Wood (Tinsley, 1976) demonstrates renewed forest clearance and the growth of mixed farming due to monastic influences from the Cistercian Abbeys of Byland and Fountains in the 12^{th} and 13^{th} centuries AD. The available documentary evidence relating to the North York Moors region suggests, however, that the 14^{th} century was characterised by "demographic collapse as a direct result of the constant recurrence of plague" (Menuge, 1997 p13), while climate reconstructions from palaeoecological data indicate wet conditions throughout the 14^{th} century (Chiverrell and Atherden, 1999). The impact of both of these factors does not

Plates 7.4 and 7.5 The Cistercian Abbey of Fountains, Yorkshire

Plate 7.6 The Cistercian Abbey of Byland, Yorkshire

Plate 7.7 The Cistercian Abbey of Rievaulx, Yorkshire

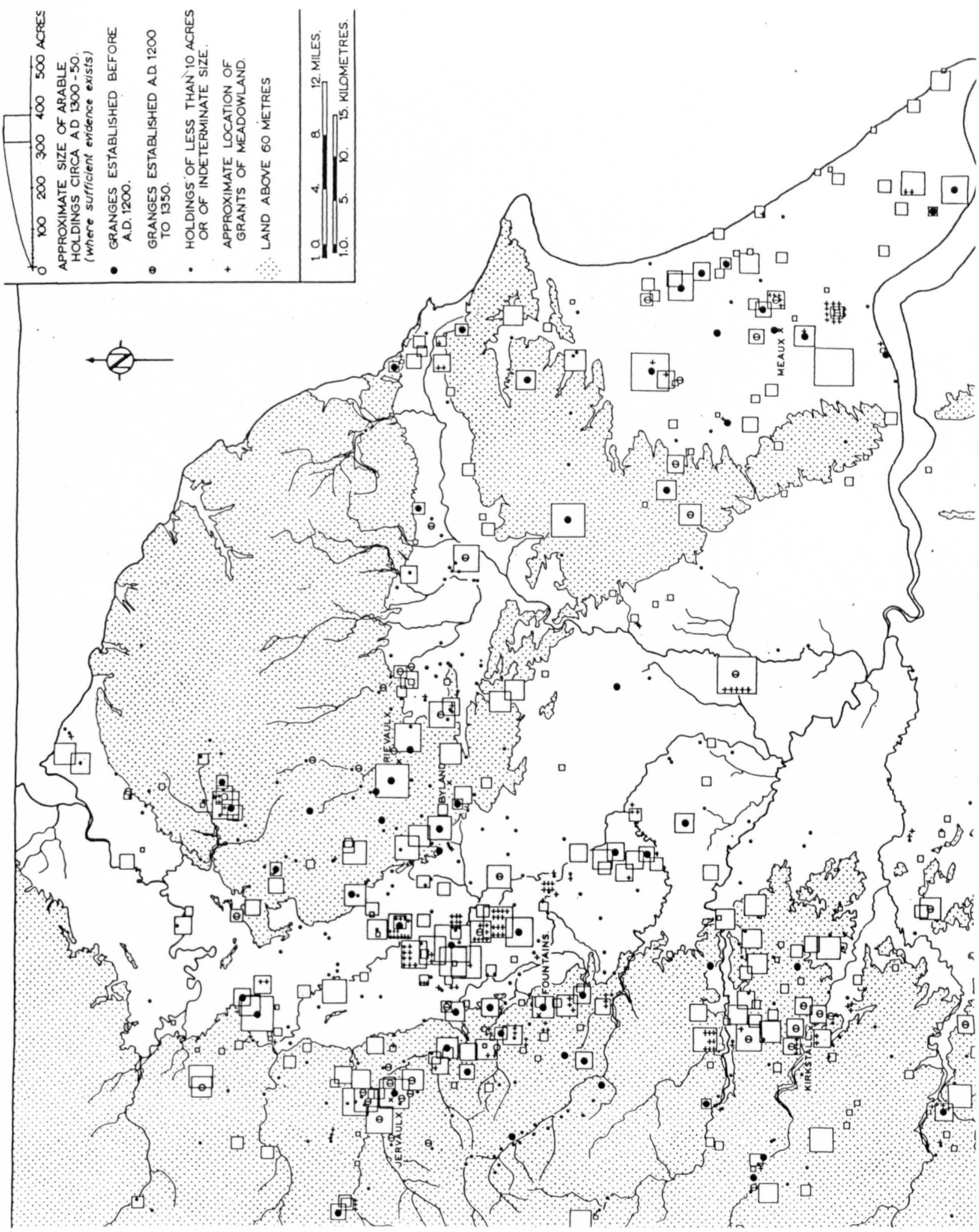


Figure 7.10 Cistercian estates in Yorkshire (from Donkin, 1964)

appear to be particularly obvious from the pollen analytical record, but this may partially be a function of the 1 cm sampling resolution which actually represents c. 10 years of sediment accumulation.

Using the sediment accumulation rate calculated in Chapter 4, the 15th century AD is thought to begin at around a depth of 60 cm in the middle of zone GOR1 1 and marks the beginning of a phase of increased arable cultivation, which continues to almost the end of the zone. A period of increased *Cannabis sativa* type pollen is noticeable from the c. mid 1400's to c. mid 1500's AD. The association of other cereals with high quantities of *Cannabis* pollen may suggest that hemp was being cultivated in the pollen source area, rather than representing wild hops (Sergerström, 1991). The palaeoecological data indicates that this is still a relatively wet period, with some evidence of a drier phase around 1550 – 1680 AD (Chiverrell, 1998; 2001).

Zone GOR1 2 is thought to start in the c. 17th century AD, and marks a transitional period in the pollen record. There is a distinct drop in arable indicator frequencies, with occurrences of *Cannabis sativa* type pollen becoming quite isolated across this zone. If this is a real decline in local hemp cultivation, then it may be a response to cheaper imports from the British colonies (Barber, 1981). Furthermore, zone GOR1 2 marks the virtual end of the *Centaurea cyanus* type pollen curve with only sporadic incidences during the remainder of the profile. At the same time the pastoral indicators of *Poaceae* and *Plantago lanceolata* continue to rise gradually, while *Lactuceae* undiff. and *Pteridium* record quite substantial increases in frequencies. This would appear to suggest a shift towards a more pastoral farming economy, with declining arable activity, and may be due to the growth of Yeoman or Statesmen farmers after the Dissolution of the monasteries in the 16th century. This is accompanied by declines in *Corylus avellana* type and *Quercus* percentages, although there would appear to be a peak in *Alnus* in the middle of the zone and a slight increase in *Betula* values from around the same depth in the profile. The increase in *Betula* frequencies may reflect some recolonisation of formerly cultivated land. Documentary records from 1621 – 23 note unusually wet weather resulting in poor crop yields and famine, while the winter of 1641 – 2 was registered as being particularly severe (Menuge, 1997), which may account for some of the decline in arable indicators. Furthermore, the palaeoecological evidence suggests that this century was mainly wet (Chiverrell and Atherden, 1999). While increases in mainly pastoral activity are also recorded from North Gill Wood (Tinsley, 1976) during the 15th to 17th centuries, Atherden

(1976, p122) suggests that from Fen Bogs "the trend seems to have been towards more intensive arable agriculture in the lowlands rather than the former extensive pastoral agriculture on the uplands".

This zone is also marked by the rapid and substantial increase in frequencies of *Myriophyllum alterniflorum* pollen, which peaks at the upper zone boundary. Oldfield and Wake (pers. comm.) also found this feature in pollen analysed cores from Lake Gormire and dated it to c. 1770 AD on the basis of sediment accumulation rates derived from a suite of ^{210}Pb dates (see Chapter 4). This rise in *Myriophyllum alterniflorum* suggests that the lake was becoming more acidic over this zone (Riis *et al.*, 2000). This may have been caused by changes in land use in the lake catchment. One tentative explanation is that a decline in arable cultivation, as suggested by the pollen evidence, may lead to increased leaching of the soil, while at the same time expanding areas of acid grassland, which may be indicated by the increase in *Pteridium* and *Cyperaceae* percentages, could combine to increase the acidity of the lake water (Hughes, pers. comm.).

The subsequent zone, GOR1 3, exhibits a gradual decline in *Myriophyllum alterniflorum* values towards the surface, although the suggested indicators for acid grassland remain relatively constant and arable cultivation continues to be fairly subdued. Rintanen (1996) notes that this species became progressively rarer between the 1930's and 1980's AD in a sample of 113 Finnish lakes, and argues that is the result of increased use of agricultural and forest fertilisers. The post-c. 1770 AD decline at Lake Gormire may possibly be attributed to the same causes.

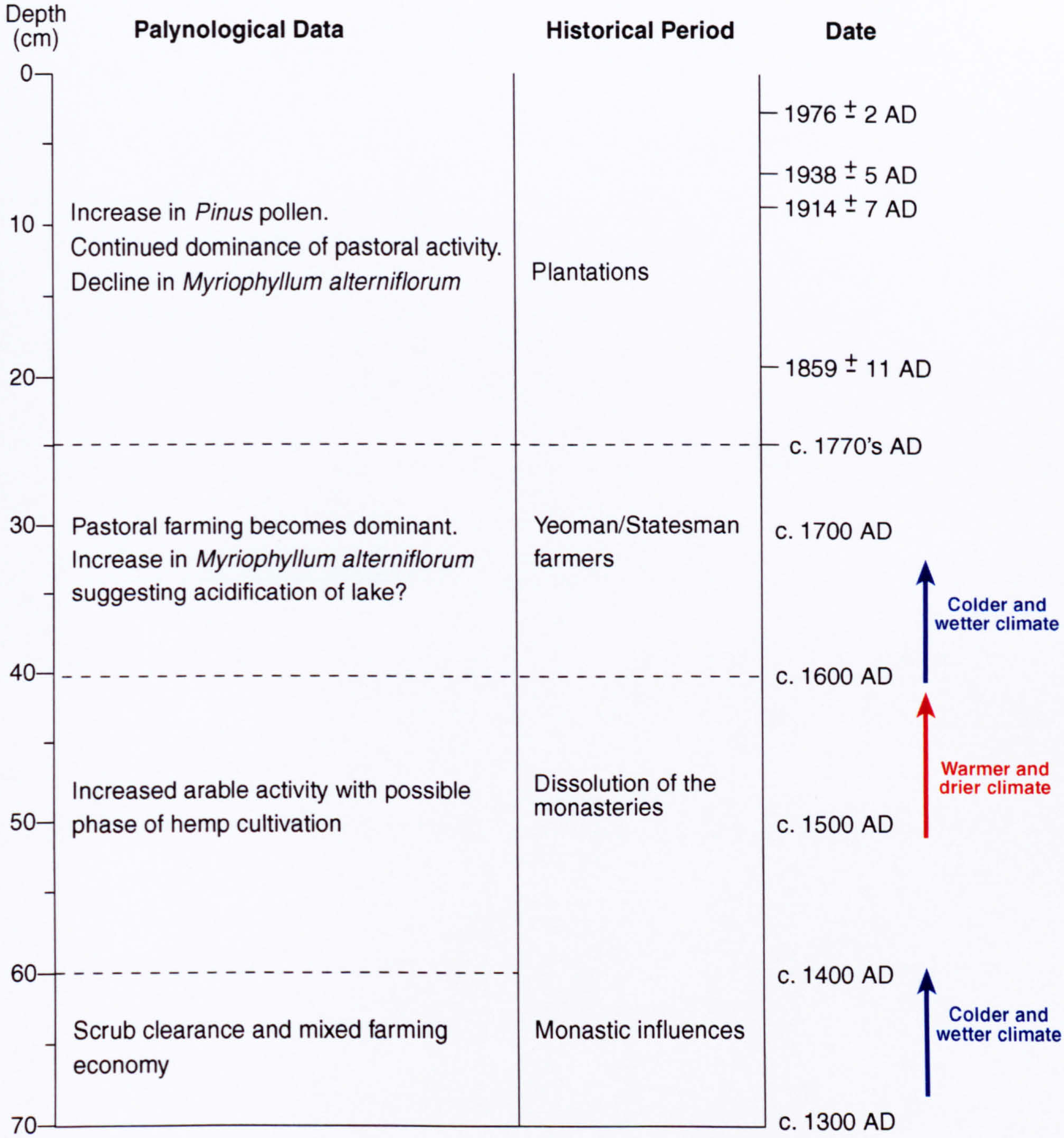
The final zone thus dates from the c. late 18th century and the palynological data indicate a rise in the woodland taxa of *Pinus*, *Ulmus*, *Betula* and to a lesser extent *Quercus*, while the *Corylus avellana* type and *Alnus* curves experience quite significant declines. This zone reflects the period of the plantations and correlates well with evidence from the documentary record that states Scotch fir, larch, spruce, some oaks and a few beech were planted in the North Riding at this time (Tuke, 1800). Tinsley (1976) also registered increased frequencies of *Quercus* pollen in the c. 19th century which were attributed to planting rather than natural regeneration. The components of the woodland taxa at the beginning of this zone also compare well with contemporaneous descriptions, such as those of Tuke (1800, p182) "The spontaneous produce of the wood-lands is principally oak, ash and broad-leaved or witch elm; the produce of the mountains, much birch and alder; and of the hedge-rows and cultivated places, various other trees, the consequence of improvements and art". The reference to hedgerows also appears to match the palynological data with hedgerow taxa generally increasing across this zone, although it does appear to have always been present in this area of Yorkshire for the duration of the profile. Indeed Tuke (1800) notes that much of the better land of the North Riding had already been enclosed by the time of this writing, which may account for the presence of hedgerow taxa as boundaries for enclosed fields.

This zone continues to be dominated by pastoral farming until the final phase of the diagram indicates a drop in frequencies. Arable cultivation appears to remain low across zone GOR1 3 and there is no obvious effect of the "plough-up" campaigns during the Napoleonic Wars in the early 19th century AD. Similar to the results from Shaw Moss, there is no indication of a decline in *Artemisia* type pollen with the introduction of new ploughing techniques in the 19th century (c.f. Oldfield, 1963). In general the pollen analytical data correlates well with Tuke's (1800 p101) writings, which note that "In the Vale of York, one third of the ground is in tillage, and two thirds in grass. On the western end of the Howardian Hills and from thence to Thirsk (being chiefly a dairy county), not more than one quarter is in tillage. In the dales upon the Eastern Moors [North York Moors], only about one fifth is in tillage". Further evidence for the bias towards pastoral activities is noted from Tuke (1800 p198): "the Eastern Moorlands are principally stocked with sheep, at the will of the farmer: and it has been calculated in the proportion of one sheep to ten acres".

The documentary records indicate that the last decade of the 18th century was cold in the North York Moors (Menuge, 1997), while palaeoenvironmental data suggest that the early 19th century was possibly slightly drier or warmer, followed by a return to colder or wetter conditions for the remainder of the century (Chiverrell and Atherden, 1999).

The main periods of landscape change identified from Lake Gormire are summarised in Figure 7.11. The profile begins with a phase of scrub clearance and mixed farming in the c. 1300's AD probably as a result of monastic influences. This is followed by an episode of increased arable cultivation in the latter section of zone GOR1 1, with a distinctive period of higher *Cannabis sativa* type pollen percentages suggesting a phase of local hemp cultivation in the c. mid 15th to mid 16th centuries AD. The 17th century sees a transition towards a more pastoral based farming economy which is accompanied by a rise in *Myriophyllum alterniflorum* pollen, which peaks around c.1770's AD. This suggests that the lake became more acidic during this period which may have resulted from an expansion of acid grassland in the catchment. The final zone dates from the late 18th / early 19th centuries and marks the rise of the plantations while pastoral activities continue to dominate the local farming economy.

Figure 7.11 Schematic diagram of landscape history inferred from palynological evidence from Lake Gormire



7.5 Talkin Tarn

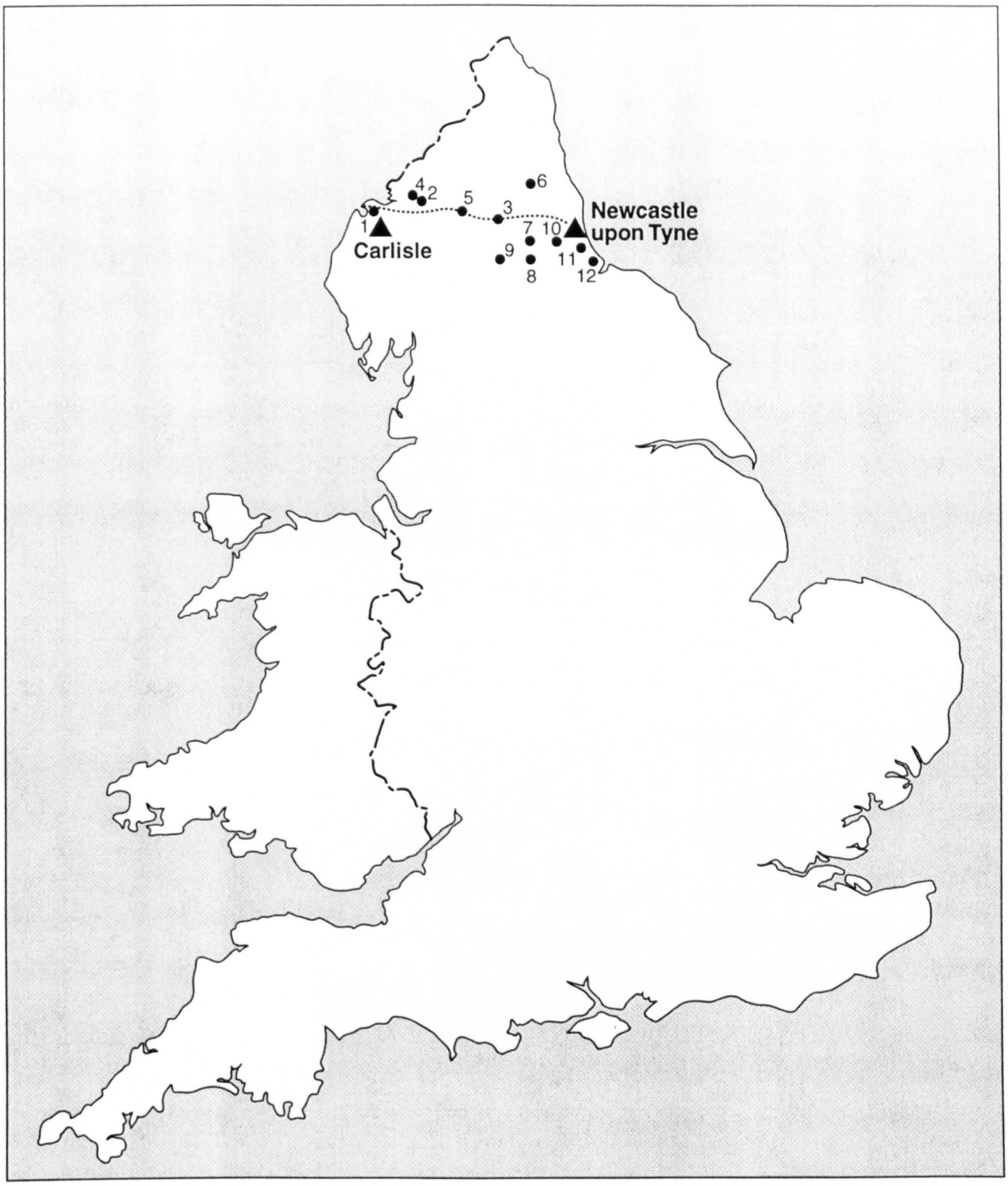
Since the radiocarbon dates from the TAL2 profile indicate that this pollen analytical record spans c. the last 3,500 years, a brief summary of previous research into prehistoric and Romano-British impact is given in section 7.5.1. A review of existing studies on human impact over the last millennium can be found in Chapter 2. Due to the fact that Talkin Tarn lies approximately 5 km south of Hadrian's Wall in Cumbria and the reconstructed vegetation history covers the Roman period, this review has been limited to radiocarbon dated sites in the vicinity of the Wall and therefore includes different studies to the previous overview covering northwestern England (see Section 7.3.1). Again this summary is not exhaustive, but aims to introduce the context of the present research and outline the current understanding of the nature and extent of Iron Age/Romano-British activity in this northern frontier zone. Further reviews can be found in Dark and Dark (1997) and Dark (2000), while Clack (1982) discusses the northeast of England and Fenton-Thomas (1992) covers the Tyne-Tees region.

The Romans reached northern England in 78 AD and Hadrian's Wall was built between Bowness-on-Solway and Wallsend-on-Tyne between 122 – 130 AD (Barber *et al.*, 1993).

7.5.1 Previous research into Iron Age and Roman impact in the Hadrian's Wall zone

Limited Bronze Age activity characterised by a series of small temporary clearances in which pastoral and/or arable farming may have taken place is suggested by the palynological records from Walton Moss, Glasson Moss and Fozy Moss (Dumayne and Barber, 1994) (see Figure 7.12 for location of the sites mentioned in the text). Similar clearings amongst a heavily wooded landscape were suggested by Barber (1981) at Bolton Fell Moss, although no evidence for cereal cultivation was recorded. Davies and Turner (1979) also found short-lived clearance episodes at Fellend Moss and Steng Moss, which were mainly dominated by grazing with little arable agriculture. At a further distance away from the Wall, palynological evidence from Steward Shield Meadow and Bollihope Bog in Weardale also suggests limited Bronze Age impact (Roberts *et al.*, 1973), along with the record from Valley Bog in the upper reaches of Teesdale (Chambers, 1978). Temporary woodland clearances, possibly allowing grazing and coppicing, were identified

Figure 7.12 Location of Iron Age/Romano-British sites from the Hadrian's Wall zone (after Dark, 2000)



⋯⋯ Hadrian's Wall

1. Glasson Moss
2. Walton Moss
3. Fozy Moss
4. Bolton Fell Moss
5. Fellend Moss
6. Steng Moss
7. Steward Shield Meadow
8. Bollihope Bog
9. Valley Bog
10. Hallowell Moss
11. Hutton Henry
12. Thorpe Bulmer

in the early Bronze Age at Hallowell Moss, near Durham City (Donaldson and Turner, 1977).

A subsequent phase of major deforestation was registered in the late Iron Age (2212 ± 55 BP to 2175 ± 45 BP) from Valley Bog, whilst a similar episode was recorded at Walton Moss which was associated with arable and pastoral agriculture and lasted until c. cal. 65 AD. The decline in arboreal pollen at Bolton Fell Moss is more gradual than that at Walton Moss over this period but is also accompanied by some settled agriculture (Dumayne-Peaty and Barber, 1998). Pollen evidence from Glasson Moss indicates some disturbance of woodland cover between c. cal. 295 BC – 125 AD with some arable and pastoral farming, although the record from Fozy Moss demonstrates very little human impact in the Iron Age period. Bartley *et al.* (1976) record evidence for the intensive cultivation of hemp and some cereals from Thorpe Bulmer dated to 2064 BP during the late pre-Roman Iron Age, which peaks in the Roman period at c. 1730 BP. Some late Iron Age grazing activity was suggested by Donaldson and Turner (1977) from Hallowell Moss. Furthermore, Topping (1989) identified a number of Iron Age and Romano-British cord rig cultivation terraces in the Tyne-Forth area, thus giving more evidence for settled arable agriculture during this period.

A number of sites register extensive clearances that "more or less coincide with the Roman occupation of the north of England" (Davies and Turner, 1979 p802), although unfortunately the age ranges produced by radiocarbon dates means that such episodes of increased human activity can not easily be attributed to either native impact in the late Iron Age or Romano-British influences. These include Steng Moss and Fellend Moss, where clearance was dated to cal. 152 BC – 211 AD and cal. 47 BC – 208 AD respectively (Davies and Turner, 1979), while at Hallowell Moss it was dated to cal. 147 BC – 235 AD (Donaldson and Turner, 1977), Hutton Henry at cal. 23 – 379 AD (Bartley *et al.*, 1977), Steward Shield Meadow and Bollihope where it is recorded at cal. 385 BC – 211 AD and cal. 83 – 536 AD respectively, and Bolton Fell Moss where clearance is registered just before cal. 4 – 322 AD. (N.B. The aforementioned radiocarbon dates, with the exception of that from Bolton Fell Moss, have not been reproduced here in their original published form, but calibrated to the 2 sigma range to allow comparison with the historical record).

High resolution pollen analysis by Dumayne (1992) investigated the extent and nature of Roman impact in more detail. Dumayne and Barber (1994; Dumayne-Peaty and Barber,

1998) demonstrate that during the period of Roman invasion (65 – 122 AD), palynological evidence from Walton Moss indicates a phase of woodland regeneration, possibly as a result of the disturbance to society, although this was not recorded from Bolton Fell Moss or Glasson Moss. This may have been a function of sampling resolution at the former site, while the latter record may suggest less local resistance to the Roman invaders. Renewed clearance was then registered at Walton Moss, Glasson Moss and Bolton Fell Moss during c. cal. 125 – 395 AD, which corresponds to the period of Roman occupation. Fozy Moss experiences substantial and rapid deforestation for the first time at the beginning of this period, with an almost totally cleared landscape from c. cal. 130 AD. At all sites, this clearance episode is accompanied by increases in arable and pastoral agriculture. The authors suggest that such clearances may reflect the felling of timber in order to build Hadrian's Wall and its associated structures. Manning *et al.* (1997) argue, however, that the landscape around Vindolanda was already open, cleared of nearly all woodland and intensively grazed by c. 85 – 92 AD, with arable cultivation being important by c. 160 – 180 AD. Thus their evidence from two ditch fills would appear to indicate the clearance occurred prior to the construction of the Wall and claim that such deforestation was of native rather than Roman origin and was for agrarian expansion rather than military purposes. This period of land use change prior to and during the construction of Hadrian's Wall would therefore appear to be somewhat contentious. Most diagrams from the area show the continuation of agriculture during the period of Roman occupation.

Further debate surrounds land use histories after the withdrawal of the Romans in c. 400 AD. Turner (1979 p289) reviewed the evidence from nine sites in northeast England, most of which are included in this overview, and concluded that "forest regeneration almost certainly occurred well after the Roman withdrawal and this implies that there was a measure of political stability well into the 6th century AD and in some places, considerably longer, allowing settled farming to continue more or less as it had been under Roman rule". Dark and Dark (1996 p67) disagree, however, and state that "The re-examination of these sites ...... makes it clear that arguments for post-Roman landscape continuity in this area have been based on an insufficiently close analysis of the evidence. Several of the sites discussed by Turner (1979) do seem to indicate woodland regeneration directly connected with Roman military withdrawal from the North". They do note that this regeneration phase appears to be registered in sites close to the Wall rather than being typical of Britain as a whole. Fozy Moss and Glasson Moss do indicate woodland regeneration in the c. cal 4th century AD, which largely continues into monastic times

(Dumayne and Barber, 1994). This is not so marked at Walton Moss and Bolton Fell Moss (Barber, 1981), however, where some regeneration is accompanied by subdued agricultural activity, possibly reflecting a decline in population and local settlement after the breakdown of Roman rule (Dumayne-Peaty and Barber, 1998).

The next phase of extensive clearance is registered at 1005 ± 40 AD at Fellend Moss and 865 ± 35 AD at Steng Moss (calibrated to 1018 – 1206 AD and 894 – 1017 AD respectively) (Davies and Turner, 1979), whereas renewed clearance takes place in monastic times at Walton Moss, Glasson Moss and Fozy Moss. Bolton Fell Moss registers a short period of rapid deforestation at cal. 980 – 1260 AD (Dumayne-Peaty and Barber, 1998). A summary of previous research into vegetation change and land use histories for the second millennium AD can be found in Chapter 2.

To summarise, limited Bronze Age activity is followed by major deforestation in the late Iron Age and Romano-British periods with evidence for arable and pastoral farming, indicating that there was some native activity prior to Roman occupation. Clearance and mixed farming largely continued throughout the Roman period, although there is still debate as to whether Roman withdrawal resulted in woodland regeneration or whether settlement and agriculture continued to take place in the following two centuries or so. Some element of declining activity and increased regeneration is generally recorded for the late Anglo-Saxon period, with renewed clearance possibly resulting from Scandinavian settlement and later from monastic activity in the c. 12 century AD.

7.5.2 TAL1

The radiocarbon dates indicate that the first zone in this profile dates from cal. 12,346 – 11,700 BP in the Lateglacial. This zone is dominated by *Artemisia* type pollen, with significant amounts of *Poaceae*, Cyperaceae, *Rumex* undiff. and *Thalictrum*, and smaller frequencies of *Caryophyllaceae* undiff., *Silene dioica* type and *Filipendula*. Tree and shrub pollen generally remain low, with the *Betula* and *Pinus* curves possibly reflecting long-distance deposition. These pollen spectra suggest an open, steppe type of environment, which is similar to the Lateglacial pollen assemblages described by Walker *et al.* (1993) and Andrieu *et al.* (1993) from eastern Yorkshire and western Ireland respectively.

The beginning of zone TAL1 2 is marked by rapid increases in *Corylus avellana* type, *Betula*, *Quercus*, *Alnus* and to a lesser extent *Ulmus* pollen frequencies. At the same time there are sharp declines in the *Artemisia* type, *Poaceae*, Cyperaceae, *Rumex* undiff., *Thalictrum*, *Caryophyllaceae* undiff. and *Silene dioica* type pollen curves. This would appear to suggest some kind of hiatus in the profile, since such quantities of these arboreal taxa are not usually associated with the Lateglacial.

The beginning of the final zone, TAL1 3, is radiocarbon dated to cal. 3961 – 3723 BP, yet the take-off in *Pinus* values just above this date would suggest that the overlying sediments are relatively recent, perhaps originating from the c. last 200 years. This would appear to indicate another hiatus in the profile. Overall, the high level of disturbance to this profile means that it is not suitable for investigating the research aims and questions in Chapter 1 and thus is not discussed in any more detail here. Possible causes for such disruption to the profile are not known, but the bathymetry of the lake (see Figure 3.11) indicates that the core may have been taken from an area of sloping lake bed which may have been subject to some slumping action, thus causing hiatuses in the sediment record.

7.5.3 TAL2

According to Jacobson and Bradshaw (1981), a relatively small lake such as Talkin Tarn (see Section 3.2.5 for a description of the site) should receive the majority of its pollen input from the local and extra-local components of pollen deposition. Jackson (1990) demonstrated, however, that regional pollen contributions from the canopy were still significant. Thus the vegetation history recorded from this site is thought to be sensitive to local to regional scale disturbances.

The pollen analytical evidence from zone TAL2 1 (see Figures 5.7a and 5.7b) suggests that the surrounding landscape was dominated by woodland, consisting mainly of *Betula*, *Quercus* and *Corylus*, at the beginning of the profile in the mid-Bronze Age at c. cal. 1500 BC (see Figure 4.6c). Temporary clearings for subdued pastoral activity may be indicated by the presence of *Poaceae*, *Plantago lanceolata* and *Rumex* pollen, as well as *Pteridium* spores. The low levels of charcoal (see Figures 6.4a and 6.4b) in the first part of this zone also suggest little anthropogenic activity. Such limited human impact during this period corresponds well with the scant archaeological evidence for Bronze Age activity in north Cumbria (Fowler, 1983) and with previous palynological investigations from the vicinity (e.g. Barber, 1981; Dumayne and Barber, 1994) and from the Hadrian's Wall region as a whole (e.g. Roberts *et al.*, 1973; Donaldson and Turner, 1977; Chambers, 1978; Davies and Turner, 1979). This period coincides with a known climatic deterioration at c. 3500 BP, evidence of which was recorded from both the nearby bogs of Bolton Fell Moss (Barber *et al.*, 1994b) and Walton Moss (Hughes *et al.*, 2000).

This is followed by a period of increased human activity in the later part of zone TAL2 1 with Cereal type pollen being recorded for the first time in the profile, alongside greater frequencies of *Artemisia* type pollen. This episode of arable farming is accompanied by a phase of increased pastoral indicators as well as higher charcoal concentrations and dates from c. cal. 900 BC in the late Bronze Age. The proxy climate reconstructions from Bolton Fell Moss and Walton Moss both show an improvement in climatic conditions at this time (Barber *et al.*, 1994b; Hughes *et al.*, 2000). Cereal pollen was also recorded from Bolton Fell Moss at c. 840 BC (extrapolated from the age-depth model) (Barber, 1981), although it must be remembered that "northern Cumbria was an agricultural and social backwater until the Roman occupation" (Barber *et al.*, 1993 p226) with agricultural practices changing little from those of the mid-Neolithic (Walker, 1966; Davies and Turner, 1979). This phase of increased human activity appears to end at c. cal. 150 BC in the late Iron Age when there is a decline in frequencies of arable, arable weeds and arable/disturbed/waste pollen, as well as a reduction in pastoral indicators. This recession in farming activity appears to coincide with a climatic wet-shift that was recorded at Walton Moss as commencing between cal. 2320 and 2040 BP (Hughes *et al.*, 2000) and hence may provide a partial explanation for this decline. This is followed by more subdued mixed farming for the remainder of the zone, although charcoal concentrations decline slightly later than the pollen indicators for human activity.

The first half of zone TAL2 2 registers a significant increase in both arable and pastoral agriculture, with *Secale cereale* being recorded for the first time in the profile. This is accompanied by an increase in *Artemisia* type pollen and the start of an almost continuous *Sinapis* curve. At the same time there is a rise in the *Poaceae* and *Rumex* undiff. records, the beginning of an unbroken *Lactuceae* undiff. curve, and a decline in woodland pollen frequencies. The age-depth model indicates that this episode dates from c. cal. 300 AD and therefore places this phase of increased farming activity in the Romano-British period. This vegetation history differs somewhat from that recorded at Walton Moss, where rapid woodland clearance was experienced in the pre-Roman Iron Age, although deforestation was more gradual over this period at Bolton Fell Moss (Dumayne-Peaty and Barber, 1998). A period of regeneration followed at Walton Moss during the Roman invasion which was then succeeded by renewed clearance and agricultural activity at Walton Moss and Bolton Fell Moss from c. cal. 165 AD. Thus the activity recorded from the Talkin Tarn profile would appear to be rather late, despite the fact that it is only 5 km away from Walton Moss and around 5 km south of Hadrian's Wall with its associated military structures and settlements. This may imply that the land around Talkin Tarn was not farmed until an increase in population pressure in the c. cal. 4th century AD forced the expansion of agricultural activities into this area. This would seem somewhat surprising, however, since Talkin Tarn is surrounded by good quality agricultural land and Higham (1981 p110) suggests that the "route of the Wall from Bowness to Birdoswald displays a tendency to maximise the land of arable potential south of the Wall, and thereby optimise the reliable supply-territory of the garrison". By this time the pollen records from Walton Moss and Bolton Fell Moss indicate that the landscape was generally relatively open and the high arboreal pollen frequencies registered from Talkin Tarn may reflect the presence of woodland immediately surrounding the lake, which would influence the pollen rain by depositing larger proportions of extra-local pollen and have the effect of "swamping" the pollen indicators of human activity (c.f. van der Veen 1985; Rosen and Dumayne-Peaty, 2001). Furthermore, this apparently late date for activity may be a result of the difficulties and errors associated with the radiocarbon dates obtained for this site. This horizon would therefore benefit from additional radiometric determinations.

The pollen evidence indicates a peak in arable cultivation at a depth of 58 cm, which has been radiocarbon dated to cal. 342 – 597 AD, implying that agriculture continued after the Roman withdrawal of troops from Britain that began in the 4th century AD (Higham, 1986). This would appear to support Turner's (1979) earlier conclusion that settled farming continued well after the breakdown of Roman rule and agree with Casey's view (1993 in Dark and Dark, 1997 p144) that "fort communities along the Wall 'stayed put' after the end of Roman rule". This, however, disagrees with Dark and Dark's (1996) argument that woodland regeneration was directly connected to military withdrawal, especially at sites in close proximity to the wall. This more intensive farming episode appears to continue until c. cal. 950 AD at Talkin Tarn, when there is a decline in arable indicators, the beginning of a reduction in pastoral pollen frequencies, an increase in woodland taxa and a recession in charcoal concentrations. This date does, however, mark an episode of *Cannabis* cultivation. This may suggest that *Cannabis* was grown on land that was previously used for cultivating cereals (c.f. Hicks, 1971).

The remainder of this zone is characterised by fluctuating arable and pastoral pollen frequencies, suggesting the continuation of more subdued agricultural activity until the beginning of zone TAL2 3. The relatively slow sedimentation rate of the lake makes it more difficult to interpret individual palynological events and therefore does not allow such detailed comparison with the historical record. In this instance, Si and Ti records may provide very useful information which could aid correlation with documentary evidence. The survival of agriculture implied from this pollen profile may reflect the fact that Cumberland was outside Norman rule and therefore spared the so-called "Harrying of the North", while at the same time benefiting from the establishment of the Cistercian monastery of Holm Cultrum in 1150 AD and the Augustinian Priory at Lanercost in 1160 AD (Barber, 1981). Downturns in the arable and pastoral pollen indicator curves may be a response to the "war, pestilence and famine" (Barber, 1981 p116) that were particularly severe during the 14th century AD. There is a peak in arable frequencies at c. cal. 1450 AD which would appear to correlate with a similar revival in agriculture recorded from Bolton Fell Moss (Barber, 1981) despite the deteriorating climatic conditions of the Little Ice Age.

Using the age-depth model, zone TAL2 3 is thought to date from c. cal. 1650 AD. This date marks the end of the period of *Cannabis* cultivation and may possibly reflect the import of cheaper hemp from abroad (Barber, 1981). The record of *Artemisia* type pollen ends at almost the same time, although this is somewhat earlier than from records in south Cumbria (c.f. Oldfield, 1969). This zone is marked by the beginning of a rapid increase in pastoral indicators and rising arable frequencies, suggesting the resurgence of the local farming economy.

The pine rise at a depth of 10 cm in the profile is thought to reflect the beginning of the 19th century, by which time planting was common on local estates (Bailey and Culley, 1805; Hughes, 1965). This is accompanied by a peak in arable cultivation and the continued rise of pastoral indicators and are most likely to represent the plough-up campaigns of the Napoleonic Wars (Winchester, 1987). The palynological evidence from this zone for the expansion of a mixed farming economy correlates well with Whellan's (1860 p678) description of the Talkin Township: "They are principally engaged in agriculture ..... The land in the neighbourhood of the village is good, and in a fair state of cultivation. It is well suited for the growth of potatoes, turnips and all sorts of grain. The common, to the extent of about 1,400 acres, has been recently enclosed under the Commons Enclosure Act." This zone is also characterised by substantial charcoal concentrations suggesting significant anthropogenic activity.

The main palynological and charcoal trends and their corresponding historical periods are summarised in Figure 7.13. There would appear to be an element of land use continuity in the mid- to late Bronze Age, although the pollen evidence suggests declining exploitation in the pre-Roman Iron Age and Romano-British period until c. cal. 300 AD. This profile differs from others in the area by suggesting the continuation of settled farming after Roman withdrawal rather than widespread woodland regeneration and land abandonment. Fluctuating levels of agricultural activity suggest some continuity in land use between c. cal. 950 – 1650 AD, which is followed by a period of change as land use exploitation increases in the 19th century AD.

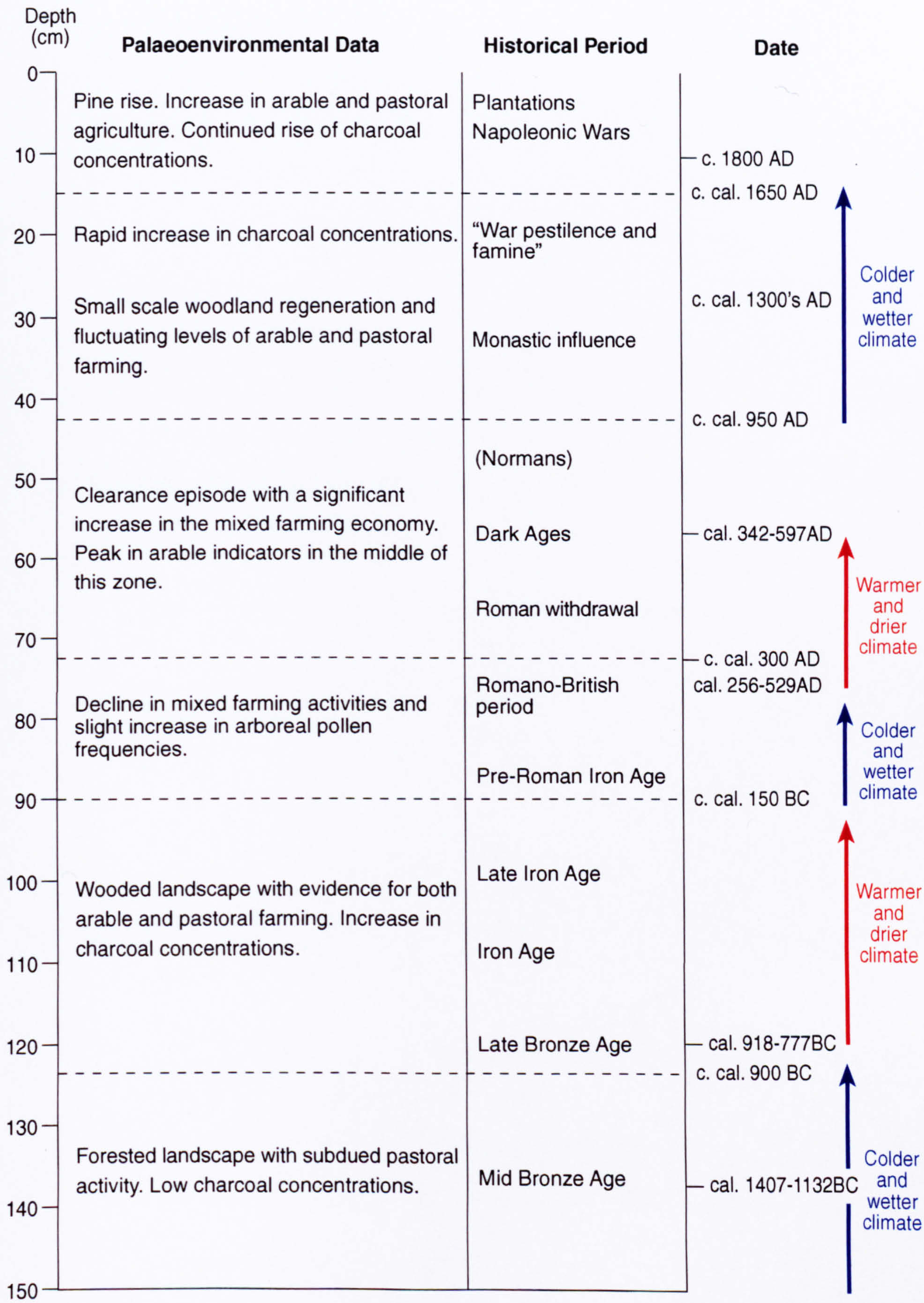
7.5.4 Pollen replicability from lake cores

It was hoped that analysis of two cores from Talkin Tarn would allow some discussion concerning the degree of pollen analytical variability between cores from the same lake basin. Unfortunately, the Lateglacial origin of TAL1 and obvious disturbance to sediment accumulation means that it is not possible to compare this core with the pollen analytical record obtained from TAL2.

7.6 Comparison of regional Iron Age/Roman impact

This section explores the regional trends in human impact spanning the Iron Age, Roman and post-Roman periods. The issues of "continuity and change" (Bell and Dark, 1998) are discussed in relation to the expansion and contraction of agricultural activity, the type of farming practised and the introduction of new crop regimes (c.f. Dark, 1996). It is recognised that consideration of the latter issue cannot be undertaken in any great detail since many important anthropogenic indicators cannot be identified to a species level and thus cannot be distinguished from species within the same family that are not associated with cultivation (Jones, 1988). The profiles covering this timeframe consist of TRE'98

Figure 7.13 Schematic diagram of landscape history inferred from palaeoenvironmental evidence from Talkin Tarn



(Southeast Bog), TRWA 2000 (West Bog), SAW2 and TAL2. AKM'99 is not included in this discussion because of the lack of Roman impact on Ireland.

The palynological and geochemical records from TRE'98 suggest that there is evidence of pastoral farming with the possibility of some small-scale arable activity in the late Iron Age prior to the Roman invasion. There does, however, appear to be an expansion in agricultural activity during the period of Roman occupation and although there would appear to be greater arable farming than in previous centuries, the main emphasis continues to be on pastoralism. In terms of crops grown, both Cereal type and *Secale cereale* pollen were found in the late Iron Age and Roman periods, but *Cannabis* cultivation appears to be a Roman introduction. Both the pollen analytical and geochemical evidence from the centuries immediately following the Roman withdrawal in c. 400 AD indicate the regeneration of woodland coupled with a decline in arable and pastoral farming activity to a more subdued level, although the actual crops cultivated appear to remain the same. This phase of discontinuity differs from Turner's (1964b) record from the Southeast Bog at Tregaron, where pastoral activities are recorded as continuing from the 5th century into the 12th century AD. This record, however, is subject to a dramatic drop in bog growth rates over this critical period with approximately 13 cm of peat accumulating in around 700 years and only 6 pollen analysed levels between the dated horizons of 473 and 1182 AD (Turner, 1964b), resulting in a rather coarse resolution which does not allow the question of continuity to be discussed in any great detail. The profile from the West Bog (TRWA 2000) also suggests a phase of regeneration and declining pastoral activity immediately after the Roman withdrawal, and it is not until the c. cal. late 6th century AD onwards that there is an increase in both arable and pastoral agriculture.

The data from Shaw Moss indicate an element of land use continuity between the late Iron Age and Roman periods as the mixed farming economy gradually expanded until c. cal. 250 AD. This was followed by a phase of woodland regeneration which appears to have begun before the Roman withdrawal, although in this case it may be due to the political instability of the 3rd century AD in the northwest of England and the remote location of Shaw Moss. The palaeoenvironmental records from all of these profiles would therefore suggest some caution with regard to generalised conclusions for the continuation of settled farming after Roman withdrawal, such as that of Bell (1989 p286), who states "The environmental evidence ...... suggests a significant element of continuity in landscape exploitation from Roman into post-Roman Britain".

The palynological record from Talkin Tarn also appears to differ from other land use histories in the frontier zone of northern England. For example Dark (1996 p39) argues "One of the most notable patterns to emerge from these data is the evidence for a major reduction of agricultural activity and widespread woodland regeneration in the north of England, in the vicinity of the Hadrianic frontier. All sites in this area show evidence for abandonment of agricultural land and woodland regeneration ..... this pattern may reflect collapse of agricultural systems which had previously supplied the Roman forces based on, and around, Hadrian's Wall. This contrasts strongly with previous arguments for an initial period of continuity in this area". Yet at Talkin Tarn, an episode of subdued agricultural activity based on mainly pastoral farming appears to have begun in c. cal. 150 BC and continued through the period of Roman invasion and early occupation until c. cal. 300 AD when there is a phase of increased human activity which continues to c. cal. 950 AD. Thus there would appear to be no evidence for regeneration during the time of the Roman withdrawal, indeed this date appears to mark changes in local cultivation practices as *Secale cereale* and *Cannabis* are recorded for the first time in the profile. However, the problems involved in dating this profile and the relatively low pollen analytical resolution achieved due to the slow sedimentation rate means that it is difficult to precisely correlate this palynological record with historical events. Furthermore, the high quantities of arboreal pollen throughout this profile, coupled with a low level of local farming activity, could possibly make a woodland regeneration episode difficult to identify.

Thus the hypothesis set out in Chapter 1, that the Roman invasion of Britain in the 1st century AD resulted in considerable landscape change in the local area, would appear to be upheld for the area surrounding Tregaron, but not so obvious for the regions around Shaw Moss and Talkin Tarn. This of course is dependent on the location of the sampling site in relation to local Roman activity and the remoteness of Shaw Moss may explain the lack of significant impact, although the results from Talkin Tarn are surprising. Furthermore, the issue of continuity of landscape exploitation from the period of Roman withdrawal to the immediate post-Roman era would appear to remain somewhat contentious and dependent on local histories.

7.7 Comparison of regional monastic impact

This section considers the theme of "continuity and change" (Bell and Dark, 1998) with respect to the establishment of the monasteries in the 12th century AD and their Dissolution in the 16th century AD. Again consideration is given to trends in agricultural expansion and recession and the type of farming practised. This discussion involves those profiles that cover the period prior to monastic influence and the establishment of the monasteries in some detail, such as AKM'99, TRE'98 and TRWA 2000; and those profiles which span the monastic period and the subsequent Dissolution in detail, such as AKM'99 and GOR1.

The establishment of the Cistercian monastery of Strata Florida in 1164 AD near Tregaron resulted in significant change to the local landscape, which is evident from both the pollen profiles TRE'98 and TRWA 2000 as well as from the rapid peak in geochemical concentrations at the Southeast Bog. There was a large increase in local land use exploitation, with the expansion of both arable and pastoral farming, although the emphasis appears to have remained on pastoralism. Turner (1964b), Moore (1968) and Moore and Chater (1969) also recorded an increase in activity around this time which was attributed to monastic influences through the establishment of Strata Florida Abbey. Similar clearance phases with an associated increase in farming activities as a result of the establishment of a local Cistercian Abbey have been recorded by Oldfield (1963; 1969), Wimble *et al.* (2000), Birks (1965), Tinsley (1976), Butler (1984) and Dumayne-Peaty (1998c) (see Chapter 2). Alternatively, the records from Walton Moss and Bolton Fell Moss (Dumayne, 1992; Dumayne-Peaty and Barber, 1998) record a small amount of pastoral activity and extensive woodland regeneration during the monastic period despite the proximity of Holm Cultram and Lanercost Priory. Barber (1981) attributed this to the war, pestilence and famine that was particularly severe during the 14th century AD, as well as Border raids by the Scots and the Black Death in 1348-50 AD.

Landscape change is also registered from the AKM'99 profile as the result of the establishment of the Cistercian Abbey of Abbeyknockmoy in 1190 AD, although changes in land use and agricultural activity would appear to be more gradual here, with again more emphasis on pastoral farming. With respect to Ireland, Mitchell (1965) and Jelicic and O'Connell (1992) also recorded an increase in farming activities which they attributed to the influence of the Cistercian Abbeys at Kilcooly and Corcomroe respectively.

In terms of landscape change and continuity with reference to the Dissolution of the monasteries, AKM'99 demonstrates a very rapid and significant increase in landscape exploitation in the c. cal. 16th century AD with continued emphasis on pastoral farming but increasing arable activity. Similarly, Oldfield (1963; 1969) and Wimble *et al.* (2000) identify a phase of increased farming activity after the Dissolution of the monasteries as a result of the rise of the yeoman farmers. There is also an element of land use continuity at Lake Gormire around the period of the Dissolution, with pastoral activities increasing gradually although arable frequencies do enter a period of decline in the c. cal. 16th century AD.

Therefore the results of the pollen analytical and geochemical investigations discussed here would largely support the hypothesis that the establishment of Cistercian monasteries in the 12th century AD began a major phase of land use and landscape change in the local area. The Dissolution of the monasteries appears to have limited effect at Lake Gormire, while at Abbeyknockmoy it would seem to be followed by a rapid increase in activity.

7.8 Comparison of the pollen analytical and geochemical records

In general, there would appear to be a very close correlation between the pollen analytical and geochemical records for identifying periods of increased human activity. Hölzer and Hölzer (1998) found a particularly good relationship between Si and Ti concentrations and the records of Cereal and *Plantago lanceolata* pollen. A similar relationship appears to be evident from the Abbeyknockmoy profile, although at Tregaron Southeast Bog the Poaceae curve also seems to correlate well with the geochemical record. The relationship between Cereals, Poaceae, *Plantago lanceolata* and Si and Ti concentrations at Shaw Moss appears to be slightly more complex. The records correlate well until zone SAW2 3 when the geochemical proxies register increasing concentrations while the pollen indicators of human impact, including Poaceae, *Plantago lanceolata* and Cereals remain relatively stable. In this instance, the pollen evidence alone could give a misleading impression of the level of human activity and this highlights the importance of using a multi-proxy approach to land use history reconstructions.

Another notable feature of the geochemical curves is the apparent inverse relationship between Si and Ti concentrations and reforestation in the c. last two centuries. Due to a lack of available sample material in the upper sections of the profiles from Tregaron

Southeast Bog and Shaw Moss, this unfortunately could not be investigated in more detail at these sites. However, there does appear to be a trend of declining geochemical input with the recent regeneration or planting of woodland. This may either be the result of reforestation creating a reduction in the amount of soil erosion or the trees acting as a filter to aerial inputs of mineral particles to the mire surface, or perhaps a combination of the two.

A further interesting feature of the geochemical profiles is that the sequence from Abbeyknockmoy records the lowest concentrations of both Si and Ti. One possible explanation for this may be that the higher levels of rainfall here make it difficult for the aerial transfer of dust particles released through soil erosion, resulting in reduced windblown deposition on the bog surface. Alternatively, the type of agricultural activity itself may affect Si and Ti concentrations. For example, a record with lower concentrations of Si and Ti may reflect an area that is dominated by pastoral rather than arable farming.

There have been questions raised concerning the sensitivity of pollen analysis to short-lived or rapid phases of land use change (c.f. Astill, 1998) and in some cases it is difficult to recognise brief periods of human activity from palynological profiles with any certainty. The ability of the geochemical proxies to supplement pollen data by indicating whether very low frequencies of indicator taxa in a pollen profile are "real" disturbance events or just "background noise" make this technique a powerful tool (c.f. Hölzer and Hölzer, 1998). Furthermore, the Si and Ti records may augment pollen analytical profiles by providing more information on the intensity and rate of change during an episode of increased activity, which is not always detectable from palynological evidence alone due to the production, dispersal and deposition characteristics of some important indicator species (see Chapter 3). Thus a multi-proxy approach that combines palynological data with geochemical evidence is an important technique for land use reconstructions.

7.9 Comparison of the two proxies for human impact with documentary evidence

In general, the pollen analytical and geochemical results appear to correlate well with the documentary record for periods of major land use change and human activity (c.f. Astill, 1998). However, a few difficulties were experienced. First, the very detailed nature of some of the historical documents could not be replicated by the palynological data. For example, agricultural inventories listing individual fields with their cultivated root crops could not be identified from the fossil pollen spectra since "the pollen of many groups of plants, such as legumes, cannot be separated into cultivated and 'wild' types" (Dark, 1996 p25). Similarly, with the exception of *Secale cereale*, individual cereal crops could not be recognised due to the difficulties associated with cereal pollen grain identification (see Chapter 3). Furthermore, the very low quantities of pollen produced by such cultivated plants (c.f. Hall, 1989) means that their absence from the fossil pollen spectra does not automatically indicate that they were not being grown in the local area. Thus the establishment of broad ecological groups for each land use type was sufficient to give an indication of the changing level and importance of pastoral farming or mixed agriculture including cereal cultivation (c.f. Edwards, 1988) and allowed comparison with the more generalised historical trends.

Another problem experienced in this research involving the comparison of palaeoenvironmental data with the historical record were the age-ranges associated with the calibrated radiocarbon dates (c.f. Dumayne *et al.*, 1995). Radiocarbon dates need to be calibrated to allow correlation with historical timescales, yet the oscillations in the calibration curve result in age estimates which may span several hundred years and give rise to the effects of "suck-in" and "smear" (Baillie, 1991) when trying to date a particular palynological event (see Chapters 3 and 4). In order to minimise these effects as much as possible, several of the recommendations set out by Dumayne *et al.* (1995) were followed. These included AMS dates rather than bulk dates and searching for tephra horizons. Unfortunately the patchiness of tephra fall-out and hence deposition (e.g. Dugmore, 1989) meant that only one profile contained quantities of tephra suitable for geochemical typing (see Chapter 4). A series of wiggle matched dates were considered for the Tregaron Southeast record but could not be justified for this project in light of the disturbance to the profile and the high costs involved.

Thirdly, the "swamping" of some profiles by extra-local pollen, such as at Tregaron West Bog and Talkin Tarn, made comparison between the palynological sequences and documentary evidence more difficult because it tended to obscure the relatively low frequencies of indicator pollen and hence the record of human activity (c.f. Hicks, 1985; Rosen and Dumayne-Peaty, 2001). In addition, profiles that were subject to low accumulation rates, such as Talkin Tarn, resulted in lower resolution pollen diagrams, despite sampling intervals of up to 2 cm, which again made comparison to individual historical events more difficult.

Chapter 8 – Conclusions

8.1 Conclusions

- Using a multi-proxy approach that combines the pollen analytical evidence with the geochemical record greatly enhances reconstructions of past human activity and land use change. By supplementing the palynological data with Si and Ti records, more information can be gained about the intensity of human impact. Furthermore, some assessment can be made as to whether the occurrence of very low frequencies of indicator taxa on a pollen diagram are reflecting "background noise" or are indeed registering short-lived or small-scale disturbance events. Thus a multi-proxy approach reduces some of the uncertainties involved in data interpretation.

- The three profiles analysed for Si and Ti concentrations in this research demonstrate a very good correlation with their corresponding palynological records. This suggests that geochemical profiles can be used to test the sensitivity of the pollen record.

- From these three profiles, it is suggested that there is an inverse relationship between recent afforestation and geochemical deposition.

- The division of the relevant pollen indicator species into basic ecological groups allowed significant trends in land use change to emerge and facilitated comparison with the documentary record.

- Both the pollen and geochemical records demonstrate a close correlation with the documentary evidence for land use change.

- The presence of an historic tephra at Abbeyknockmoy Bog allows direct comparison between the palaeoenvironmental and historical records and also serves to constrain the radiocarbon chronology from this site.

- The palaeoenvironmental evidence from Abbeyknockmoy Bog suggests that the Iron Age "lull" in human activity is not synchronous across the whole of Ireland.

- The pollen analytical and geochemical evidence from Tregaron Southeast Bog and Shaw Moss indicate some farming activity in the mid- to late Iron Age prior to Roman invasion, whilst more subdued agricultural activity is also recorded from the Talkin Tarn (TAL2) profile for this period. An expansion in agricultural activity is recorded from the Tregaron Southeast Bog profile throughout the period of Roman occupation, while farming continued at Talkin Tarn until c. cal. 250 AD. This evidence from Tregaron is particularly significant since Bell (1989 p276) noted that "central Wales is .... of special interest because the Romano-British period seems to have made so little impact on native economy and settlement".

- The period immediately after Roman withdrawal around c. 400 AD is characterised by a phase of woodland regeneration and declining agricultural activity at Tregaron Southeast and West Bogs, which contrasts with the evidence of Turner (1964b) that pastoral farming continued until the 12th century AD and the conclusion of Bell (1989 p286) that there is a "significant element of continuity in landscape exploitation from Roman into post-Roman Britain".

- The evidence from Talkin Tarn (TAL2) contrasts with the view that the Hadrian's Wall frontier zone of northern England was characterised by woodland regeneration and land abandonment immediately after the Roman withdrawal (e.g. Dark, 1996), with this profile recording an increase in agricultural activity between c. cal. 300 - 950 AD. Better dating control is needed to investigate this apparent difference in land use histories in more detail (see Section 8.2).

- The pollen analytical and, where applicable, geochemical evidence from Abbeyknockmoy and Tregaron Southeast and West Bogs indicates that the establishment of local Cistercian monasteries in the 12th century AD had a significant impact on the local landscape. Furthermore, the evidence from Abbeyknockmoy and Lake Gormire suggest that the Dissolution of the monasteries in the 16th century AD did not result in widespread land abandonment and woodland regeneration.

- The use of environmental magnetism to reconstruct a history of charcoal deposition from the catchment of Lake Gormire proved inconclusive.

- Finally, the results presented here demonstrate the difficulties involved in trying to investigate and reconstruct the more recent human impact on the environment, not least because of the large number of peat and lake deposits that have been disturbed in some way.

8.2 Future research

- The resolution of the current Ti profiles needs to be increased to 1 cm intervals in order to allow direct comparison with the existing Si records. Furthermore, it would be beneficial to undertake geochemical analyses at both lake sites so that these records can be correlated to the existing palynological profiles.

- In order to constrain the chronologies from the lake sites, it would be useful to look for tephra horizons at both Lake Gormire and Talkin Tarn. At Lake Gormire, the unsuitability of the sediments for radiocarbon analysis means that a tephra layer could provide a date for the lower sections of the profile that are outside the range of ^{210}Pb dating. With respect to Talkin Tarn, the prehistoric tephra of Glen Garry (c. 2100 BP) has been found at other sites in northern England (e.g. Fleet Moss and Harthope Moss, Pilcher and Hall, 1996; Walton Moss, Langdon, pers. comm.) and if found at this site could constrain the radiocarbon chronology, which would be especially useful in view of the reversed dates already obtained from this profile.

- In view of the results obtained here, more work needs to be undertaken on the question of land use "continuity and change" after the withdrawal of the Romans in c. 400 AD. Such investigations require well-dated, high-resolution pollen analytical sequences, supplemented if possible by geochemical profiles and comparison with the archaeological record.

- Similarly, more radiocarbon dated, high resolution pollen and geochemical investigations need to be undertaken in Ireland in order to assess the assumption of a synchronous Iron Age "lull" in human activity. It would be useful to radiocarbon date those existing profiles that lack any form of independent chronological control.

- More work is needed on the geochemical typing of historic tephra horizons in order to match the unknown tephra from Abbeyknockmoy Bog.

- In order to answer the specific question of whether the establishment of the fort and *vicus* at Llanio did occur at the same time as the increase in farming activity recorded by the palynological and geochemical profiles from the Southeast Bog at Tregaron, a programme of high precision wiggle match dating is required.

- It would be very interesting to incorporate these results into existing computer models that currently use simulated data to try and delimit pollen source areas (e.g. Sugita, 1994), detect humanly induced landscape disturbances (e.g. Sugita, 1998) and attempt to quantify the relative "openness" of landscapes from modern and fossil pollen spectra (e.g. Sugita *et al.*, 1999).

- Having demonstrated the ability of the geochemical signal to respond to what look like very minor disturbances in the palynological record, it would be interesting to apply this multi-proxy approach to vegetation histories in the Neolithic and even Mesolithic periods, where human impact is often represented by very subtle changes in fossil pollen assemblages. In terms of the Mesolithic, this could be very useful for sites that do not have distinct fire histories. Additionally, the geochemical signal could be used to investigate areas where there is an apparent mis-match between the palynological and archaeological records for the occupation of prehistoric sites.

The research presented here demonstrates the potential of combining the palynological and geochemical records to produce a multi-proxy approach for the reconstruction of land use change and past human activity. This is thought to be one of the first applications of this technique in Britain and Ireland and in light of the extremely encouraging results, it is hoped that more researchers will adopt this strategy when investigating anthropogenic impact on the landscape.

Appendix 1: Abbeyknockmoy Bog, Co. Galway, Ireland
Palynological record from profile AKM'99

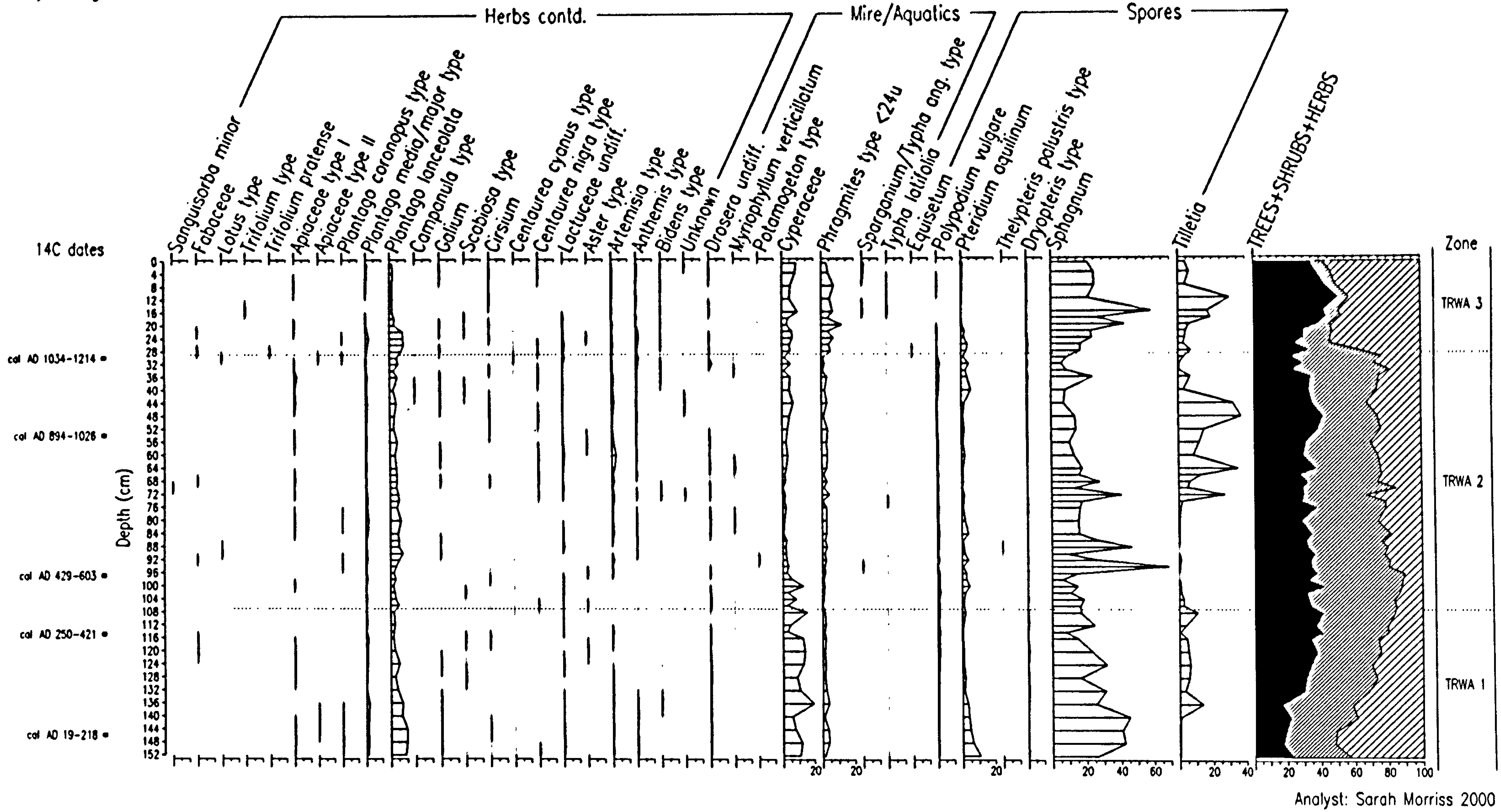
Appendix 1: Abbeyknockmoy Bog, Co. Galway, Ireland
Palynological record from profile AKM'99

Appendix 2: Tregaron Southeast Bog, Ceredigion, Wales
Palynological record from profile TRE'98

Appendix 2: Tregaron Southeast Bog, Ceredigion, Wales
Palynological record from profile TRE'98

Appendix 3: Tregaron West Bog, Ceredigion, Wales
Palynological record from profile TRWA 2000

Appendix 3: Tregaron West Bog, Ceredigion, Wales
Polynological record from profile TRWA 2000



Appendix 4: Shaw Moss, Cumbria, England
Palynological record from profile SAW2

Appendix 4: Shaw Moss, Cumbria, England
Palynological record from profile SAW2

Appendix 5: Lake Gormire, Yorkshire, England
Palynological record from GOR1

Appendix 5: Lake Gormire, Yorkshire, England
Palynological record from GOR1

Appendix 6: Talkin Tarn, Cumbria, England
Palynological record from profile TAL 1

Appendix 6: Talkin Tarn, Cumbria, England
Palynological record from profile TAL 1

Appendix 7: Talkin Tarn, Cumbria, England
Palynological record from profile TAL 2

Appendix 7: Talkin Tarn, Cumbria, England
Palynological record from profile TAL 2

Analyst: Sarah Morriss 2000

Appendix 8 Marginal cutting at Tregaron Southeast Bog

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