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Postglacial vegetational dynamics in Lowland North Wales.

Watkins, Ruth

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POSTGLACIAL VEGETATIONAL DYNAMICS IN LOWLAND NORTH WALES

RUTH WATKINS

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School of Ocean Sciences
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Menai Bridge
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ABSTRACT

This study elucidates the Postglacial vegetational history of lowland lake sites in Gwynedd using detailed palynological work integrated with radiocarbon dating, loss-on-ignition, chemical, charcoal, and X-ray diffraction analyses.

An early Postglacial phase of *Juniperus*-*Betula* scrub was succeeded by open *Betula*-*Corylus* woodland at Llyn Cororion, a kettlehole site on the Arfon Platform (SH597688). *Quercus* and *Ulmus* were established by 8600 BP and *Pinus* dominated locally at 8425 BP. A subsequent water level rise and fire disturbance encouraged the spread of *Alnus*. *Tilia* was established by 5650 BP. Progressive deforestation began in the Late Bronze Age with increased fire use and spread of grassland; cereals are first recorded at 2900 BP. There is evidence that Llyn Cororion was used for *Cannabis* retting during Mediaeval times.

Postglacial vegetation at Llyn Hendref (SH398765), an exposed lake basin on Anglesey, was dominated by *Corylus* and *Alnus*; mixed, open oak woodland occurred away from the lake basin but *Tilia* and *Pinus* were never abundant. In the late Postglacial there was increased fire disturbance resulting in effective soil erosion and acceleration of mire development. Mire encroachment increased around 8700 BP resulting in lake shallowing and increased sediment erosion and redistribution.

Site comparison with published work (Melynllyn and Nant Ffrancon) shows that there were variations in vegetational development within North Wales. Radiocarbon dating shows that similar vegetational events were time transgressive determined by migration rates, soil conditions, competition, hydrology and altitude.

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Thanks to Steven for his patience and love during sad times in the last two years. May the end of this thesis be the beginning of new adventures for us both.

TO DAVID

(1965-1989)

As the hand held before the eye conceals the greatest mountain, so the little earthly life hides from the glance the enormous lights and mysteries of which the world is full, and he who can draw it away from before his eyes, as one draws away a hand, beholds the great shining of the inner worlds.

Rabbi Nachmann of Bratzlav

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CHAPTER 1

AIMS AND OBJECTIVES

STUDY AREA DESCRIPTION

Chapter 1 sets out the aims and objectives of the project and defines the terminology and conventions. The study area is introduced and previous palynological work in North Wales is briefly discussed.

1.1 AIMS AND OBJECTIVES

1) To elucidate the Postglacial palaeoecology, vegetational history and sedimentological history of lowland (<100m OD.) lake sites in Gwynedd; to study influences on the variability of vegetational succession at low altitudes and on a local scale; to use pollen accumulation rate and concentration diagrams to supplement frequency data in order to study the impact of new incoming tree species on established taxa.
2) To present environmental data for archaeology and to assess the impact of early man on the lowland landscape.
3) To produce pollen diagrams with high biostratigraphic and temporal resolution for comparison with published data from upland sites, thus allowing the temporal and spatial variations in Postglacial vegetational development over a small geographic area to be examined; to study the effect of altitude on the distribution of tree taxa within North Wales during the Postglacial, and enable more accurate correlation for undated diagrams in the area.
4) To provide detailed palynological data for lowland North Wales within a well defined chronological framework.

1.2 TERMINOLOGY & CONVENTIONS

All ages are expressed in uncorrected radiocarbon years before present (yrs. BP), with present taken as AD. 1950.

The climatological scheme of Lowe and Gray (1980) is adopted, (table 1.1) as being simple to use and flexible, it allows for the time transgressive nature of vegetational change and the uncertainties associated with radiocarbon dating (Ince, 1981).

Table 1.1 The chronostratigraphic units used in this study, (after Lowe and Gray, 1980)

Radiocarbon Yrs. BP	Chronostratigraphic Unit
	Flandrian/Holocene/Postglacial
10 000	
	Transition
10 500	
	Younger Dryas/Loch Lomond Stadial
11 000	
	Transition
12 000	
	Lateglacial Interstadial
13 000	
	Transition
14 000	
	Late Devensian

The following definitions have been used, (after Lowe and Gray, 1980):

Lateglacial: The body of rock (sediment) formed between the start of the Lateglacial Interstadial and the end of the Younger Dryas Stadial.

Lateglacial Interstadial: The body of rock (sediment) strata formed between the marked thermal improvement that occurred between about 14,000 and 13,000 BP and the thermal decline that took place between 12,000 and 11,000 BP.

Younger Dryas Stadial/Loch Lomond Stadial: The body of rock (sediment) strata formed between the thermal decline that took place between about 12,000 and 11,000 BP and the marked thermal improvement that took place between about 10,500 and 10,000 BP.

Flandrian (Holocene, Postglacial): This is taken as starting at 10,000 years BP (Mitchell et al., 1973).

Definitions related to pollen concentrations and accumulation rates are defined in section 3.4.

'Rational' limit and 'Empirical' limit have been defined after Smith and Pilcher (1973).
Empirical Limit: The point at which pollen of the taxon first becomes consistently present in consecutive samples.
Rational Limit: The point at which the curve begins to rise to high values.

Vascular plant nomenclature follows Clapham, Tutin and Moore (1987).

1.3 STUDY AREA

Work for this study took place in North Wales with particular emphasis on lowland Gwynedd (Anglesey and Arfon) and with reference to the Nant Ffrancon valley and Melynllyn tarn, (fig. 1.1). The area has diverse topography, geology, climate and soils, the main aspects of which are reviewed here. The locations of sites discussed are shown in figure 1.2. Detailed site descriptions are given in sections 2.3 and 2.4.

1.3.1 RELIEF

North Wales is dominated by the Snowdonia mountains which comprise three main areas, Snowdon, the Glyders and the Carneddau. These massifs are separated by two major NW-SE trending valleys, (fig. 1.1) Nant Ffrancon and Nant Peris, which were over-deepened by Late Devensian ice (Whittow and Ball, 1970), and are now occupied by lakes (Llyn Padarn and Llyn Peris) or infilled with Devensian Lateglacial and Flandrian sediments (Nant Ffrancon). The north-eastern facing mountain slopes contain glacial cwms defined by rock basins, and often containing lakes dammed by the remains of Loch Lomond Stadial moraines (Unwin, 1975; Gray, 1982). Summits have accumulations of in-situ frost-shattered debris, and on steep south-westerly slopes, gravitational scree deposits have

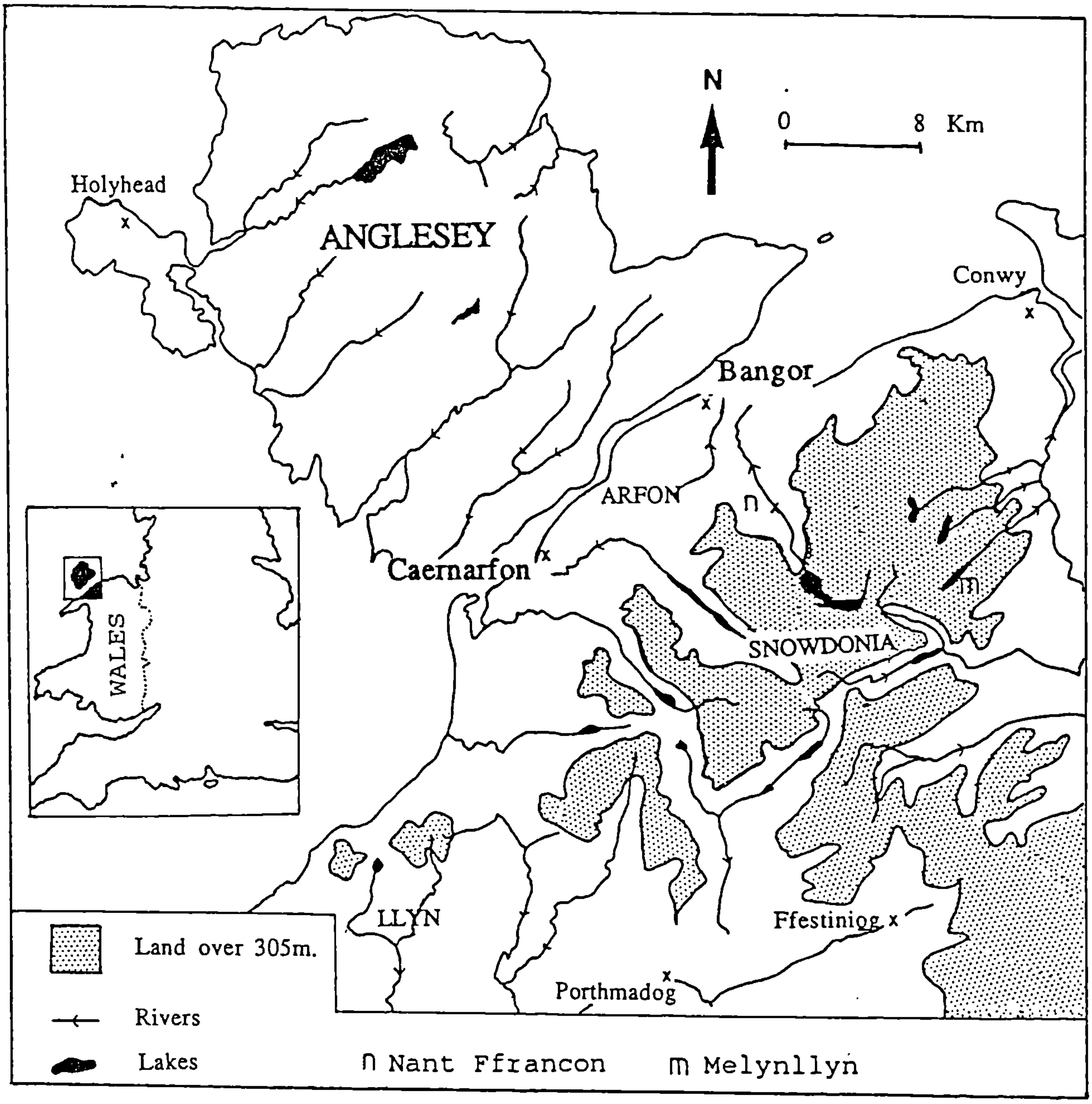


Figure 1.1 Study Area (modified from **Addison *et al*,.1990**)

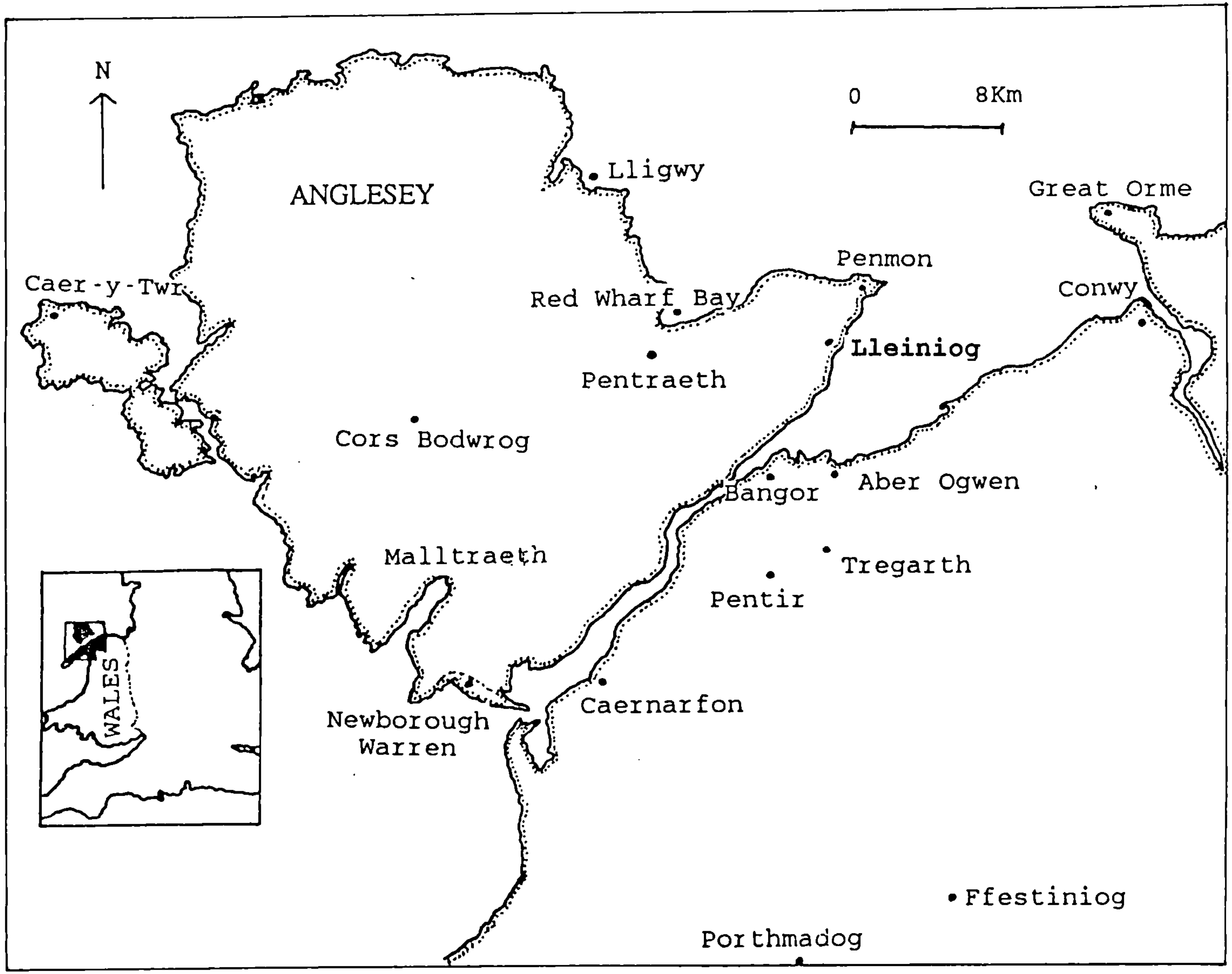


Figure 1.2 Location of sites discussed in Chapter 1

accumulated (Sissons, 1979).

To the north and west of Snowdonia, between Bangor and Caernarfon, the Arfon Platform forms a low-lying undulating plateau which abruptly terminates along a fault defined break of slope. The majority of this area has an elevation of 0-100m and is 5-6Km in width. A few isolated hills and ridges rise up to 200m. The plateau stretches west along the Llŷn Peninsula and eastwards towards the undulating hills of the Vale of Conwy. In upland areas, topography is strongly related to geological structure, but along the coast, surface features are disconcordant with the platform cross-cutting stratigraphy and structure. Drainage is dominated by the Afon Seiont and the Afon Ogwen which cut across the platform, with a series of tributaries flowing NE-SW parallel to the mountain front.

Anglesey is separated from the mainland by the Menai Strait, a depression submerged during the Postglacial sea level rise (Embleton, 1964a) which now forms a double tidal channel striking ENE-WSW. Anglesey is of low relief, except for several fault controlled, parallel valleys running NE-SW (eg. Malltraeth Marsh, fig. 1.2) and a few isolated hills in the north-west (eg. Holyhead Mountain, 220 m). Drainage is controlled by faults but is generally poor with large areas of marshy ground (eg. Cors Bodwrog; fig. 1.2).

1.3.2 CLIMATE

The climate of North Wales is maritime, with warm winters and cooler summers than southern Britain or inland areas (Ball, 1963), but superimposed on this are strong variations resulting from the considerable relief of the area. Ratcliffe (1959) concluded that in the Carneddau, climatic variation was related to altitude 'more than any other single factor'. Anglesey and lowlying Arfon have a similar cool temperate climate characteristic of coastal areas, but climatic gradients rise with increasing altitude southwards towards Snowdonia.

At higher altitudes there is increased precipitation and a corresponding temperature decrease (Rudeforth et al., 1984). Snowdonia is one of the wettest parts of the British Isles, a result of Atlantic frontal systems advancing eastwards and rising over the mountains. Both orographical and convectional rainfall occurs, with the rainfall gradient decreasing eastwards towards the Carneddau, (Ratcliffe, 1959). On average there are 200 days of rain per year, (Bilham, 1937) with Snowdonia receiving >2500 mm/yr and Anglesey and Arfon receiving <1000 mm/yr (Pedgley, 1970).

With altitude, there is also a rapid increase in frost occurrence, and in the frequency, amount, and duration of snowfall and snowcover (Manley, 1971). In Anglesey and Arfon, snowfall generally occurs in January and February but seldom settles for longer than a day. In Snowdonia at 1000m there is an annual average of 108 days of snowcover (Manley, 1971) with the majority of snow falling between October and February, (Ratcliffe, 1959). The first frosts on Anglesey (December 1st) are later than those on Arfon (November 15th) and the last frosts are earlier (April 1st cf. May 1st). Above 450m, where the average monthly relative humidity is always greater than 75%, mist and fog are common, especially in the winter (Ratcliffe, 1959).

The area is predominantly affected by moist south-westerly and westerly winds (Fairbairn, 1968). On Anglesey there are on average 10-20 days of gale force winds per year compared with 5-10 days for Arfon and the highest frequency of gales are on the west coast (Manley, 1952); wind exposure on Anglesey and mountain tops is a major influence on vegetation (Ratcliffe, 1959). Arfon is relatively sheltered except on ridges which are open to prevailing winds (Ball, 1963).

The temperature on the lowlands is modified by the influence of the sea, resulting in an average January temperature of 4°C (Manley, 1971). A generally accepted lapse rate for increasing altitude is approximately 0.5°/100m (Fairbairn, 1968) which is also accompanied by greater diurnal temperature ranges

(Edgell, 1969). Temperature is influenced by aspect, insolation, degree of shelter, and exposure, (Manley, 1971). Temperatures are reduced on shaded NW and NE slopes, especially in the winter, and there are slightly lower summer temperatures and higher winter temperatures in the west compared with the east (Ball, 1963). Anglesey receives an average of 7.5 hours of bright sunshine in July, compared with Arfon which receives 6-6.5 hours. On average there are a total of 1450 hours sunshine per year on the coast compared with 1300 hours in the mountains (Bilham, 1937).

The climate of the area is therefore oceanic but local conditions are highly variable. Reduced temperatures, increased frosts, wind exposure, rainfall, cloud cover, humidity and decreased sunshine and evaporation occur at higher altitudes (Harrison, 1974). The climate in the mountains is such that a rich Arctic-Alpine flora has survived since glacial times (Ratcliffe, 1959).

1.3.3 GEOLOGY

North Wales is characterised by Lower Palaeozoic rocks containing numerous unconformities and there is a noticeable absence of Mesozoic and Tertiary deposits. Throughout geological history, intense deformation has resulted from periodic and uplift, metamorphism, faulting and folding and subsequent erosion. Block and basin tectonics have controlled sedimentation from the pre-Cambrian to the Cenozoic. During the Quaternary the landscape was modified by periglacial and glacial action.

Early geological work was undertaken by Greenly (1919) and the British Geological Survey mapped the region in 1961 (Smith and George, 1961). Detailed geological maps and interpretations have been undertaken by Ball (1963), Wood (1974), Bates (1972, 1974), Howells et al., (1981) and Gibbons (1983). Figure 1.3 is a simplified geological map of the area and a general description of the geological formations is given here; more specific details are noted under site descriptions (sections

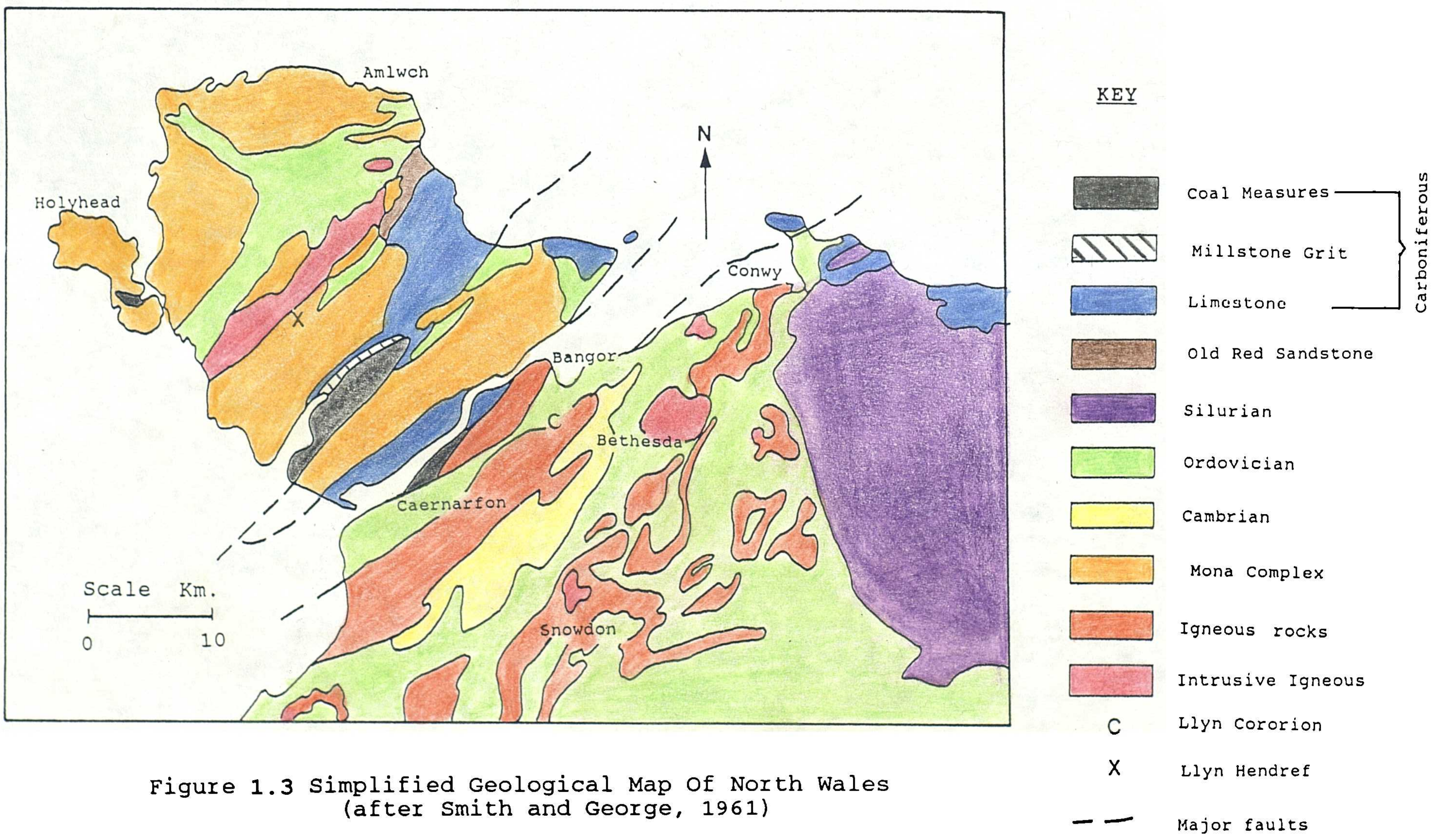


Figure 1.3 Simplified Geological Map Of North Wales
(after Smith and George, 1961)

2.3.1 and 2.4.1).

Pre-Cambrian

The oldest rocks on Anglesey are Pre-Cambrian and include the highly deformed and metamorphosed sediments of the Mona Complex (Greenly, 1919), which are sub-divided into three major groups; gneisses, a plutonic series and a bedded series, (Smith and George, 1961). They consist of a series of grits, shales, muds, conglomerates and volcanics which have undergone at least two phases of folding and metamorphism, with maximum deformation occurring along the Penmynydd Schist zone. Intrusive rocks associated with the sequence include the Coedana Granite with an associated hornfels aureole which has been dated at 615-633 My. (Moorbath and Shackleton, 1966).

The oldest rocks on the mainland are the Arfon group, of either pre-Cambrian (Greenly, 1945) or Cambrian (Challinor and Bates, 1973) age. These form two distinct ridges (from Bangor to Port Dinorwic and Bethesda to Llyn Padarn) consisting of a volcanic sequence, including rhyolites with occasional tuffs and agglomerates. Above is the Minfford Formation, a sequence of sandstones, basic igneous rocks, coarse acidic rocks and rhyolites.

Cambrian

Cambrian deposits on the mainland consist of the Bangor Formation (sandstones, conglomerates and interbedded tuffs and silts) and the Fachwen Formation (a lateral equivalent but consisting of interbedded ash flows, tuffs and silts). The Llanberis Slate Formation is a fine grained deep water mudstone and has been dated to the Late Lower Cambrian (Challinor and Bates, 1973). This is unconformably overlain by coarse basal conglomerates (the Bronllwyd Grit Formation), above which are cross bedded grey-green sandstones with minor mudstone partings. The Cambrian sequence has been interpreted as representing deposition in a subsiding basin in a convergent plate setting (Anderton et al., 1979).

Ordovician

Ordovician rocks outcrop between the two Cambrian ridges and are a predominantly sedimentary sequence (the Nant Ffrancon Formation) of non-calcareous grits, conglomerates, sandstones, shales and oolitic limestones. Ordovician deposits are extensive on Anglesey (Greenly, 1919), outcropping in a large tract across the island, (fig. 1.3). They consist of a basal conglomerate (derived from the underlying Mona Complex) gradually grading into deeper water shales.

Ordovician slates and volcanics dominate the Snowdonia area; the volcanics are essentially a sequence of ignimbrites, pyroclastics, rhyolites and dolerite sills which are interbedded with shales and slates. The whole sequence has been folded into a synclinorium, smaller folds of which can be seen in areas such as Cwm Idwal (Challinor and Bates, 1973).

Silurian and Devonian

There is no outcropping Silurian on the Arfon Platform but deposits have been mapped on Anglesey where they consist of an alternating series of shales and grits of Llandovery age. Sedimentation was intermittent throughout the Silurian and by the Ludlow stage the Welsh basin was in a state of uplift. Lower Palaeozoic earth movements culminated in the Caledonian Orogeny, a period of rapid uplift and erosion during the late Silurian and early Devonian. Devonian deposits are exposed in north-west Anglesey and Lligwy Bay (fig. 1.3), where they form a series of folded calcareous sandstones and siltstones.

Post-Devonian

During the Carboniferous, block-basin tectonics controlled sedimentation and a sequence of shallow sandstones and limestones were deposited deepening upwards into shales. Basal Carboniferous limestone outcrops along the southern shore of the Menai Strait (the Treborth and Menai Strait Formations) and periodic uplift produced karstic surfaces, now exposed in Red Wharf Bay (Anglesey). During the Permo-Trias, North Wales formed high ground and was a sediment source. There are no Mesozoic or Cenozoic rocks in this area but offshore evidence suggests that there may once have been an extensive cover of Lower Jurassic sediments (Hallam and Sellwood, 1976), which were eroded during uplift in the Upper Jurassic and Cretaceous.

Structure

The structure of North Wales is complex due to a large number of deformation events and continual reactivation along older faults. There was a long history of intermittent movement throughout the early Palaeozoic which radically affected patterns of early sedimentation and volcanism and produced a sequence of NE-SW (eg. Aber Dinlle fault) trending fault lines and associated folds (Bates, 1974). Regional metamorphism during the Caledonian was low grade with the development of greenschists. During the Variscan Orogeny there was strong compression on the southern margin of Wales, but a rapid northwards attenuation of deformation occurred (Owen, 1974), so that in North Wales there was only re-activation of pre-existing faults and some refolding.

A number of planation surfaces observed around North Wales (Embleton, 1964b) have been used as evidence for pulsed uplift during Cenozoic times but recent evidence has suggested that this interpretation for the pre-glacial evolution of Wales is no longer acceptable. Battiau-Queney (1984) states that the Welsh massif emerged in mid-Cretaceous times, resulting in a tectonic inversion relative to Anglesey, and since then has suffered 'a long sub-aerial evolution'. In the Neogene morphotectonic equilibrium, which until then had maintained the planation surfaces, was lost and vertical adjustment took place resulting in the present day topography.

1.3.4 QUATERNARY GEOLOGY

The Late Devensian was characterised by a change to a more oceanic climate, resulting in the expansion of ice sheets over substantial areas of the British Isles. The highlands of Scotland were the greatest area of precipitation, ice accumulation and glacier dispersal (Lowe and Walker, 1984) and a major ice sheet spread southwards. This coalesced with ice from the Southern Uplands and the Lake District before flowing down the Irish Sea, over-riding Anglesey and spreading over the Llŷn Peninsula into Cardigan Bay.

Contemporaneous with the development of the Scottish ice was the formation of a local ice cap over North Wales, perhaps reaching thicknesses of up to 1000m (Boulton, 1977). The ice accumulated in cwms, flowed down the main valleys (Llanfairfechan, Aber, Ogwen, Llanberis and Gwyrfai), and produced over-deepened valley profiles, before coalescing to form a continuous ice sheet on the lowlands. A complex and oscillating zone of confluence with the Irish Sea Ice occurred in the vicinity of the Menai Strait (Bowen, 1977).

North Wales was therefore dominated by ice from two sources, and Anglesey, the Llŷn Peninsula and the Arfon Platform are important localities lying within what was the boundary zone between the two ice masses (fig. 1.4b).

Ice Movement

The limits and direction of ice movement have been delimited using erratic trains, contrasting till lithologies, and heavy mineral and clay assemblages (Greenly, 1919; Saunders, 1968) but the nature of deposits in the Menai Strait area is complex due to interaction between the Welsh and Irish ice-sheets. Interpretation and correlation of Quaternary sequences have been hindered by the lack of inland exposure, limited offshore research, and the absence of absolute dates. Much discussion has centred on the number and extent of Late Devensian ice advances and the nature of the boundary between the ice

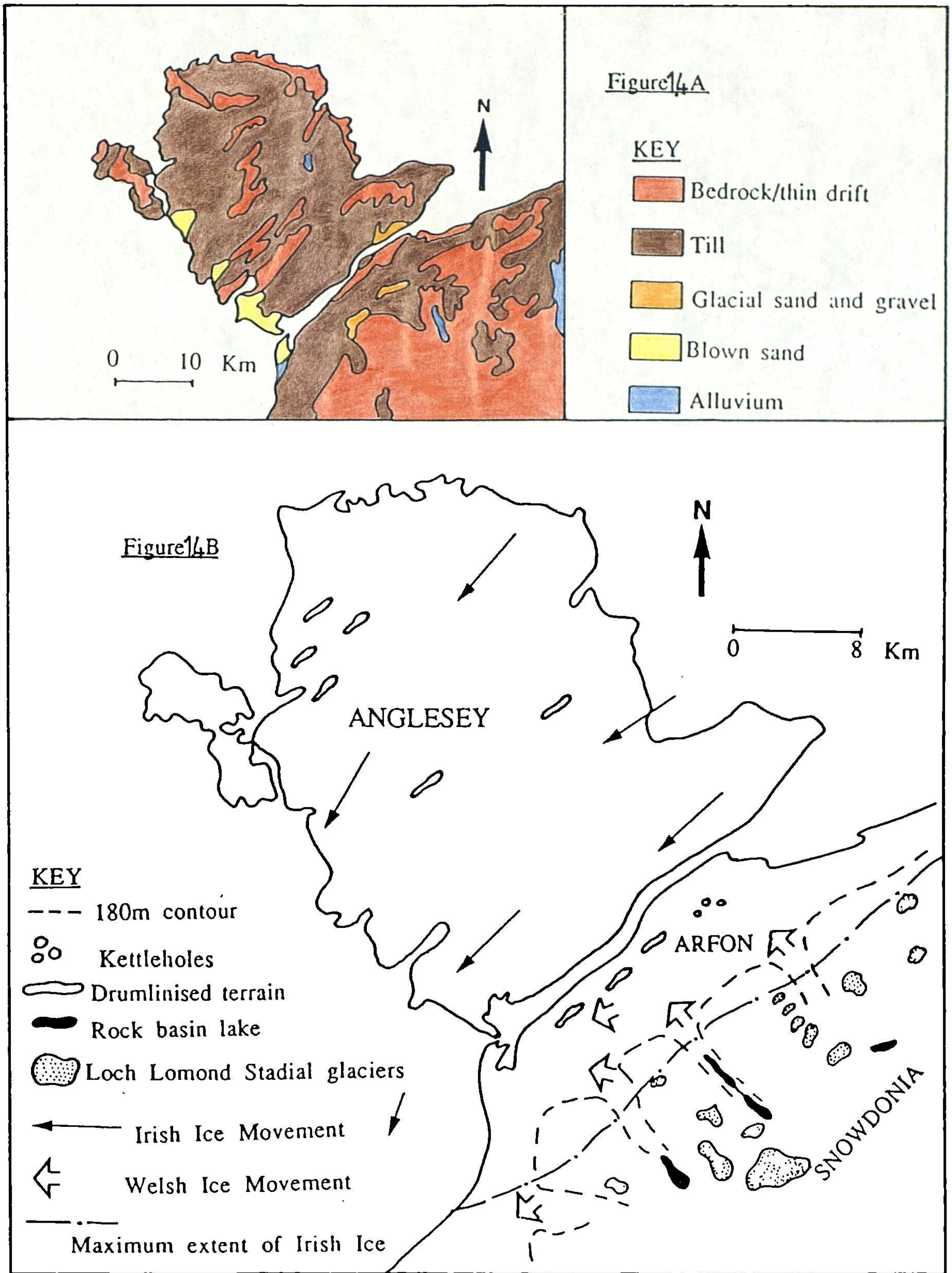


Figure 1.4 A General cover of Quaternary sediments in North Wales (after Addison, 1990)

Figure 1.4 B Late Devensian ice movement and landforms, and the extent of Loch Lomond Stadial glaciers sheets. Mitchell (1960, 1972), Synge (1964), Bowen (1973) and Whittow and Ball (1970) have all proposed ice limits for the North Wales area based on various lines of evidence (discussed in Bowen, 1977). Offshore ice limits for West Wales have been based on borehole and seismic data (Garrard and Dobson, 1974).

Quaternary deposits

Early mapping of Quaternary deposits was carried out by Jehu (1909) and Greenly (1919, 1942). Whittow and Ball (1970) reviewed the relevant literature. The most recent information for this area can be found in Addison, Edge and Watkins (1990), and the N.C.C. Geological Conservation Review (Campbell and Bowen, 1989).

Irish Sea till is characteristically red (due to derivation from Triassic marls) and clay mineralogy is dominated by chlorite, illite and kaolinite (Clark, 1982). It also has a high carbonate content and contains Galloway and Ailsa Craig granite, other erratics and marine shells. Welsh drift is typically grey (due to derivation from slate), contains locally derived clasts and the clay mineralogy contains little carbonate and no kaolinite (Younis, 1983).

Quaternary deposits (fig 1.4a) are well exposed around the coastline (eg. Aber Ogwen, Lleiniog, fig. 1.2) but inland exposure is limited. Complex sequences of interbedded sands, gravels and boulder clay led Whittow and Ball (1970) to recognise three advances during the Late Devensian. The first (Criccieth and Irish Sea Advance) produced deposits of shelly till at Moel Tryfan and mixed sediments on the Welsh lowlands. Ice wastage and periglacial activity followed, before the main advance (the Arfon and Anglesey Advance) in which Northern ice crossed Anglesey from the north-east and coalesced with ice flowing radially from Snowdonia (fig. 1.4b). This deposited till, described by Greenly (1919) as the 'Lower Boulder Clay'. Subsequent deglaciation produced extensive deposits of sands and gravels in the area.

A third and limited advance was then postulated, where ice impinged on the east coast of Anglesey and to the east of Bangor. However Synge (1970) states that there has only been one ice advance, a theory supported by Boulton (1977) who described detailed sections at Criccieth and explained the complex sequence in terms of one ice advance and wastage cycle.

Deglaciation

Embleton (1964a) mapped deglaciation features including meltwater channels (eg. Malltraeth Marsh, fig. 1.2) which extend up to 1 km offshore (Curry, 1982), and subglacial channels overdeepened by meltwater (eg. SW of Tregarth). Eskers, deposited by meltwaters flowing from stagnant ice in Red Wharf Bay have been identified in the Pentraeth area (Greenly, 1919; Embleton, 1964a), and esker and kame topography has been identified around Pentir.

Deglaciation of the area was complete around 14,500 BP with C^{14} dates suggesting that melting on the southern Llŷn Peninsula occurred between 14,468+/-300 BP (Simpkins, 1974) and 12 556+/-230 BP (Boulton, 1977). After a brief interstadial (14,500-11,000 BP) there was renewed ice activity (11,000 and 10,000 BP) with the formation of cwm glaciers in upland areas of Wales (fig. 1.4b). This cold period is called the Loch Lomond Stadial and coincides with the southward spread of polar waters (Lowe and Walker, 1984).

The Loch Lomond Stadial

The Loch Lomond Stadial in Snowdonia produced a number of 'Younger Series' moraines within cwms. These have been described by Godwin (1955), Seddon (1957), Gray (1982) and Unwin (1973, 1975). The distribution of end moraines, lateral moraines, hummocky topography and drift have been used to reconstruct the distribution, area and limits of cwm ice. A firn line which increased from SW (450m) to NE (710m) has been inferred by Gray (1982) and this, together with data on moraine heights, has been used to estimate precipitation rates (Gray, 1982). Temperature ranges are estimated to have been on average 7°C in the summer (reduced to sea level) and -17° to -20°C in January (Lowe and Walker, 1984).

Recent dates from Llyn Gwernan (Lowe, 1981) estimate the onset of minerogenic sedimentation (taken as the beginning of the Loch Lomond Stadial) as 11 160+/-90 BP with a return to organic sedimentation (end of the Loch Lomond Stadial) estimated at 10 040+/-80 BP. The change in lithology is thought to reflect a rapid rise in temperature coincident with the northward movement of the Polar Front. A temperature rise of around 7°C over 50 years is considered possible for the North Atlantic region (Dansgaard et al., 1989) with an associated increase in precipitation and decrease in storminess.

1.3.5 SOILS

In general early Postglacial soils were relatively unstable, having low accumulation rates of organic material and a high mineral content and base status. Initially soils were weakly developed and had little ability to hold water, often consisting of only a thin upper horizon overlying unaltered rock fragments (Pears, 1980). These thin soils persisted in the steep uplands, but in low-lying areas brown earths developed, with a mull humus associated with increased deciduous woodland. Local conditions controlled variations in acidity, colour, texture and profile development. Fen peats began to form in topographic hollows and raised bogs developed in poorly-drained localities. After 5000 BP soil retrogression resulted from progressive leaching and reduced nutrient content. Soil retrogression has been attributed to both natural causes (eg. climate change, Godwin, 1975; or 'inevitable pedogenic processes', Iversen, 1958), and also human activity (Moore, 1973). In upland areas, podzolization occurred with increasing acidity and waterlogging encouraging the spread of blanket peat.

North Wales is now dominated by acid brown soils and related gley soils in the lowlands, and blanket peat soils and peaty gleyed podzols at higher altitudes (Pears, 1980). The soils of the Arfon Platform and Anglesey have been mapped and described in detail by Roberts (1958) and Ball (1963), and details of the distribution and descriptions of soil types are recorded on map sheets 93 and 105. Figure 1.5 shows the general variations in soil type with topography.

The soils of Arfon are dominated by brown earth soils of low base status, and in isolated patches (eg. around Llyn Cororion) there are patches of gleying. The majority of soils are derived from outwash deposits overlying Ordovician sediments and as a result tend to be gravel-rich, with good drainage, and rapid leaching of soluble bases. The mull humus surface horizon is generally neutral or moderately acidic. Gleying occurs where drainage is imperfect, but usually sufficient air remains within the soil to allow root development (Ball, 1963). On higher ground and ridges (which tend to be Cambrian volcanics), the bedrock contributes directly to soil formation and the soils tend to be skeletal and interspersed with rocky outcrops, or gley soils develop due to inefficient drainage.

In the Nant Ffrancon valley the geology is more complex and a number of soil formations exist. On steep slopes and higher ground rock outcrops dominate and thin, immature soils and scree accumulations are widespread. As a result of the base-poor parent material and the high rainfall, podzolised soils are extensive although the process of podzolization is inhibited in areas of instability, or at sites enriched by flushing (Ratcliffe, 1959). Interspersed are peaty gley soils and organic soils which accumulate in topographic depressions.

On Anglesey the coincidence between ice movement and geological strike means that soil types are generally related to the underlying formation. Anglesey is essentially dominated by brown earths of the Arvon Series, except where organic soils have accumulated within depressions. On steep slopes and

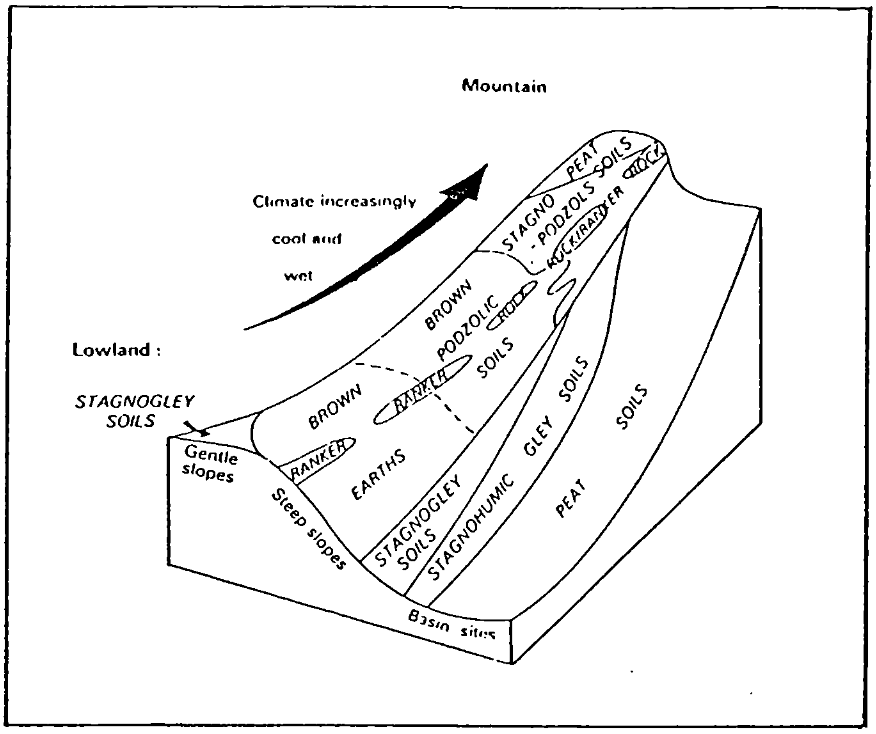


Figure 1·5 Relationship between soils, climate and relief in Wales (Rudeforth et al., 1984) isolated highs, the soils tend to be thin and immature. The parent material of the Arvon Series includes pre-Cambrian and Cambrian slates, acid igneous rocks and also softer Ordovician metasediments. The soils have an average pH. of 4-4.5, tend to be sandy and are well drained resulting in a low moisture content. They typically have a high humus content and a low base status, a reflection of the geology, except in the south-east of the island where limestone outcrops. Local gley soils occur in areas of impeded drainage and are often associated with major rivers.

1.3.6 VEGETATION

Generally the lowlands are dominated by agriculture and upland areas are composed of rough ground and rock outcrops. There are no extensive tracts of broad-leaved woodland. The history and exploitation of woodlands in North Wales have been reviewed by Linnard (1979) and a brief account of forestry is published in Ball (1963). Detailed vegetational surveys include Hughes (1949), and Ratcliffe (1959) surveyed the vegetation of the Carneddau massif, commenting on the relationship between soil moisture, soil base status and land management on present day vegetation. The detailed description of the upland vegetation of the Carneddau (Ratcliffe, 1959) is generally applicable to the Snowdonia range, although there will be variations due to the precipitation gradient (from west to east) and local factors (eg. slope, drainage). The ecology and historic ecology of four small oak woodlands in north-east Wales has been discussed by Edwards (1980) with emphasis on their disturbance histories and the distribution of Atlantic bryophytes.

By 1900 the majority of replanted woodland (eg. that planted by the Penrhyn Estate in the 1760's) and native trees, had been reduced to scrub, and with increased felling during the two World Wars, woodland area in North Wales was reduced to 7.6%, (Ball, 1963). Half of this is owned by the Forestry Commission with 70% taken up as conifer plantations. Isolated patches of broad-leaved trees remain and are most common on valley slopes (especially around the Conwy valley) and in locations unsuitable for agriculture. The present potential tree line is estimated to be at 460m, (Ratcliffe, 1959) and above this there are only isolated trees and scrub.

The climatic limit for cultivation is at approximately 380m (Ratcliffe, 1959) due to the extreme weather conditions and the short growing season. As a result the majority of farms use mountain terrain for grazing. On the lowlands, the dominant cultivated crop is oats, but wheat and barley are also common, with lesser quantities of kale and rape, and sheep and cattle grazing is common. Farmers are becoming increasingly interested in reclaiming uneconomical land (often by draining water-logged areas (eg. Cors Bodwrog, fig. 1.2), which occasionally leads to a conflict of interest with conservationists who wish to preserve bogs and fens for both fauna and flora.

Grasslands, bogs and heaths predominate on the mountains, and the vegetation type is largely controlled by topography and drainage. Grassland and heath dominate on drier sites and steeper slopes interspersed with rocky outcrops or scree. Ratcliffe subdivided heath and grasslands depending on the dominant vegetation. Heaths were classified as either Calluna or Vaccinium rich, and there were five major divisions for grasslands; 1)Festuca-Agrostis, 2)Festuca-Nardus, 3)Festuca-Nardus-Juncus squarrosus, 4)Festuca-Juncus squarrosus and 5)basic grassland.

Bogs dominate poorly drained areas either within depressions (eg. Cors Bodwrog, fig. 1.2) or, on slopes of $<15^{\circ}$, as blanket bogs; their distribution is largely controlled by topography. Three types of blanket bog are recognised, depending on the dominant vegetation type; Juncus squarrosus, Eriophorum vaginatum and Calluna-Eriophorum, with the bogs grading into flushed bogs at breaks of slope, or into heath and grassland in drier areas. Ratcliffe (1959) concluded that land use (especially grazing) has been a major factor in maintaining the present day vegetation communities.

1.3.7 ARCHAEOLOGY

Any attempt to consider the Postglacial vegetational history of the area can only be done against a background of human history (Pearsall and Pennington, 1947). The application of pollen analysis in elucidating problems relating to man's influence on vegetation is now well established (eg. Turner, 1965), and in Wales has been illustrated by the work of Seddon (1958), Turner (1965), Moore (1968, 1973), Moore and Chater (1969b), Walker and Taylor (1976) and Chambers and Price (1985, 1988).

The beginning of the Mesolithic coincides with the start of the Holocene, and by the late Mesolithic there is evidence in Wales for occupation and exploitation in both the uplands and lowlands (Caseldine, 1990). Most sites in North Wales are located around the coast (eg. Newborough Warren and Lligwy, fig. 1.2). It is generally believed that the effect of Mesolithic man on the environment was minimal. Slight forest recession may have occurred, associated with burning, but full regeneration took place (Megaw and Simpson, 1979).

The Neolithic population are believed to have been the first people to permanently colonise the area, at around 3000 BC. (Ball, 1963). Environmental evidence is limited but the main occupation areas in North Wales were Anglesey and the Llŷn Peninsula (Caseldine, 1990). The influence of the Neolithic population on the vegetation in upland Wales has been studied by Moore (1973) who postulated that early woodland clearance aided the initiation and spread of blanket bogs. There has also been much discussion over the influence of Neolithic man on the elm decline, and the general consensus is that human influence was small and varied at different sites (Moore 1973). This would not have produced the synchronous decline that is often seen in the pollen record, and other causes (eg. disease, climate change) are often invoked (eg. Hirons and Edwards, 1986).

Evidence from central Wales suggests that upland areas were used by Neolithic people for pastoral activity (sheep and cattle grazing), and the lowlands for cereal growing. They practised a system of shifting cultivation, mostly small temporary clearances and livestock husbandry (Linnard, 1979). Larger more permanent clearances resulted from the felling and burning of woodland.

The Bronze Age in North Wales is taken as between 600-1400 BC., when North Wales was influenced by the culture of pre-Celtic Ireland. The first people of a recognisable Bronze Age culture arrived in Caernarfonshire at around 1500 BC. (Ball, 1963). Archaeological evidence exists in the form of small round barrows, stone circles and enclosures although dating of this period is scarce (Griffiths, 1950) and is largely based on cultural correlation. There was the intensification of cultivation and deforestation (Moore, 1968) with increased stock rearing and gradual immigration onto coastal plains and into higher altitudes; many hut circles and enclosures are found between 1000-1500′ (Ball, 1963). As populations migrated and areas were abandoned there was an increase in scrub and the replacement of woodland by heath and the beginning of podzolisation (Linnard, 1979).

Throughout the Late Bronze Age and the Early Iron Age there was settlement in the foothills and the development of pastoral and hunting groups culminating in the construction of hillforts (Ball, 1963). The evidence for the Iron Age occupation is scarce, especially in Anglesey, and it has been suggested that perhaps the climate here was unsuitable at this time (Roberts, 1959). Generally there was a move towards a more settled lifestyle with major clearance of the lower altitude forests (Linnard, 1979) and pastoral activities becoming increasingly important. Cattle, sheep and pigs were probably kept with seasonal migration between higher and lower pastures (Ball, 1963). Extensive deforestation was taking place (Turner, 1964; Moore, 1968) with the introduction of field systems.

The Romans arrived in the latter half of the first century with the invasion of Anglesey in AD.61, although Roman power was not finally established until between AD.71 and AD.78 (Ball, 1963). The native population remained relatively undisturbed, living in hut circles and enclosures along the coast, on the lowlands and into the valleys. Hillforts were occupied but remained unfortified, and, although Anglesey generally lay outside the occupied area, it was still controlled from Segontium (Caernarfon), which was the main fort for Roman rule in North Wales. The Romans mined lead, iron and slate from around Betws-y-Coed, and copper was extracted from the Great Orme, (fig. 1.2), but the economy was based largely on agriculture. An increase in pastoral farming was the most important factor in forest clearance (Moore, 1968) although with the increasing population there was a corresponding move towards the valleys, and arable farming rapidly increased. The utilisation of wood for building and charcoal has been documented (Kelly, 1988) and there was also the introduction of new tree species including figs (*Ficus carica*), walnut (*Juglans regia*) and sweet chestnut (*Castanea sativa*).

From the 3rd century onwards the coasts were continually attacked and there was an increase in fortification around the coasts of Anglesey (eg. Caer-Y-Twr, Holyhead, fig. 1.2; Ball, 1963) until the final withdrawal of the garrisons took place in AD.380. In early post-Roman times there was invasion by the Irish, the maintenance of local kingdoms, and internal tribal warfare. Before the Norman invasion, agricultural practices did not change significantly although there were periods of less intensive cultivation that allowed some forest regeneration (Moore, 1968). Settlement patterns were similar with hillforts still in use and increased valley settlements. There are numerous hut circles and monuments estimated to be from this phase, and pollen work from Dinas Emrys (Seddon, 1958) shows that in some areas there was renewed but periodic forest clearance. The economy was based on small farming groups growing cereals and keeping livestock.

Christian centres were founded with centres such as Penmon (fig. 1.2) on Anglesey (founded in the 6th century) and St. Deiniol at Bangor, (Ball, 1963). The coasts were frequently attacked in the 9th and 10th centuries by Norse raiders, but raids were sporadic and did not have much influence on existing lifestyles or settlement patterns. The Saxons conquered Wales in 1053 but were later defeated by the Normans, resulting in the restoration of native rule (Ball, 1963). In medieval times, the former tribal conditions and the subdivisions of the area were preserved. In 1283, Edward I invaded, and Gwynedd was divided into a number of counties governed from Caernarfon. This invasion may have had a direct impact on woodland as forest were systematically cleared for the advance of troops (Moore, 1968).

After this agriculture changed to more settled small-holdings and there was seasonal migration from the lowlands to the uplands. Forest clearing continued into the 12th and 13th centuries and land was given over to cultivation by a number of monastic estates. Prosperity subsequently declined, and by the 14th century much property was leased out to tenant farmers.

By the 15th century clearance of woodland in the lowlands was almost complete, and upland areas were reoccupied as the population expanded and arable land became impoverished. In some areas (eg. Central Wales) there is evidence that there was a temporary pause in forest destruction (Moore, 1968). In the 16th, 17th and 18th centuries remaining woodland was subject to greater pressures from the growing population. Increased sheep farming, particularly between 1760 and 1830 (Ratcliffe, 1959) led to selective grazing and the spread of bracken and grass. The 1801 Enclosure Act meant that remaining moorland was brought into private ownership, but with depopulation of upland Wales there was the abandonment of many farms. Areas previously used for arable farming were left for rough grazing and by the late 19th century, cheap grain was being imported and arable cropping was reduced, with a simultaneous increase in the sheep population.

1.4 PREVIOUS HOLOCENE STUDIES

Snowdonia has long been the focus for work by glacial geomorphologists and palynologists, with concentration on Late Devensian glacial erosion and on Lateglacial and Postglacial sediments. Most pollen diagrams relate to upland areas where there are abundant potential sites including cwms and infilled valleys, but as yet there are little published data available for Arfon and Anglesey, (fig. 1.6). For lakes, the work has usually concentrated on pollen analysis, but long, complete sequences with good biostratigraphic and chronostratigraphic resolution are rare.

There has been little multidisciplinary work on lake sites and often alternative aspects of the same site have been studied by different authors (eg. Nant Ffrancon, pollen analysis by Seddon, (1958), and plant macrofossil analysis by Burrows, (1974)). Elner and Happey-Wood (1980) studied Llyn Peris and Llyn Padarn, producing an integrated study of pollen, diatom and chemical analysis with complimentary magnetic susceptibility results, but data only extends back to 4600 BP. Crabtree (1972) was the first to analysis Welsh core material chemically and further work was done by Elner and Happey-Wood (1980) and Botterill (1988). Botterill investigated the Postglacial development and management of lowland mires in North-west Wales (Anglesey and the Llŷn Peninsula).

Pollen analysis and magnetic susceptibility of sediment from upland lakes were undertaken by Ince (1981) and diatom studies and complimentary pollen analysis were carried out in Llyn Glas and Llyn Clyd by Evans and Walker (1977). Pollen analysis was also used at Melynllyn as a means of core correlation for diatom studies (Walker, 1978). Except for Edwards' (1980) study in North-west Wales there have been no attempts to use pollen concentration data and pollen accumulation rates for North Wales sites, and there are also very few examples of palynology being used in an archaeological context.

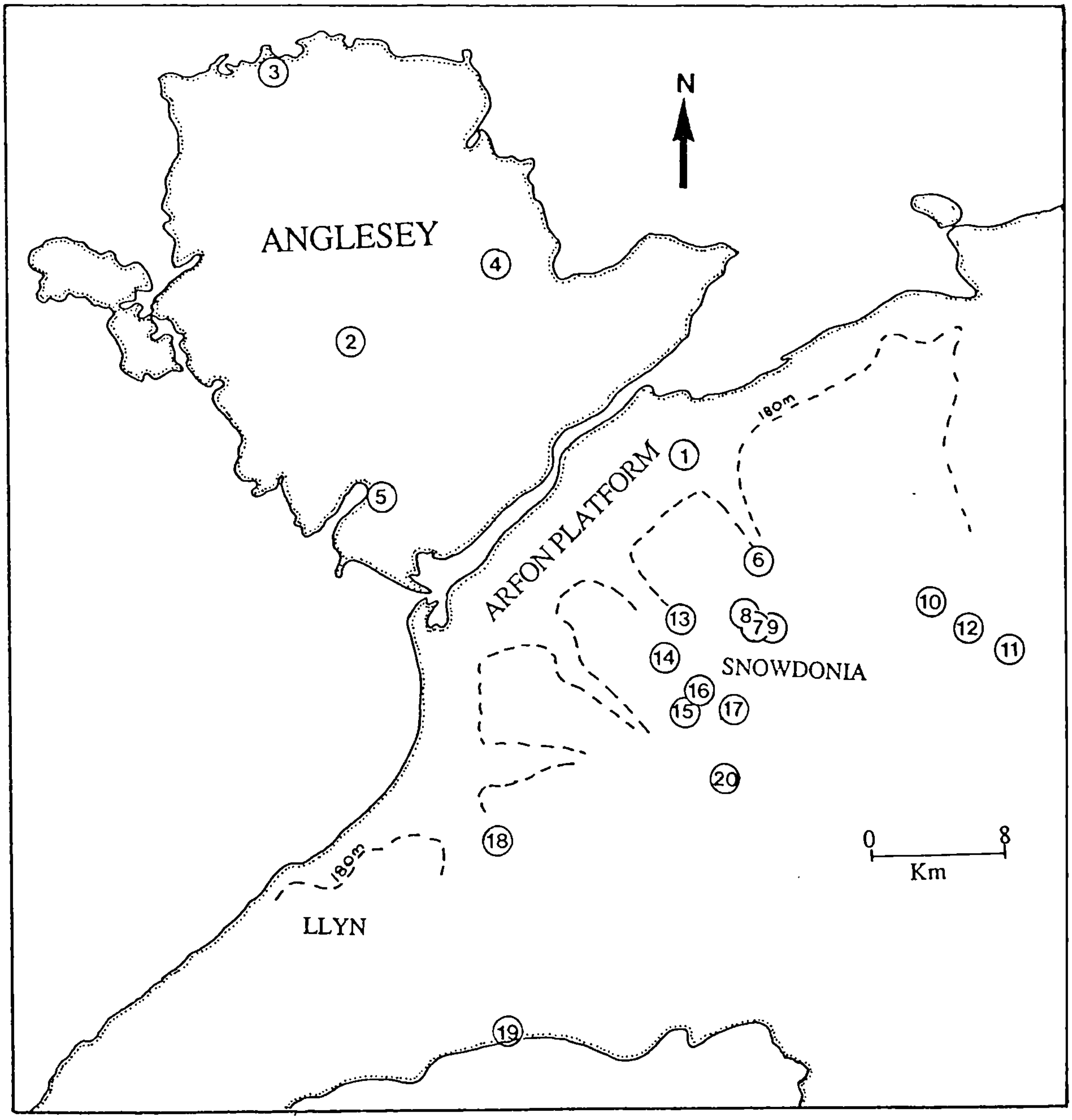


Figure 1.6 Palynological work in North Wales

SITE	AUTHOR
1 Llyn Cororion	Watkins, this project.
2 Llyn Hendref	Watkins, this project.
3 Tre'r Gof	Botterill, 1988.
4 Cors Goch	Seddon, 1958.
5 Malltraeth Marsh	Prince, 1988.
6 Nant Ffrancon	Hibbert and Switsur, 1976 Burrows, 1974, 1972. Seddon, 1958.
7 Llyn Clyd	Evans and Walker, 1977.
8 Cwm Cywion	Ince, 1981.
9 Cwm Idwal	Tipping, 1990.
10 Melyllyn	Walker, 1978.
11 Llyn Goddionduon	Ince, 1981.
12 Cors Geuallt	Crabtree, 1965.
13 Llyn Peris	Elner and Happey-wood, 1980. Tinsley and Derbyshire, 1967.
14 Llyn Dwythwch	Seddon, 1958.
15 Glogwyngarreg	Ince, 1981.
16 Llyn Glas	Evans and Walker, 1977.
17 Llyn Llydaw	Ince, 1981.
18 Cors Gyfelog	Botterill, 1988.
19 Glanllynau	Simpkins, 1974.

Moore (1973) discussed the influence of prehistoric culture on the spread of peat in upland Wales, and vegetational changes in relation to archaeological and historical evidence has been discussed by Walker and Taylor (1976). Chambers and Price (1988) reported on the environmental setting of prehistoric upland enclosures (Erw-wen and Moel-y-Gerddi), and Seddon (1958) studied organic deposits from Dinas Emrys, an Iron Age hillfort above Nant Gwynant. Caseldine (1990) concludes 'there has been a significant under-provision for environmental work on, or associated with, archaeological sites in Wales'.

CHAPTER 2

SITE SELECTION, FIELDWORK AND SITE DESCRIPTIONS

2.1 SITE SELECTION

The process of site selection is of critical importance to palaeoecological studies (West, 1970) as this 'determines the level of detail that can be resolved in the reconstruction' (Jacobson and Bradshaw, 1981). Jacobson and Bradshaw discuss the information required to choose an appropriate site for a particular study, and the advantages of using lake sediments for palaeoecological projects has been discussed by Faegri and Iversen (1975), Moore and Webb (1978) and Birks and Birks (1980).

For this project it was necessary to obtain lake cores that would provide a thick, continuous sequence of Flandrian sediments providing both good stratigraphic and temporal resolution. A number of lakes were identified on OS. maps and subsequently visited (appendix A1). Five were chosen for further investigation and fieldwork, (table 2.1).

Table 2.1 Lakes under initial investigation

Name	Grid Ref.	Altitude m.OD.	Echo-sound	Core taken	Organics present
Llyn Cororion	SH597688	82.5m	+	+	+
Llyn Hendref	SH398765	58.5m	+	+	+
Llyn Padrig	SH364727	25.0m	+	+	+
Mynydd Bodafon	SH467851	140.0m	+	no	?
Llyn-yr-Wyth -Eidion	SH474819	65.0m	+	+	no

These lakes were chosen after considering their potential for containing organic sediments, altitude, location, lake size and site accessibility. Location and altitude were important as sites had to be low-lying (<100m), and away from limestone substrates to avoid the problems of hard water error in radiocarbon dating (Jacobson and Bradshaw, 1981). Lake size and the presence of major inflows or outflows, which affect pollen source area (Peck, 1973), were also important considerations, with the latter affecting the pollen input (Bonny, 1978) and sedimentary regime.

Jacobson and Bradshaw (1981) define the pollen source area as 'the area from which a fixed percentage of the pollen sampled at a site is derived'. A simple theoretical model was developed to describe the relationship between pollen source area and basin size (appendix A4) and this can be used to predict the proportions of regional, extra-local and local pollen deposited in lake basins of contrasting size. The model is essentially for closed sites but takes account of pollen transport modes which also affect potential source area. When reconstructing vegetational history it is important to estimate the potential pollen source area for the derived pollen as this will indicate the scale over which vegetational change was occurring; large lakes (>300m diameter) are more suitable for regional studies. For this project smaller lakes were required with diameters <300m so that the pollen source area would be predominantly local and extra-local, ie. derived from up to several hundred metres of the lake edge. Due to the paucity of natural lakes in Arfon it was not possible to satisfy all the criteria. With the exception of Llyn Cororion, final site selection was not undertaken until preliminary fieldwork and laboratory work had been undertaken.

2.2 FIELDWORK

It is generally accepted that it is preferable to core in the deepest part of a lake. Theoretically this is the location of highest sedimentation rates resulting in maximum sediment thickness and greatest stratigraphic resolution (Davis, 1968). The deepest part of a lake also has greatest potential for a complete undisturbed sequence (Faegri and Iversen, 1975; Birks and Birks, 1980) and has minimum risk of sediment disturbance due to erosive currents, streams (Davis, 1967a) and fluctuating water levels (Lowe and

Walker, 1984). In larger lakes coring in the deepest areas avoids over-representation of local pollen which is often associated with shallow deposits.

For this project it was assumed that lake morphometry had remained relatively unchanged since formation, and hence the deepest area and point of sediment focus had remained stationary. This assumption was necessary to avoid a detailed and time-consuming exploratory coring program.

2.2.1 ECHO-SOUNDING

To deduce present-day lake morphometry, a Raytheon Depth Sounder was deployed from an inflatable boat. A series of transects were steered across the lakes, and position fixing was done using parallel aligned poles surveyed onto a base map. After calibration of the instrument, sufficient traverses were completed to allow the production of a depth contour map. Four of the five lakes in table 2.1 were mapped and produced reliable records, (fig. 2.1 and appendix A2). Llyn Hendref contained approximately 0.7m of water above 2.2m of seston which did not produce a coherent echo-sounding trace. Water depths are accurate to within +/-25cm, due to the transitional boundary between seston and water which does not produce a well defined reflection.

This is an ideal technique for depth sounding lakes. Use of the instrument is quick, it is easy to deploy, and produces immediate output. For larger lakes, more precise position fixing techniques would be required. Results can be used to calculate various parameters (eg. total volume and mean depth, and shore development). Lacustrine sedimentary mechanisms can then be inferred from lake morphometry (see Hakansson and Janssen, 1983, for detailed discussion).

2.2.2 CORING

From the echo-sounding results, four lakes were chosen for coring. The fifth, Mynydd Bodafon was rejected as the

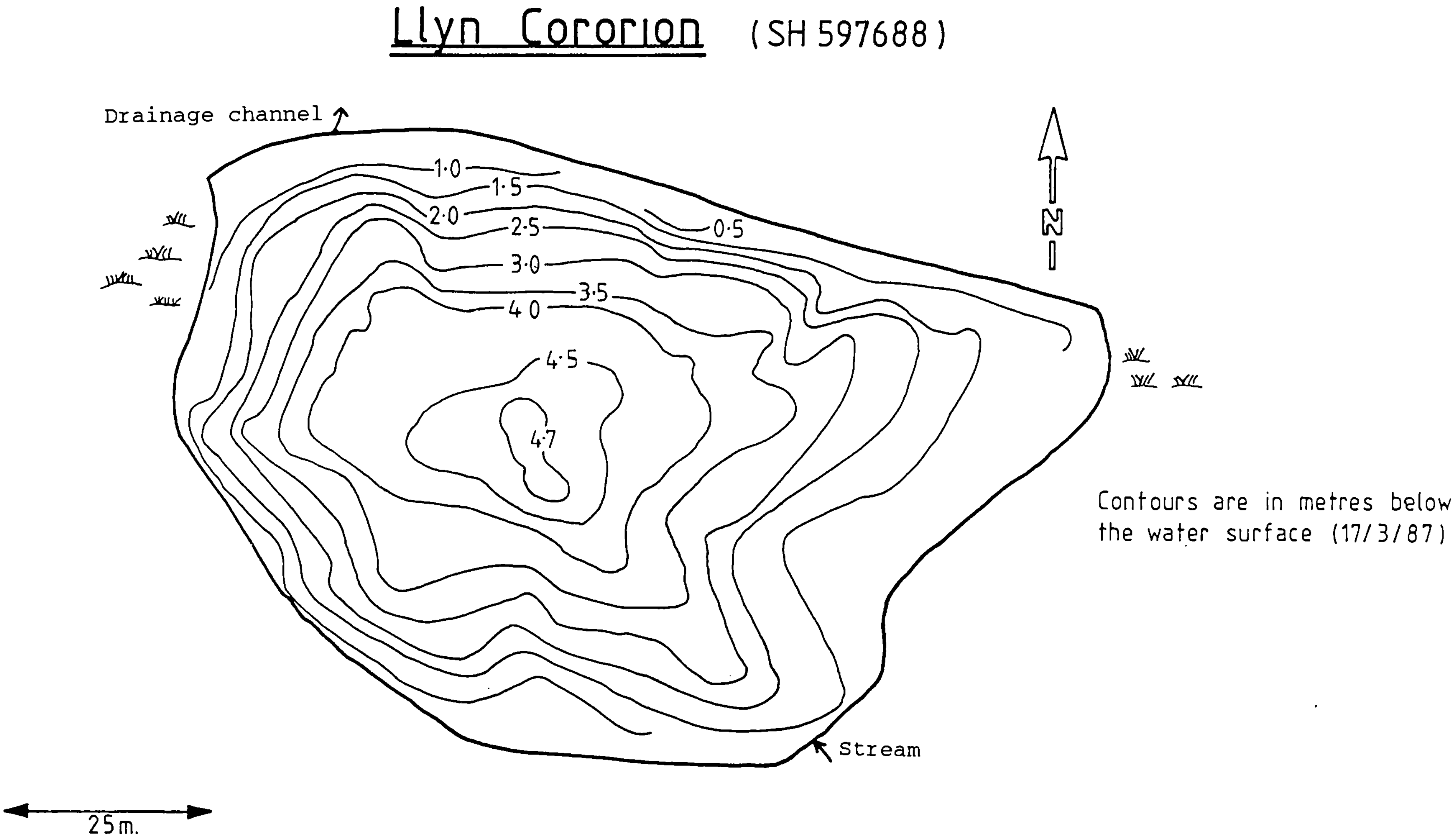


Figure 2.1 Bathymetric map of Llyn Cororion (SH597688)

bathymetry suggested that the substrate was composed of disturbed inorganic debris (possibly waste from nearby quarrying activity?) with potentially very little organic material.

Coring was done using a modified Livingstone piston corer (chamber size 100 x 5cm), from a raft secured over the deepest part of the lake (for description of corer, see Livingstone, 1955: Wright, 1967). Casing was attached to the raft and pushed into the upper seston to ensure that the same hole was re-located between extraction of one metre long core sections. The transitional seston was not collected for analysis. Depths quoted are depths below core surface.

On recovery, cores were immediately extruded into split plastic drainpipes, briefly described, wrapped in cling film and aluminium foil, and labelled. Duplicate overlapping cores were taken to ensure that a complete sequence was recovered and to provide back-up material should it be needed for supplementary pollen analysis or radiocarbon dating. All possible care was taken to minimise potential contamination, although the possibility of material falling into the core hole cannot be totally eliminated, (section 7.1). Cores were stored at 4°C to prevent desiccation and microbial activity.

Only three lakes produced organic sequences (table 2.1) and both Llyn Padrig and Llyn-yr-Wyth-Eidion were rejected. Llyn Padrig contained four metres of organic sediment and a skeleton pollen diagram showed that the introduction of tree taxa occurred within the basal inorganic sequence. This would have resulted in poor pollen preservation and potential difficulties with dating. Llyn-yr-Wyth-Eidion contained no organic deposits and eight samples showed that although pollen was present, preservation was poor and concentrations were low. Llyn Cororion and Llyn Hendref were therefore the two sites chosen for this project.

2.3 SITE DETAILS: LLYN CORORION

Grid Reference SH 597688
Longitude 4°6′W Latitude 53°12′N
Altitude 82.5m OD.
Area 0.681 hectares
Catchment of lake = 46 hectares
Status: Site of Special Scientific Interest

Llyn Cororion (plate A) lies within the parish of Llandegai, approximately 1 km NW of Tregarth and is the only natural lake on the Arfon Platform (fig. 2.2). To the south of the lake is a sharp break of slope which separates the platform from the foothills of the Snowdonia range. To the north, the slope gradually decreases towards the Menai Strait. The platform is dissected to the NE by the Afon Ogwen and to the SE by the Afon Cegin; Llyn Cororion lies raised on a plateau between the river valleys.

2.3.1 GEOLOGY

The area is dominated by heavily faulted and folded Lower Palaeozoic rocks. Llyn Cororion lies within a NE-SW trending belt of Ordovician rocks (the Nant Ffrancon Formation), the majority of which are heavily cleaved siltstones and mudstones. To the south and south-east of Llyn Cororion a large NE-SE striking fault separates the Nant Ffrancon Formation from the older rocks of the Bronllwyd Grit Formation, the Llanberis Slate Formation and the Fachwen Formation. These are dominated by siltstones and mudstones with interbedded sandstones and tuffs. To the north-west of Llyn Cororion the base of the Nant Ffrancon Formation (Graianog Sandstone) is exposed passing down into Cambrian rocks including the Bangor Formation (conglomerates and acid tuffs), the Minffordd Formation (sandstone and tuffs) and the Padarn Tuff Formation.

Llyn Cororion has been interpreted as a former kettlehole in an extensive tract of outwash gravels and sands (Nature

Plate A LLYN CORORION (looking south)

Plate B LLYN HENDREF (looking north-east)

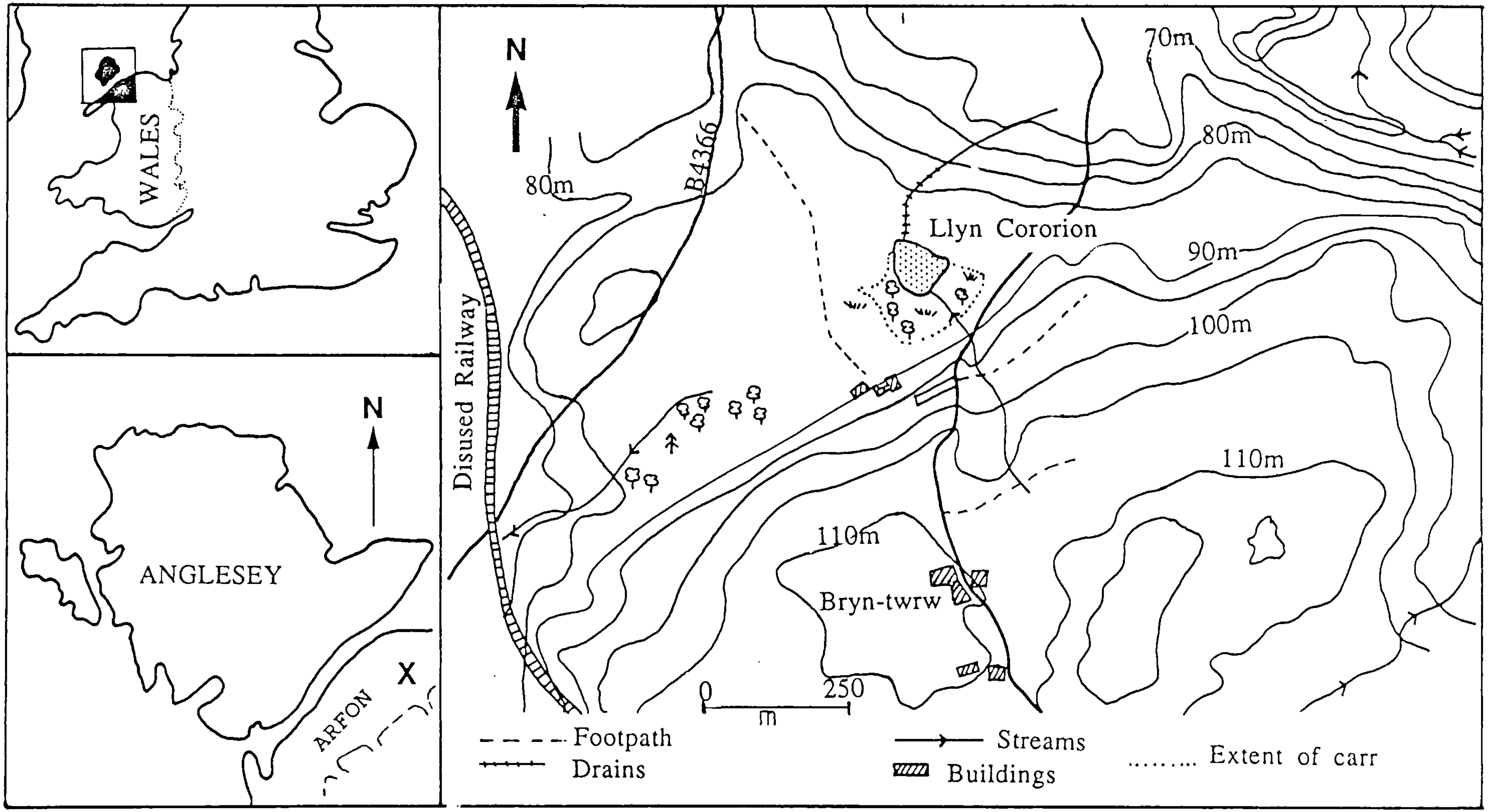


Figure 2.2 Llyn Cororion location map

Conservancy Council report, file SH248; 1977), and a series of infilled kettleholes have been mapped to the south associated with kame and esker topography (Embleton, 1964a). The derivation of the tills is complex due to the interaction of the Welsh and the Irish ice. Llyn Cororion has been mapped both inside (Whittow and Ball, 1970) and outside (Saunders, 1968) the limits of the Welsh ice. Llyn Cororion is located outside the limits of the Loch Lomond Stadial advance.

2.3.2 SOILS

Llyn Cororion lies within a belt of brown earth soils, and specifically within the Deiniol Soil Series. The parent material is a mixture of Cambrian volcanics, softer Ordovician sedimentary rock and Welsh and Irish Sea till, containing a high proportion of sand and gravel resulting in relatively good drainage. Locally the soils may develop features more typical of a gley soil (Ball, 1963). Interspersed with these around Llyn Cororion is the Arvon Series, a brown earth of low base status derived from acid igneous rocks and hard grits. This is a typical stony sandy loam in the upper horizons above a moderately acid or neutral substrate (Ball, 1963).

2.3.3 HYDROLOGY AND LAKE CHANGES

From archive material and Nature Conservancy Council reports it is possible to deduce changes in lake area during historical times (fig. 2.3). Maps from 1768, 1794, 1840 and 1983 have been studied. The early maps show a circular lake with surrounding field boundaries and little evidence of woodland. Lake size was reduced between 1768 and 1840 with the development of a small marshy channel to the south and the spread of marsh to the east. By 1889 there was extensive marsh development and a stream and an outflow were present. An area of trees had also developed to the south and south-east, possibly associated with increased drainage or decreased grazing. Since 1889 lake size appears to have been constant. Since 1930 spruce trees have been present on the

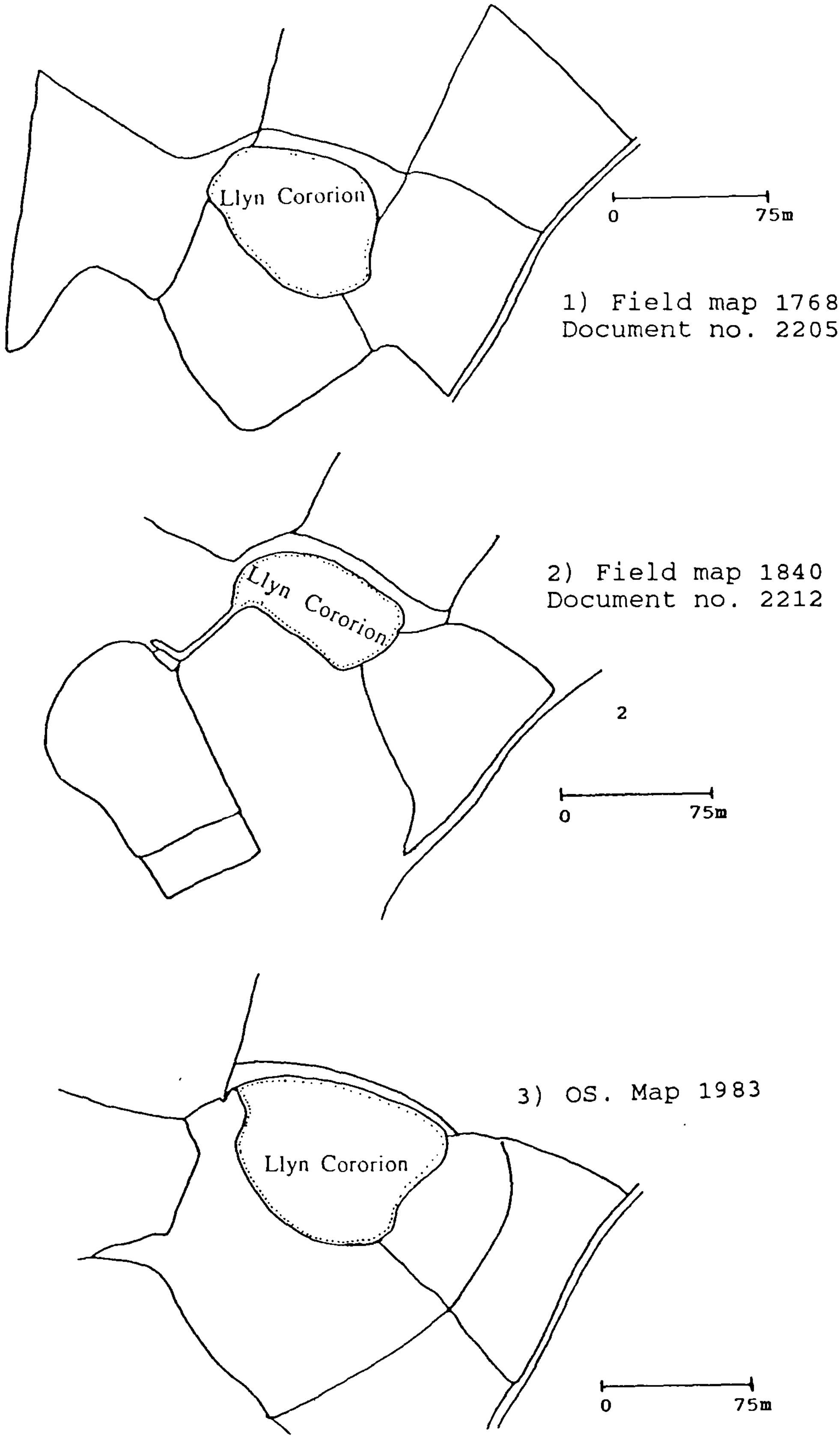


Figure 2.3 Llyn Cororion: Changes in lake size since 1768

Maps 1 and 2 are from the Penrhyn Estate Archives north shore, and by 1955 much of the area to the south and south-west has become increasingly wet, with extension of carr woodland.

There has therefore been little change in the lake size over time, with only minor water fluctuations controlled by changes in drainage.

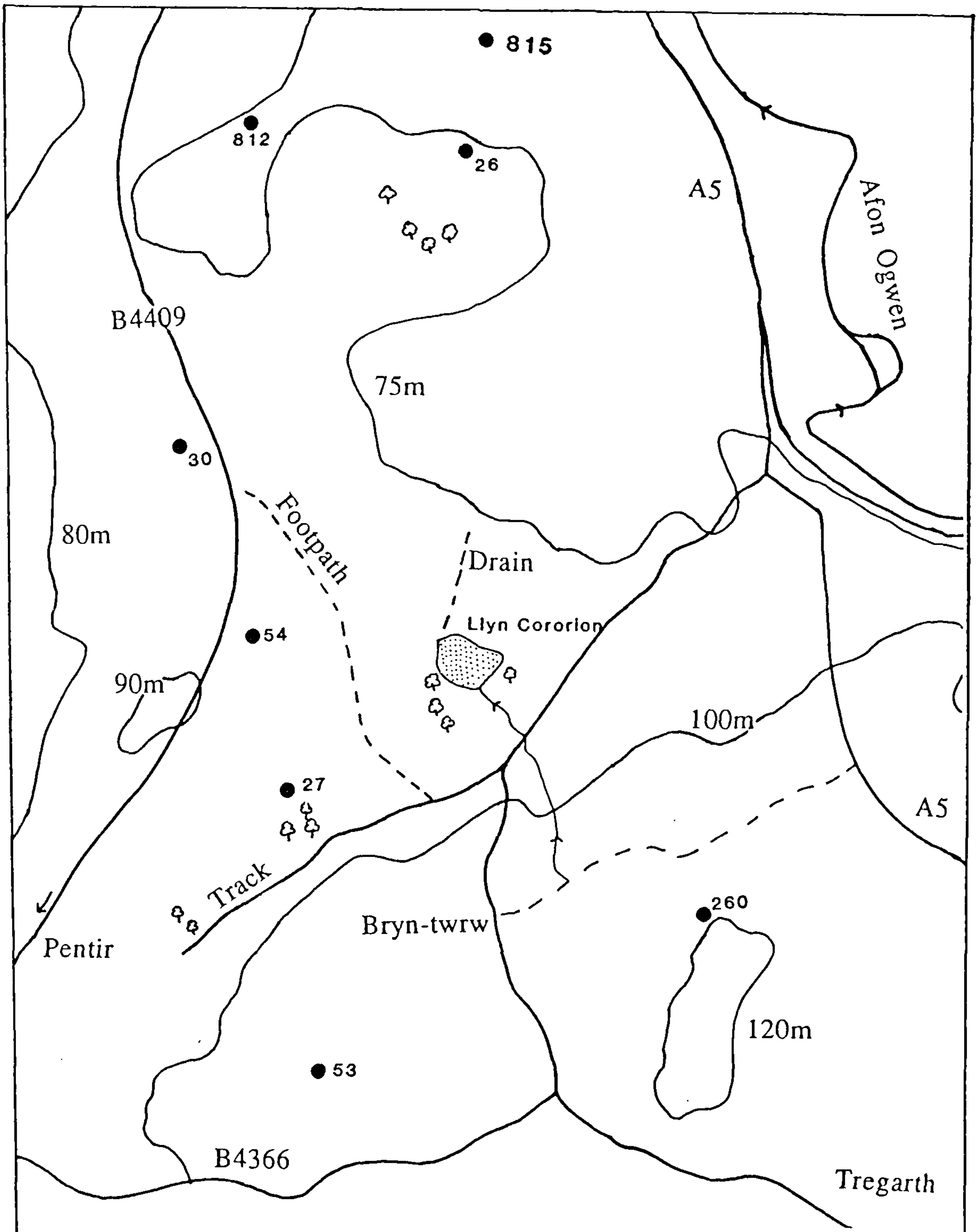
2.3.4 MORPHOMETRY

The echo-sounding results (fig. 2.1) show that the present day morphometry is a regular and approximately symmetrical basin. The basin sides are generally steeper to the north and west, with the maximum depth (4.7m+/-25 cm) approximately central. Maximum length is estimated at 113m (E-W) with a width of 75m.

2.3.5 VEGETATION

The lake is surrounded by fringing reedswamp which grades into wet willow-alder-birch carr, covering approximately 2 hectares. The carr extends to the east and south-east, but the area to the south is slightly drier, and there are ash, oak and sycamore trees (Blackstock, 1987). The land around the lake is permanent grassland, and livestock graze down to the northern shore, but the carrland areas along the other shores are ungrazed. To the south and east there is a fringing margin of water lilies and reedswamp with wet alder and willow woodland.

Vegetational surveys have been undertaken by Seddon (1962, 1972), Ward (1977), and Oliver and Blackstock (1986) (unpublished surveys, Nature Conservancy Council File SH56.2) Oliver and Blackstock (1986) recorded two communities: *Salix cinerea*-*Galium palustre* and *Betula pubescens*-*Molinia caerulea*. *Alnus*, *Acer pseudoplatanus* and *Sorbus aucuparia* also occur with an understorey layer of varying species including *Carex paniculata*, *Lycopus europaeus* and *Agrostis stolonifera*.



Archaeological sites in the vicinity of Llyn Cororion
(Data from the Gwynedd Archaeological Trust)

Figure 2.4

KEY

812	Old Trackway
30	Neolithic Pottery, Bronze Age Food Vessels.
54	Ploughed Out Hut Circles.
27	Romano-British Hut Circles.
53	Iron Age Fort/Bronze Age Cairn.
260	Romano-British Huts.
815	Bronze Age Burnt Mound.
26	Destroyed Earthworks, (Roman?).

2.3.6 ARCHAEOLOGY

A number of nearby archaeological sites have been identified (fig. 2.4). The nearest is a group of four round huts (site ref.27), with adjoining walls, in an area that is now thickly wooded. The walls are of loose rock and earth, and excavations have revealed a hearth containing charcoal and pot boilers. It has been estimated as being Romano-British in age, but may have been initially occupied in the Iron age (Kelly pers. comm., 1988). To the south-west of Llyn Cororion, a number of ploughed out hut circles have been identified from aerial photographs. Further away from the lake (site ref.54) Neolithic pottery, and Bronze age cairns and food vessels have been found. Destroyed earth works (possibly Roman) have been identified to the north (site ref. 260 and 26) and a large complex of Romano-British huts have been identified in the south-east. Details of all these sites are held by the Gwynedd Archaeological Trust.

2.4 SITE DETAILS: LLYN HENDREF

Grid Reference SH 398766
Longitude 4°23'W Latitude 53°16'N
Altitude 58.5m OD.
Area of Lake 1.6 hectares
Catchment of mire 351 hectares
Area of lake and mire 230 acres
Status: Site of Special Scientific Interest

Llyn Hendref (plate B) is located on Anglesey, approximately 700m north-east of Gwalchmai. It lies at the south-west end of Cors Bodwrog (fig. 2.5) which occupies one of the many NE-SW tending depressions in the area. The depression is approximately defined by the 65m contour line with a maximum length of 2.5 km and a maximum width of 550m, gradually narrowing to 10m at the lake outflow. At the edge of the depression (SH413781) is a sharp break of slope with the land quickly rising to 85m The lake basin is steep sided with high

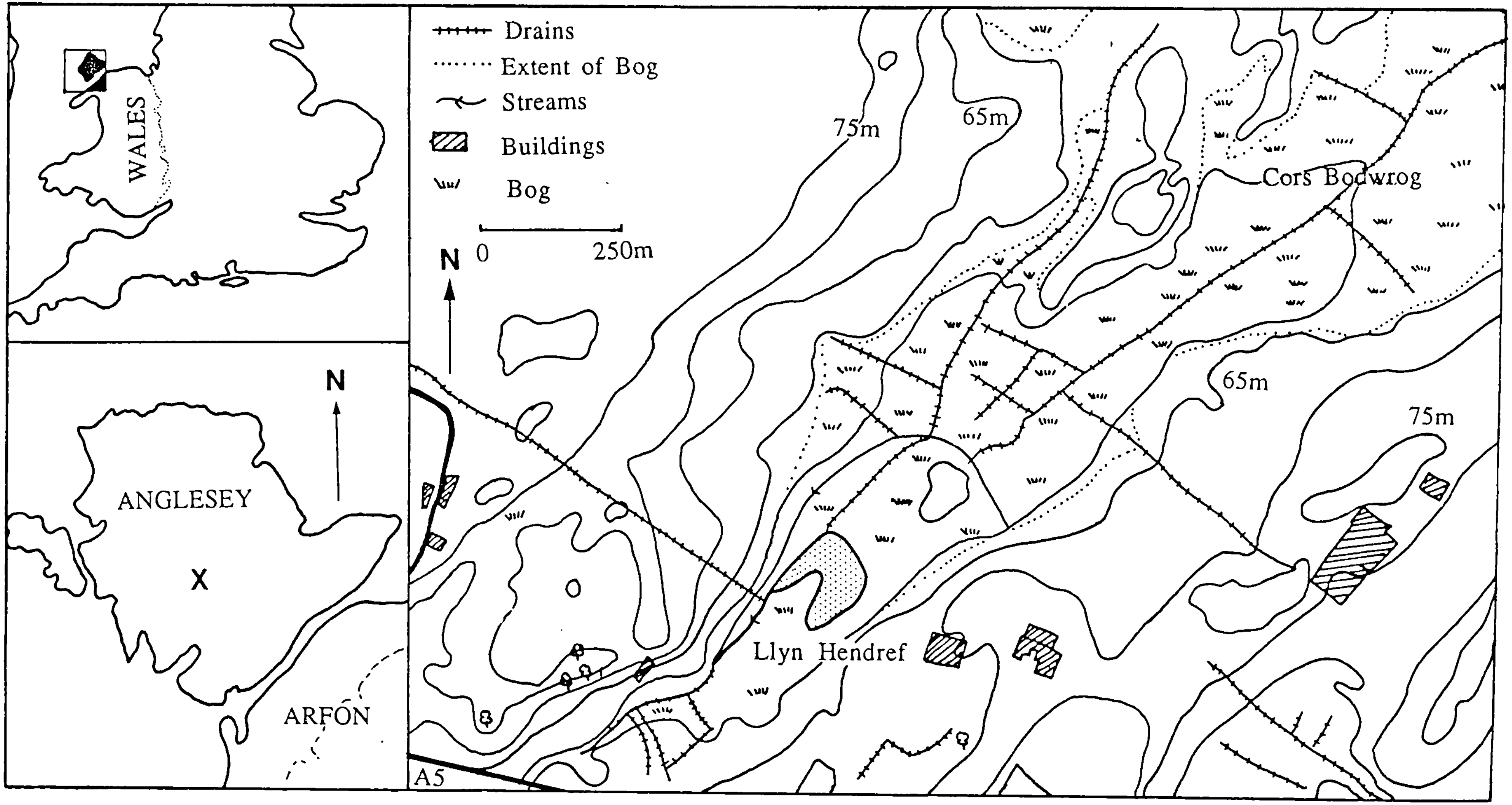


Figure 2.5Llyn Hendref location map.

land (75m) to the south-east and north-west.

2.4.1 GEOLOGY

The geology of the area is dominated by pre-Cambrian Mona Complex, and Llyn Hendref lies on a tract of NE-SW striking mica schists of the Penmynydd zone of metamorphism (fig. 1.3). The mineralogy of the Mona Complex schists is dominated by quartz, feldspars and micas in rocks that are heavily foliated and contain occasional quartz rich bands. The strong foliation is vertical, and bedding dips at >45° towards the south-east.

The high moorland to the north-west of Llyn Hendref is composed of Coedana Granite, and in the vicinity of the lake there is no intervening hornfels unit. To the south-east the Gwna Greenschists are in contact with mica schists. The greenschist mineralogy is dominated by quartz, chlorite and mica (Greenly, 1919). The rocks of the Mona Complex have been intruded by a series of NW-SE trending dykes, one of which passes under Cors Bodwrog. Towards the north-east and east of the depression are Ordovician outcrops of Llanvirn age (SH420780) which unconformably overlie the mica schists. This sequence is dominated by shales with occasional pebbly grit bands.

Llyn Hendref was mapped by Greenly (1919) as lying in an area of lacustrine alluvium surrounded by boulder clay. The till has a northern derivation and was deposited by Irish Sea ice crossing Anglesey from Liverpool Bay (Whittow and Ball, 1970), but it is a mixed sediment containing both local and exotic material. Llyn Hendref lies within a fault defined depression that was accentuated by ice movement. Llyn Hendref is located outside the limits of the Loch Lomond Stadial and was not occupied by ice during this time.

2.4.2 SOILS

Llyn Hendref lies on the Coron Soils Series (Ball, 1963) which is derived from constantly accumulating organic material (acid peat), which is permanently water-logged. Decay rates are slow and the pH. is generally <4, so limited vegetation is supported. To the north of the lake are the Arvon and Rocky Arvon Soil Series, derived from parent material of drift, acid igneous rocks, and the Mona complex. The soils have a high mica content, large quantities of aluminosilicates, and are brown earths of low base status. These are well-drained and agriculturally productive. To the south of the lake is the Gaerwen Series (Roberts, 1958) overlying the Mona Complex schists.

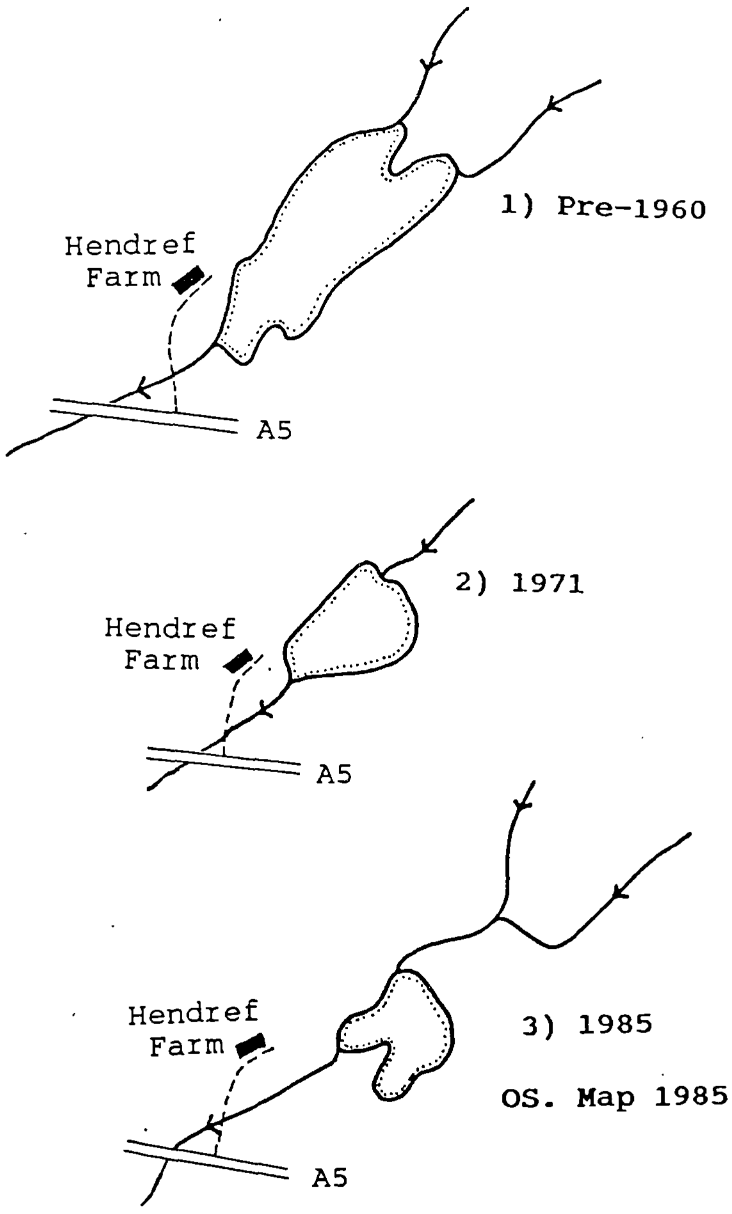
2.4.3 HYDROLOGY AND LAKE CHANGES

The majority of the depression is now filled with mire and Llyn Hendref is all that remains of a much larger lake. Figure 2.6 (taken from a tracing of photographs held by the NCC.) illustrates change in lake size since 1960. Lake hydrology of the area is controlled by an extensive drainage network. Maps of 1905 and 1960 show that during this time the lake surface area reduced by 80%, from 11.3 hectares to 1.6 hectares, and the length decreased from 650m to 150m (Blackstock, 1986). In 1971, the lake level was reduced by 1.6m in an attempt to reclaim land for agricultural purposes and the edges became colonised by carr woodland. The scheme was unsuccessful and since then only periodic drainage has been attempted resulting in a slight rise in the lake level over recent years.

Before the major changes in lake area a stream flowed into the north corner of Llyn Hendref but since the lake level has dropped the major stream flows through Cors Bodwrog and passes to the north-west of the lake. There are three minor inflows, and a small stream exits south-west from Llyn Hendref.

2.4.4 MORPHOMETRY

Echo-sounding showed the depth of water to be constant throughout, at 0.7m, with a further 2 metres of transitional seston below. The lake edges are generally indistinct, grading



Maps 1 and 2 are from aerial photographs held by the Nature Conservancy Council, Bangor.

Figure 2.6 Llyn Hendref: Lake changes since 1960 into mire and carr on the south, east and north shores, and with an open bare shoreline to the west.

2.4.5 VEGETATION

The west and east lake edge are composed of gravel, shingle and sand, and there is reedswamp to the north and south. The lake is surrounded by mire which was once open water, and now exhibits a plant succession from aquatic conditions to willow carr. The lake is moderately eutrophic, and provides near-optimum conditions for a large number of aquatic plants (Seddon, 1964). The first vegetational survey was undertaken by Seddon (1964), when the site was first listed as an SSSI. Details of this and subsequent vegetation surveys are in file SH47.7 held by the Nature Conservancy Council.

Since 1964 extensive drainage has exposed much of the lake floor, an area subsequently colonised by Salix cinerea. In 1983, a detailed survey was carried out at Cors Bodwrog (Blackstock, 1986) which ascertained that the effect of drainage had been to decrease species diversity and eliminate the aquatic higher plant species. On Cors Bodwrog the predominant vegetation types are Molinia grassland and Juncus/Holcus fen meadow. Associated with the Molinia is Erica tetralix, Myrica gale and occasionally Phragmites. Within the fen meadows are Juncus effusus and various grasses and around the lake and throughout the valley there is Salix scrub. The site is noted for some important species including Sparganium minimum (usually confined to limestone areas) and also the co-existence of Myriophyllum spicatum and Myriophyllum alterniflorum (Seddon, 1964).

The lake was included in a study by Seddon (1972) which correlated chemical parameters of lake water chemistry with species assemblage, and the flatworm fauna of the lake been studied by Taylor and Reynoldson (1962). Land around the lake is 50% mixed farming and moorland and 50% unimproved pasture.

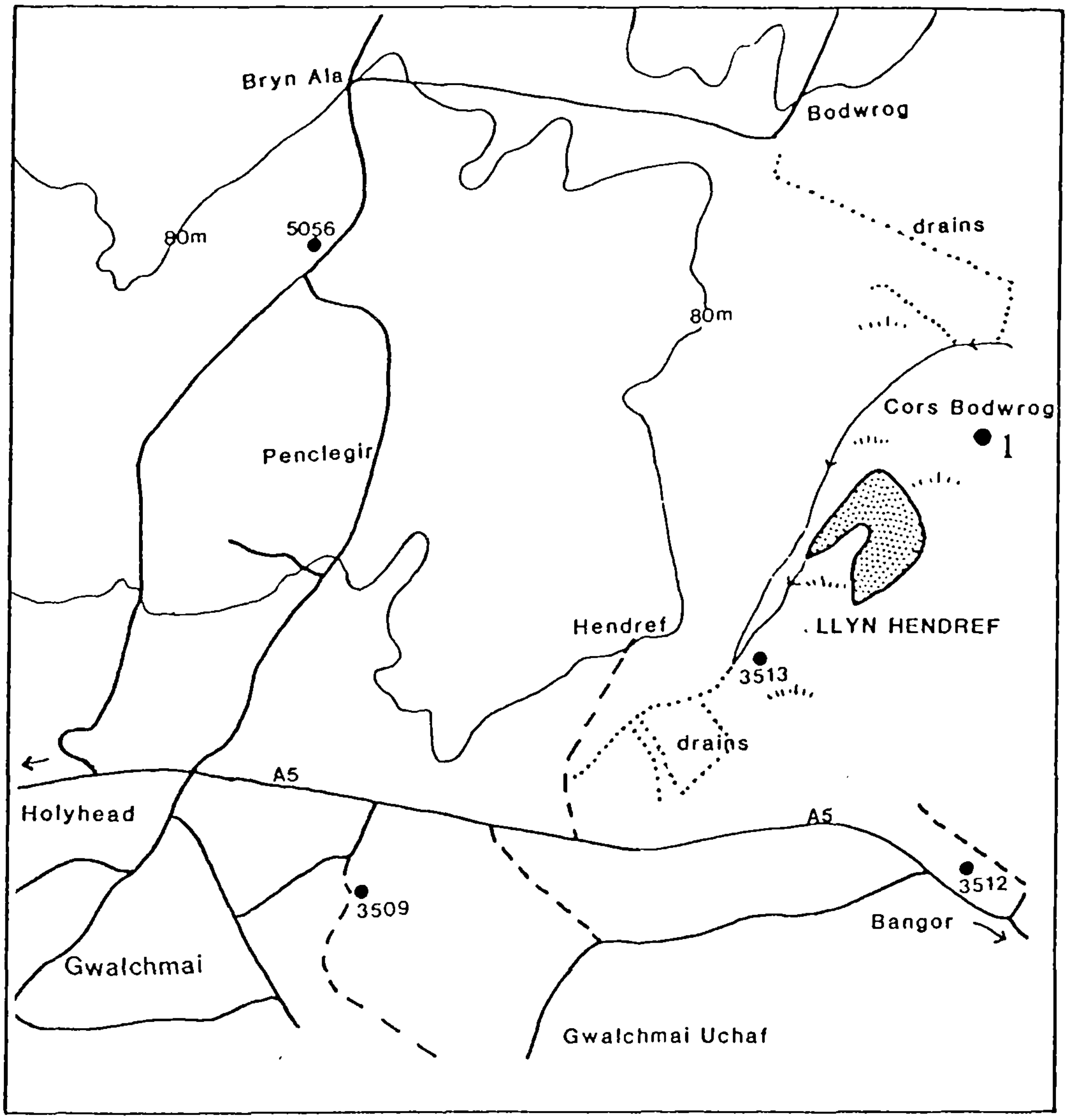


FIGURE 2.7 ARCHAEOLOGICAL SITES IN THE VICINITY OF LLYN HENDREF
(Data from the Gwynedd Archaeological Trust).

KEY

5056 Bronze Age Palstave
3509 Church (recent)
3512 Toll House (recent)
3513 Querns, bones (age uncertain)
Details of the above sites held by Gwynedd Archaeological Trust.
1 Bronze Age Trading Hoard. (Lynch per.comm.)

2.4.6 ARCHAEOLOGY

The area around Llyn Hendref is generally devoid of archaeological remains (fig. 2.7) but a group of finds near Llyn Hendref are of interest. Late Neolithic flint implements were recovered from Cors Bodwrog in 1864. These are thought to be a 'trading hoard' but records are inadequate for further interpretation. In 1974 a set of Bronze Age tools were recovered from the edge of the bog (SH406775) scattered over a site of approximately 2m x 1m (Lynch, pers. comm., 1989). The find included pieces of sword, blade axe, two palstaves, a razor, a chape and a gouge. This indicates the working of metal and establishment of a workshop in this area. Lynch comments that damp spots on the edge of marshes were frequent sites for late Bronze Age houses although at this site there is no indication of occupation.

A four metre trench cut at the downstream end of Llyn Hendref in 1971 produced animal bones and isolated artifacts (Kelly pers. comm., 1988). Finds included a Romano-British type quern and grinding stone, horse teeth and bones of Fallow and Red deer. None of the finds have been dated, but Fallow deer are generally regarded a Roman introduction. Association with modern 'debris' show that the material is mixed and not in stratigraphic context. Details of the finds have not been published but a description is given by Davies (1978, NCC File SH47.7) who concluded that the material was of antiquarian interest only.

CHAPTER 3

POLLEN PREPARATION AND ASSOCIATED TECHNIQUES

3.1 CORE DESCRIPTION

A standard system of stratigraphic description enables comparison of cores from different sites and elucidates major stratigraphic changes which can then be correlated with pollen and chemical variations. Initial sediment description also enables preliminary decisions to be made regarding sub-sampling strategy and the preparation method necessary for pollen extraction.

The cores for this project are described using the Troels-Smith (1955) system, which characterises composition, humification, physical properties, stratification and colour. Written descriptions for Llyn Cororion and Llyn Hendref are given in tables 3.1 and 3.2, and simplified sections are included alongside the pollen diagrams (enclosures 1-6). Plates C and D show the basal cores from both sites and figure 3.1 highlights the disturbed section from the base of Llyn Hendref. Core descriptions from 'rejected' sites are included in appendix A3. All colour values quoted are based on the Munsell soil colour chart.

3.2 POLLEN PREPARATION

3.2.1 REVIEW OF PREPARATION METHODS

A number of different methods exist to extract and concentrate pollen from sediments, often modified according to the sediment type (eg. peats, lake muds, soil, clay). Techniques are based on the chemical and physical removal of unwanted organic and minerogenic material in such a way that remaining pollen is unaltered in both quantity and quality. Usually organic material is removed by digestion with KOH or

Table 3.1

STRATIGRAPHIC DESCRIPTION OF THE LLYN CORORION CORE

All contacts gradational unless otherwise stated

Depth cm	Comp.	Colour	Nig.	Str.	Elas.	Sicc.	Humo.	Comments
000-100	Ld4Dg+	5Y2.5/1	3	0	1	3	4	
100-165	Ld3Dg1	5Y2.5/1	3	0	2	3	4	Dl+ Gs+
165-200	Ld3Dg1	5Y2.5/1	3	0	2	3	4	Ga+
200-353	Ld4Dg+	2.5Y3/0	4	0	2	3	4	Ga+ 243cm
353-355	Ld2Dg2	5Y2.5/1	3	0	2	3	4	
355-395	Ld4Dg+	5YR2.5/2	3	0	2	3	4	
395-400	Ld2Dh2	2.5Y2/0	3	0	2	3	4	
400-402	Ld2Dl2	5Y2.5/1	4	0	2	2	4	Wood and stems
402-485	Ld4Dg+	2.5Y2/0	4	0	2	3	4	Dl+
485-500	Ld2Dg2	10YR3/2	4	0	2	3	4	
500-510	Ld4	5Y2.5/1	4	0	2	3	4	
510-514	Ld2Dg2	5Y2.5/1	3	0	2	3	4	
514-598	Ld4	2.5Y2/0	4	0	2	3	4	
598-600	Ld2Dg2	2.5Y2/0	3	0	2	3	4	
600-677	Ld4Dg+	10YR2/2	3	0	3	2	4	
677-700	Ld3Dg1	5YR2.5/1	3	0	3	2	4	Wood at 667cm
700-722	Ld4Dg+	5YR2.5/1	4	0	4	3	4	Dh+ at 705cm
722-757	Ld2Dg2	5YR2.5/1	4	0	4	3	4	
757-851	Ld4Dg+	5YR2.5/1	4	0	4	3	4	
851-852	Gs2Cg1	5Y 4/1	2	0	0	3	1	Ld+ Sand pod
852-878	Ld4Dg+	5YR2.5/1	4	0	2	4	4	
878-882	Ld4Ag+	5YR2.5/1	4	0	2	4	4	
882-898	Ld4Dg+	10YR3/2	4	2	2	4	4	Laminae 1mm
898-949	Ld4Dg+	5YR2.5/1	4	2	2	4	4	
949	Sharp boundary							
949-954	Gs1Ga1 Ag1Cg1	10YR4/1	1	0	0	3	0	As+
954-962	Lost							
962-965	As2Ag2	10YR5/1	1	3	0	4	0	Ga+
965-967	Ga2As1 Ag1Gs+	10YR6/2	1	0	0	4	0	
967-1010	Ag2As2	10YR5/2	1	0	0	4	0	Ga+
1010-1014	Ga2Ag1 As1	10YR6/1	1	0	0	2	0	

Table 3.2

STRATIGRAPHIC DESCRIPTION OF THE LLYN HENDREF CORE

All contacts gradational unless otherwise stated

Depth cm.	Comp.	Colour.	Nig.	Str.	Elas.	Sicc.	Humo.	Comments
000-127	Ld4Ag+	5YR2.5/1	4	0	2	3	4	Alder wood
127-129	Ld3Ga1	5Y 4/1	3	0	1	3	4	
129-285	Ld4Ag+	5YR2.5/1	4	0	2	3	4	+V
285-323	Ld4Dg+	5YR2.5/1	4	0	2	3	4	
323-345	Ld4Dl+	5YR2.5/1	4	0	2	3	4	
345-376	Ld4Dg+	5YR2.5/1	4	0	2	3	4	+Birch bark
376-400	Ld3Dg1	5YR2.5/1	4	0	2	3	4	
400-457	Ld2Dg2	5YR2.5/1	3	0	2	3	4	
475-458	Ga3Ag1	10YR 6/1	1	0	0	2	0	Mica rich Ld+
458-460	Ld2Dg2	5YR2.5/1	3	0	2	3	4	Dl+ Ag+
460-497	Ld3Dg1	10YR 2/2	3	0	2	3	4	Ga+ Dl+
497-500	Ld4Dg+	5YR2.5/1	4	0	2	3	4	
500-546	Ld3Dg1	5YR2.5/1	4	0	2	3	4	
546-552	Ld3Dg1	5YR 3/1	4	0	2	3	4	
552-720	Ld4	7.5YR2/0	4	0	0	3	4	Moss, QP.659cm
720-721	Ld4Ga+	5YR 4/1	2	3	2	3	2	QP. 720cm
721-726	As1Ga3	5Y 4/1	2	3	2	0	2	Ld+ Ga^ V+
726-729	As2Ga2	2.5Y 4/2	2	4	2	3	0	
729-731	As2Ga2	2.5Y 2/0	2	4	2	3	0	Lm. 1mm QP.731
731-734	As4ga+	2.5 4/2	2	2	2	3	0	
734-742	As2Ga2	2.5Y 4/2	3	4	2	3	0	
742-743	Ld3As1	2.5Y 3/2	3	0	2	3	3	
743-744	Ld4Dg+	5YR2.5/1	4	0	2	3	4	
744-745	Gs2Cg1 As1Lc+	5Y 4/2	2	1	0	3	0	Calcareous Nodules
745-750	As3Ag1	10YR 4/2	3	1	0	3	0	
750-800	As4Ga+	10YR 4/2	1	3	0	3	0	Sand bands <1m
800-804	Slumped material							
804-900	As4Ag+	10YR 4/2	2	3	1	3	0/1	Complex bandin
900-932	As4Ag+	5YR 4/2	2	1	1	3	0	
932-942	As3Ga1	10YR 4/2	2	3	1	3	0	
942	Sharp sloping boundary							
942-966	As3Ga1	2.5Y 4/2	2	4	1	3	O	Ga^
966-1006	Cg4Ga+		2	0	1	3	0	Ag+ Fines dowr

QP. Quartz Pebble
+V. Vivianite present
Ga^ Sand increasing
Lm Laminae

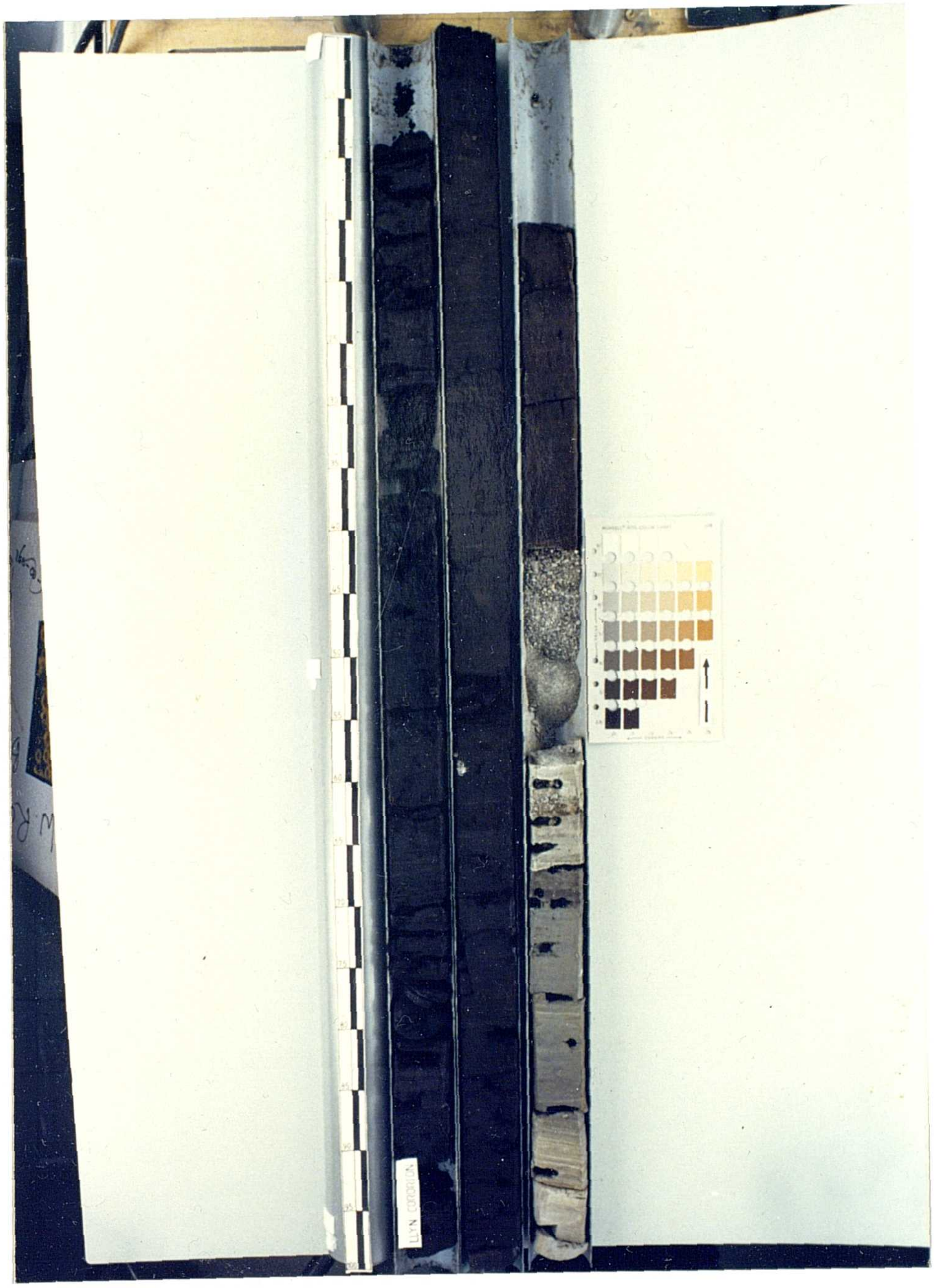


Plate C LLYN CORORION: Basal Cores

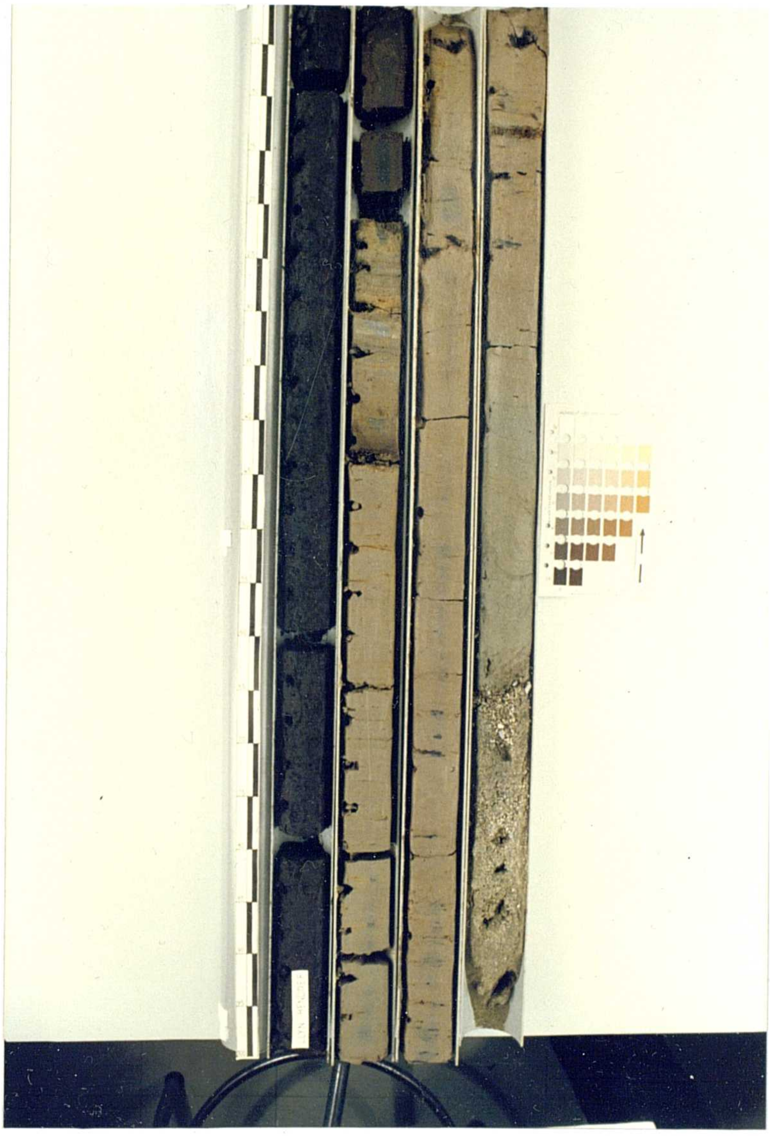


Plate D1 LLYN HENDREF: Basal Cores

Plate D2 LLYN HENDREF: Folding In Inorganic Section

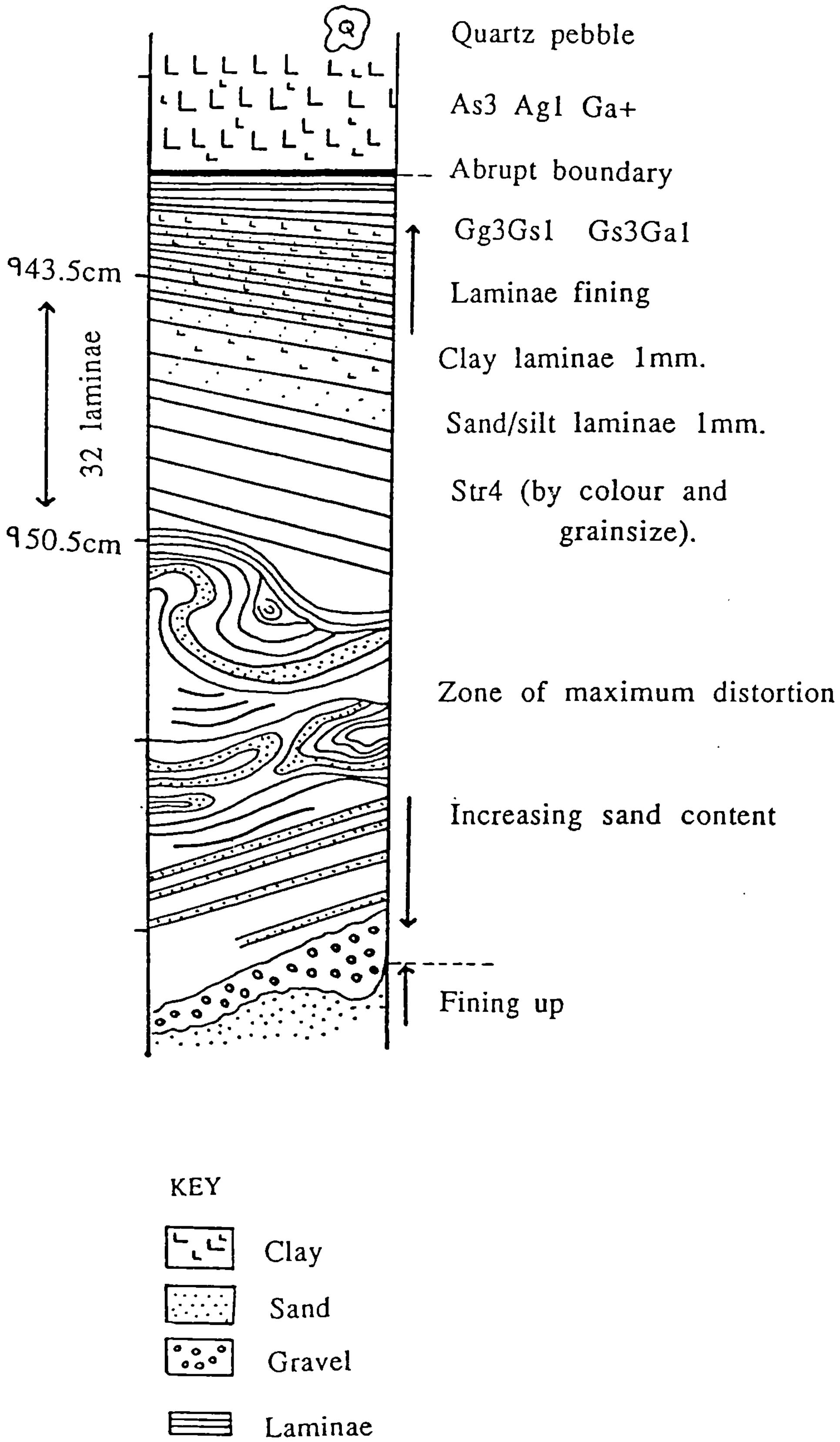


Figure 3.1 Folding in the basal clays of the Llyn Hendref core

NaOH, followed by acetolysis (Erdtman, 1960).

A variety of techniques have been developed to remove mineral matter. Coarse grains can be removed by sieving, but clay and silt sizes are often difficult to eliminate and obscure pollen during counting as well as diluting pollen concentrations in the final preparation. The use of hydrofluoric acid (HF) to digest inorganic sediments is standard practice (Faegri and Iversen, 1975). Depending on the quantity and nature of the inorganics, and acid temperature, the sample is immersed for a set period of time. Although it is generally accepted that pollen exine is resistant to HF, Bjorck et al., (1978) state that pollen grains may be ruptured after treatment due to physical or chemical breakdown.

The HF method is relatively time consuming and hazardous, and modifications have been developed to reduce contact time between the sample and acid. Sodium pyrophosphate has been used as a clay deflocculent reducing the time that samples are immersed in acid (Bates et al., 1978). This was modified by Heusser and Stock (1984), who used a series of sievings and oxidation with sodium chloride to reduce the volume of material undergoing HF treatment.

Differential centrifuging (ie. gravity separation, Knox, 1942) is a technique which utilises heavy liquids (eg. bromoform, zinc bromide) and the density difference between organic and minerogenic material. The density of minerogenic material tends to be greater that $2.6 g/cm^3$ and Holocene pollen has a density of less that $1.6 g/cm^3$ (Juvigne, 1975). A heavy liquid with a density of between $1.8 g/cm^3$ and $2.4 g/cm^3$ is thus suitable for density separation. Faegri and Iversen (1975) describe a flotation method with pollen concentrated in a froth-forming liquid and the inorganic portion sinking, although HF acid was still recommended to eliminate finer mineral grains.

Bjorck et al., (1978) compared the results from the standard HF method, with a technique involving HF acid, sieving and heavy liquid separation and concluded that the latter method resulted in higher pollen concentrations in reduced time. All the modified methods reduce the time pollen spends in acid, but the use of HF is not totally eliminated.

3.2.2 POLLEN PREPARATION METHOD

Figure 3.2 summarises the preparation technique used. It closely follows the standard technique for the preparation of organic sediments (Faegri and Iversen, 1975), but a modified method was used to extract pollen from minerogenic material. To enable pollen concentrations and accumulation rates to be estimated, a standard volume ($1cm^3$) of sediment was extracted with a brass sub-sampler, and exotic *Lycopodium* tablets were added before sample preparation (Stockmarr, 1971). Samples were taken at 8cm, 4cm, or 2cm intervals depending on the degree of biostratigraphical resolution required. After a skeleton pollen diagram identified areas of rapid change in pollen frequencies, a close sampling interval was adopted.

In initial preparations the final sample often coagulated (a problem also noted by Botterill, 1988), making accurate counting difficult. Experimentation showed that extra washing (a minimum of 5 times) after KOH treatment, and an extra rinse in glacial acetic acid after acetolysis were enough to prevent coagulation. The final residue was dehydrated in tertiary-butyl alcohol (T.B.A.), stained with 0.2% Safranin and stored in silicone oil (2000 cs; Andersen, 1960).

PREPARATION TECHNIQUE FOR INORGANIC RICH SEDIMENTS

Initial study of the Llyn Cororion core showed that samples in the top metre of the core and between 9m and 9.5m had a relatively high mineral content (10-20%). This required a quick and effective method for the removal of minerogenic material. Initially, eight samples were prepared using the standard HF method but the results were poor, with both low pollen concentrations and poor preservation. This hampered counting and identification, with grains often obscured by

Figure 3.2 Pollen preparation method

SUBSAMPLE $1CM^3$ AND WEIGH
ADD LYCOPODIUM TABLETS

WASH IN 10% HCl
*

WASH IN DISTILLED WATER
*

BOIL IN 10% NaOH (10 MINS.) RECORD COLOUR OF SUPERNATANT
DILUTE WITH DISTILLED WATER
*

SIEVE THROUGH 118 MICRON MESH, RETAIN POLLEN WASHINGS
*

WASH UNTIL SUPERNATANT IS CLEAR (5X)
*

INORGANIC SEDIMENTS

SIEVE THROUGH 10 MICRON MESH
RETAINING POLLEN ON SIEVE

WASH IN 10% HCl
*

ADD 10ml ZnCl ($p>1.8G/CM^3$)

CENTIFUGE (3000 RPM, 15 MINS)

DECANT THE SUPERNATANT

CONTAINING THE POLLEN

DILUTE SUPERNATANT WITH
DISTILLED WATER
*

WASH IN 10% HCl
*

WASH IN DISTILLED WATER
*

ORGANIC SEDIMENTS

WASH IN GLACIAL ACETIC ACID
*

ACETOLYSIS FOR 10 MINS.
*

WASH IN GLACIAL ACETIC ACID
*

WASH IN DISTILLED WATER
(X2)
*

WASH IN 2% NaOH
*

STAIN
*

DEHYDRATE IN
2-METHYLPROPAN-2-OL
*

STORE IN SILICONE OIL

* CENTRIFUGE

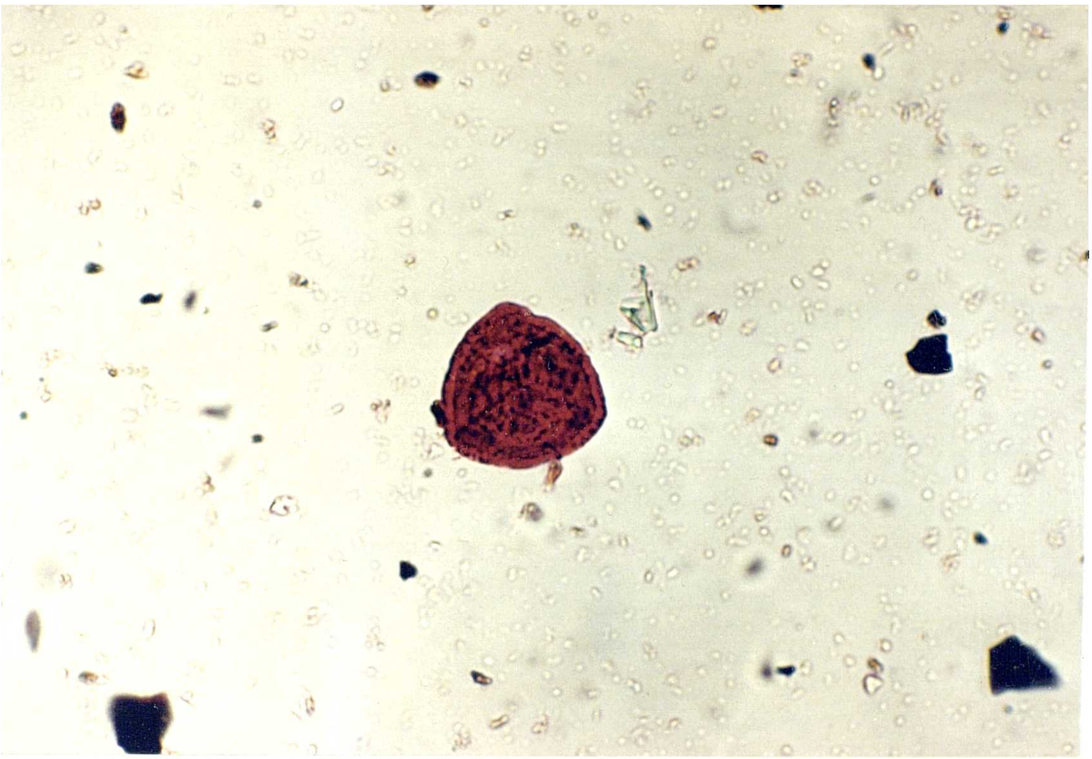


Plate E Sample prepared using the modified $ZnCl_2$ method

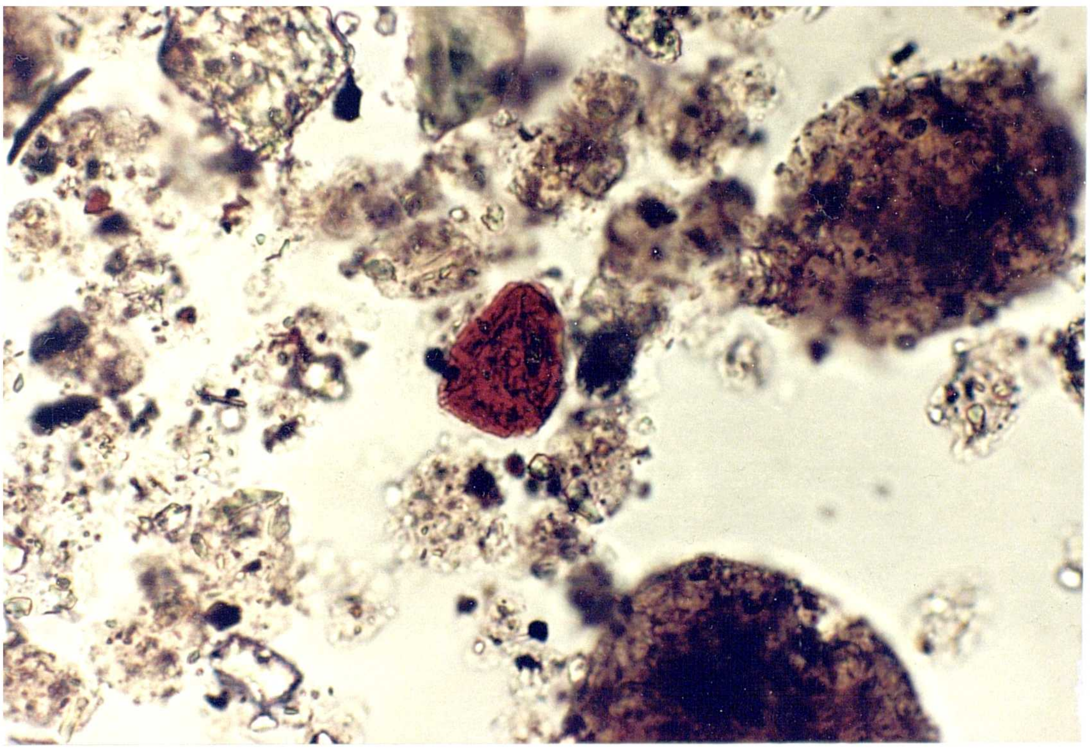


Plate F Sample prepared using the convential HF method clay material, (plate F), resulting in low pollen sums.

A modified method developed by Allen (pers. comm., 1987) totally eliminates the use of HF acid, (fig. 3.2). Coarse material was removed by sieving through a 118 micron mesh and wet sieving through a 10 micron mesh removed clay, fine silt and organic material. Zinc chloride (of density >1.8g/cm^3) was then used for centrifuging to separate out sand particles. At this stage it was important to thoroughly mix the sediment and zinc chloride so that no pollen was trapped within the denser sediment (Moore and Webb, 1978). Faegri and Iversen (1975) state that gravity separation of pollen is ineffective, but examination of the mineral residue after treatment clearly indicated that all the grains had been extracted.

MODIFIED METHOD: RESULTS AND CONCLUSIONS

Slides prepared using the modified method were clear of inorganic material and fine organic material, enabling more efficient and accurate counting (plate E). Table 3.3 shows results from samples prepared using both the $ZnCl_2$ and HF method. Material prepared using zinc chloride consistently has greater quantities of recognisable grains and a higher taxa diversity. There were some taxa, recorded in the $ZnCl_2$ samples (*Quercus*, *Alnus*, *Gramineae*, *Artemisia*, *Juniperus* and Ericales) which were not identified in the HF samples, and there were consistently more exotic *Lycopodium*.

These preliminary results show that there are certain advantages in using a combination of $ZnCl_2$ and sieving, without the use of HF acid. The pollen quality and quantities are much improved, without any requirement for special preparation facilities. In addition, the method is relatively quick, inexpensive and less hazardous than using HF or bromoform. The pollen is not exposed to corrosive acid, and sieving reduces the volume of material undergoing chemical analysis (Heusser and Stock, 1984). The residue contains a higher pollen concentration, reducing the number of slides that require counting, and identification is accurate and

Table 3.3 A comparison between samples prepared using HF and samples prepared using $ZnCl_2$

	Pollen Sum	No of taxa Counted	Exotic Lycopodium
Z 963	61	16	208
H 963	11	3	1
Z 970	20	3	92
H 970	2	0	43
Z 974	71	13	229
H 974	8	2	5
Z 978	12	7	76
H 978	11	2	15
Z 986	25	8	172
H 986	6	2	4
Z 994	30	12	83
H 994	13	4	57
Z 1002	29	12	83
H 1002	11	1	25
Z 1009	27	11	42
H 1009	14	5	63

Z = Samples prepared using $ZnCl_2$ method
H = Samples prepared using the HF method

rapid.

3.3 POLLEN ANALYSIS AND MICROSCOPY

3.3.1 POLLEN COUNTING

Slides were prepared by distributing a small volume of homogeneous residue evenly over a clean glass slide and sealing it with a slide cover held in place with nail varnish at each corner. Routine counting was carried out using an HM Lux 3 microscope fitted with 10x peniplan oculars and x40 apochromatic objective lenses. A magnification of x400 was used except for critical identification when oil immersion and a magnification of x1000 was utilised, using a x100 apochromatic oil immersion objection and anisol as the immersion fluid. To avoid the problem of differential pollen dispersion on the slide due to different grain sizes, traverses were regularly spaced and covered the whole slide, (Brookes and Thomas, 1967)

3.3.2 THE POLLEN SUM

Birks and Birks (1980) maintain that it is necessary to count grains until each pollen type is a constant percentage of the pollen sum. Five hundred tree taxa are often considered adequate to reflect forested landscapes with general vegetational changes, although it has been suggested that a pollen sum of two thousand is required when attempting to identify human impact on the landscape (Berglund and Ralska-Jasiewiczowa, 1986).

The strategy adopted here was to count many levels at a reduced pollen sum rather than to have fewer levels with a slightly increased accuracy. A pollen sum (P) of 500, including trees, shrubs, herbs and spores, but excluding aquatics, was utilised, and other categories (aquatics, algae, indeterminables, unknowns and pre-Quaternary) were recorded separately. For all organic samples, counts of between 506-1375 grains were obtainable from one or two slides, but this was not possible for minerogenic samples where counts varied between 9 and 576 taken over three or four slides.

The pollen sum for each level is shown to the right of the pollen diagram, and indicates the degree of accuracy for that level. All pollen types are included in the calculation sum on which their frequency is based (Faegri and Iversen, 1975). Taxa outside the pollen sum are calculated as a percentage using the pollen sum plus that particular taxon. This avoids the problem of having any taxa greater than 100%.

Pollen sum (P) = sum of [trees+herbs+shrubs+spores]

Aquatics (AQ) % calculated as a percentage of [P+AQ]

Algae (AL) % calculated as a percentage of [P+AL]

Indeterminables (ID) % calculated as a percentage of [P+ID]

Pre-Quaternary (PQ) % calculated as a percentage of [P+PQ]

3.3.3 POLLEN IDENTIFICATION

Pollen and spores were identified to the lowest possible taxonomic level, using the keys of Faegri and Iversen (1975), Moore and Webb (1978) and Birks (1973). Continual use was made of the reference collection at the University College of North Wales and the University of Cambridge. Photographs in Moore and Webb (1978) and those at University College of North Wales were also consulted. The standard notation of Birks (1973) was used to indicate the accuracy of identification.

To provide extra information on depositional environment and possible processes within the catchment, indeterminable grains were also classified (Lowe, 1982; Tipping, 1987a). Indeterminables can be divided into a number of categories (Cushing, 1967; Birks and Birks, 1980), but the following descriptions are adapted from Berglund and Ralska-Jasiewiczowa (1986).

Unknown: A grain that has not been identified but is intact.
Corroded: Exine etched, pitted and perforated.
Degraded: Exine thin, fusion of structural elements or sculpturing.
Broken: Mechanical damage to the grain.
Crumpled: Grain crushed or crumpled from original shape.
Concealed: Hidden due to mineral or organic debris.

Grains that had undergone more than one type of degradation were assigned to the dominant type (Tipping, 1987a).

SPECIFIC IDENTIFICATIONS

Pre-Quaternary: Pre-Quaternary grains were trilete spores identified by amorphous texture, size and thickness (plate F). Identification of the spores from Llyn Cororion was undertaken by B.McPhilemy, (section 3.7.2). Those from Llyn Hendref were identified using notes and photographs and descriptions from Smith and Butterworth (1967) and Tschudy and Scott (1969).

Salix: A few *Salix* grains at the base of the core resembled *Salix herbacea*, but no systematic separation of the grains was undertaken.

Corylus/Myrica: Separation of these two grains is possible (Moore and Webb, 1978), but due to their abundance it was too time consuming to accurately separate them. All grains are therefore included on the pollen diagram under the heading *Corylus/Myrica*. The majority of grains are probably *Corylus*, but where necessary the possibility that *Myrica* may have been present is considered.

Betula: No attempt was made to distinguish different species, although it was noted that some grains at the base of the cores were from *Betula nana*.

Ericaceae: The only species distinguished was *Calluna vulgaris*. All other grains are included under Ericales.

Rumex: At Llyn Cororion all grains were assigned to *Rumex* undiff. but at Llyn Hendref there was systematic distinction between *Rumex acetosa* and *Rumex acetosella*. All other grains were assigned to *Rumex* undiff.

Gramineae: no differentiation into species was attempted but Cerealea were distinguished using grain size (>35 microns).

Cyperaceae: Identification to species was not attempted due to the lack of a sufficiently detailed reference collection.

Polypodiaceae: *Pteridium*, *Dryopteris* and *Polypodium* were identified. All unidentifiable grains (monocolpate spores) for this category were placed under Filicales.

Cannabaceae: The problem of distinguishing between *Cannabis sativa* and *Humulus lupulus* pollen was emphasised by Walker (1955) who showed the importance of being able to recognise fossil Cannabaceae down to species level when elucidating land-use. Although many British Postglacial diagrams have substantial curves for '*Humulus type*' or '*Humulus-Cannabis*', there have been few attempts to differentiate between the two species. Where it has been done, it is often based on circumstantial evidence (eg. the presence of cereals, frequency of the pollen type) rather than positive identification.

Godwin (1967) was the first to identify distinguishing criteria: The absence of an internal annulus in *Humulus*; the tectum of the annulus in *Cannabis sativa* rising steeply above the general surface and extending down inside the grain; and the distinctive outline of the *Humulus* pore in polar view. The disadvantage with these criteria is that they demand high magnification oil immersion which is time-consuming (van Zant *et al.*, 1979; French and Moore, 1986).

Size has been used to separate the taxa (eg. Pahlsson, 1981), and although this can be done routinely Punt and Malotaux

(1984) regard this as the least useful distinguishing criteria, due to the large size variation within the species and the large overlap in grain diameter between the species (table 3.4).

Punt and Malotaux (1984) list a number of different morphological characteristics to differentiate the species, the most useful feature being sculpturing identified under the SEM. Again this is time consuming and impractical when dealing with large quantities of fossil material (Whittington and Gordon, 1987).

French and Moore (1986) concluded that the angle of slope of the annulus, and tectum penetration below the endexine, were unreliable criteria due to the small differences involved and the degree of overlap between the species. Work was then concentrated on pore protrusion, and although there was considerable variation between the populations, Cannabis generally had greater pore protrusion compared with Humulus. This has been supported by Whittington and Gordon (1987) who reviewed distinctions between Cannabis and Humulus when looking for a criteria applicable during routine analysis. Although pore protrusion could not be used to identify individual grains, it could be used to estimate the proportions of Humulus and Cannabis in a sub-fossil sample.

Table 3.4 A comparison of Humulus and Cannabis pollen grain diameters in silicone oil

Author	Diameter of grain (in silicone oil)	Range (Microns)	Average (Microns)
Punt and Malotaux (1984)	Humulus	18 - 30	20.5
	Cannabis	21 - 28	23.0
Whittington and Gordon (1987)	Humulus	10 - 30	16.2
	Cannabis	12.5-30	19.8

A combination of criteria were used in this project including pore protrusion, pore width, grain diameter and pore shape. Each grain was studied under oil immersion at x1000 magnification, and the image was transmitted to a television monitor where measurements were made using a calibrated scale. Using the pore protrusion data, and data from Whittington and Gordon (1987), it was estimated that 72%+/-3% of the grains at Llyn Cororion were attributable to *Cannabis sativa*. At Llyn Hendref the values were significantly lower at 10%+/-5%.

3.4 DATA PRESENTATION AND POLLEN DIAGRAM CONSTRUCTION

The following calculations and definitions have been used throughout:

Pollen concentration (Pconc): the number of grains per unit volume of wet sediment (gr/cm^3).

$$(\text{Pconc}) = \frac{\text{Exotic spores added} \times \text{fossil pollen counted}}{\text{Exotic spores counted} \times \text{volume}}$$

Sediment accumulation rate: The net thickness of sediment accumulating per unit time after compaction and diagenesis (Birks and Birks, 1980). This is estimated from a series of radiocarbon dates and measured in cm/yr.

Deposition time: The amount of time per unit thickness of sediment (yrs/cm).

Pollen accumulation rate/Influx (PAR): This is defined as 'the net number of grains accumulated per unit area of sediment surface per unit time'. Units are grains/cm^2/year, (gr/cm^2/yr).

PAR = Pconc x sediment accumulation rate
or PAR = Pconc / deposition time.

Percentage, concentration and accumulation data have been plotted against depth. Diagrams were constructed using the Fortran program 'POLLDATA version 4', (Gordon and Birks, 1972) modified for use on the University College of North Wales VAX by J. Allen. Data entered includes counts of pollen, spores, exotics, and sample level, and results are produced in specified categories. Taxon frequencies are calculated as a percentage of a specified sum, and pollen concentrations and accumulation values are also computed. Graphic output is as a continuous curve, or as an histogram. A timescale and depth scale are included and local pollen assemblage zones are indicated, coded with site initials and numbered from the base upwards.

The frequency curves have been grouped into broad categories of trees, shrubs, herbs, spores, aquatics, algae and indeterminables. All horizontal scales within each diagram are comparable and a 10x exaggeration curve emphasises taxa with low values. The construction of a curve as opposed to a histogram makes overall trends and variations easier to see and assess but involves data interpolation (Moore and Webb, 1978). The tree frequencies have been ordered to reflect the general sequence of arrival at each site. The pollen sum for each level is shown to the right of the diagram and states the number of taxa included within it.

Complete accumulation rate and concentration diagrams have not been included, and only curves of trees, shrubs and significant herbs are presented. Many herb concentrations are too low to show on the diagram at the chosen horizontal scale. The order of taxa is identical to the percentage diagrams and the horizontal scales for both sites are comparable. All pollen diagrams are included in a pocket at the back of the thesis, (enclosures 1-6).

3.4.1 POLLEN DIAGRAM ZONATION

INTRODUCTION AND PREVIOUS WORK

Munthe, Hede and von Post (1925) were the first to subdivide pollen diagrams into zones to aid description and correlation. Their eleven zones were related to a modified Blytt-Sernander sequence of climatic periods (eg. Boreal, Atlantic, Sub-Boreal and Sub-Atlantic; Godwin, 1975) and were used for correlation assuming that changes in the pollen record reflected vegetational variations caused by widespread climatic changes (West, 1970).

A system of eight numerical pollen assemblage zones was erected for the Postglacial of England and Wales (Godwin, 1940) based on fluctuating arboreal pollen thought to reflect climatic oscillations. A similar scheme was developed for Ireland (Jessen, 1949), later modified by Mitchell (1956). These pollen zones assume that climate was the primary cause of vegetational variation, and so any changes would be synchronous over large areas. Thus zones may be equated with climatic events (eg. Zone 2 = Allerød Interstadial of North-western Europe).

With the introduction of radiocarbon dating, pollen zones also took on chronostratigraphic significance and became regarded as 'periods of time having a particular type of climate recorded in the pollen stratigraphy', (Moore and Webb, 1978), even though the synchroneity of the vegetational changes had not been verified. Despite the confusion caused by the mixing of biostratigraphic, lithostratigraphic and chronostratigraphic criteria (Mangerund et al., 1974) the system has been extensively used as a framework for pollen analysis (eg. Moore, 1972a; Chambers, 1982a), although it has now been recognised that there are disadvantages associated with the assumptions behind the Godwin zonation system. Fluctuations in arboreal pollen are used to define the zone boundaries, but it is now known that some variations may not reflect climatic change (eg. decline in Tilia at the VIIb/VIII boundary) but may be a reflection of anthropogenic activity (Turner, 1964). This makes it unlikely that vegetational changes will be widespread or synchronous over large areas, which then questions the temporal connotations of the original zones (Moore and Webb, 1978).

Work away from southern Britain (eg. Pennington, 1977a, 1970) has shown that regional vegetational variations make it difficult to recognise Godwin's zone boundaries. Moore (1972a) noted that the behaviour of Corylus in Wales was distinctly different to that in southern England, and Moore and Webb (1978) stated that 'the significance of many regional and local variations in the general picture have been lost as a result of this conformity on the part of the British palynologist'. There is increasing evidence for strong regional differentiation of vegetation within the British Isles both in the Postglacial (Bennett, 1988a) and in the Late Devensian (Pennington, 1977b) making it difficult to apply a single zonation scheme to a number of widely separated sites (West, 1970).

A comprehensive review by Smith and Pilcher (1973) illustrated the diachronous nature of vegetational change and showed that similar pollen zones were not synchronous. The boundaries of the pollen zones have been dated at numerous sites, and the results show that the zones were transgressive in the British Isles with respect to both latitude and altitude. Smith and Pilcher (1973) recommended that the idea of synchronous boundaries should be abandoned.

Recognising these difficulties, Cushing (1967) utilised 'local pollen assemblage zones' in North America, and advocated that the pollen assemblage zone should be the basic unit for Quaternary pollen stratigraphy. This idea was adopted and used in the British Isles (eg. Birks, 1970, 1972). A pollen zone is a biostratigraphic unit corresponding to an assemblage zone (Hedberg, 1976) in which the zone is defined only on its proven fossil content. A pollen assemblage zone does not therefore necessarily reflect vegetational changes and is defined 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 frequency of its contained pollen and spores' (Gordon and Birks, 1972; Birks and Birks, 1980). A pollen assemblage zone in this context is not constrained by pre-defined limits, or by reference to other sites and each zone is unique to the location from which the pollen assemblage has been described.

Where possible local pollen assemblage zones (LPAZ) should be fully described and calibrated with a C14 chronology. Similar zones may be diachronous units and so cannot be assigned to standard chronostratigraphic units (West, 1970). When a series of local pollen assemblage zones have been correlated using radiocarbon dating, it may then be possible to construct a series of regional pollen assemblage zones (RPAZ) based on zone similarities (eg. Bennett, 1988a).

Local pollen assemblage zones have been used in a number of studies in North Wales (eg. Hibbert and Switsur, 1976; Ince, 1981) and these have illustrated the advantages of not using an imposed framework. Local pollen zones simplify the data yet retain local vegetational characteristics. Watts (1977) states that 'local pollen zones, carefully defined on the basis of available data only, and their subsequent grouping into regional zones, are the most effective and convenient means currently available for summarising succinctly the mass of information contained within pollen diagrams'. The lack of radiocarbon dates at some sites means that the Godwin zonation system and the Blytt-Sernander scheme are often used as a basic framework and some recent work (eg. Chambers, 1982a) is still correlated with these schemes.

Computer zonation of pollen diagrams has enabled accurate processing of large quantities of data. The resulting zones are strict 'assemblage zones', ie. they are based entirely on the observed fossil content, and are not constructed with bias, preconceptions or inferences (Birks and Birks, 1980). The advantages of a computerised numerical zonation system are that it requires the operator to clearly define the criteria used for the zonation, and that the process is repeatable.

ZONATION METHOD

The diagrams were initially subjectively zoned by eye and then by computer utilising the programs 'POLLDATA' and 'ZONATION' (Gordon and Birks, 1972). The three numerical programs were 'CONSLINK', a constrained single link cluster analysis, 'SPLITINF', and 'SPLITLSQ'. CONSLINK compares adjacent samples and calculates dissimilarities between samples; these are then grouped into clusters of samples of similar pollen compositions. However, CONSLINK is selective to single but atypical samples (Birks, 1986). SPLITINF and SPLITSQ examine the complete data set, measure the variability within the sequence (Birks and Gordon, 1985), and attempt to reduce within group variation. The first division is placed between the two most homogeneous pair of zones where there is the largest reduction of within group sum of squares. The remaining groups are then further sub-divided on the same basis.

The taxa chosen for the program are shown in table 3.5. All levels from the organic portion of the core were included in the zonation, and a total of ten divisions were requested. The zones broadly agreed with visually constructed zones. Birks (1974) states that 'zonations by various numerical methods generally agree with the conventional pollen zones applied by visual inspection' except for the elm decline which is not considered statistically significant by numerical methods.

Final zones are drawn on the pollen diagrams (enclosures 1-6) and are described in sections 3.5.1 and 3.5.2. The zone boundaries are drawn at levels that were actually counted. Each zone represents an interval of relatively stable pollen composition, with the boundaries placed at points of abrupt change (Gordon and Birks, 1974). These changes are usually ascribed to changes in vegetation, but at Llyn Hendref some boundaries also have sedimentological significance, (section 5.4.2). The zones have been ascribed names based on the dominant taxa, and the length of each zone has been estimated

Table 3.5 Taxa used for zonation program

Llyn Cororion:

Betula	*Ulmus*
Quercus	*Tilia*
Pinus	*Alnus*
Fraxinus	*Salix*
Juniperus	*Corylus*
Gramineae	Cyperaceae
Cannabaceae	*Plantago* undiff.
Filipendula	Compositae Liguliflorae
Rumex undiff.	*Artemisia*

Llyn Hendref:

Betula	*Ulmus*
Quercus	*Pinus*
Alnus	*Salix*
Corylus	Cyperaceae
Juniperus	Gramineae
Plantago undiff.	Cannabaceae
Filipendula	Compositae Liguliflorae
Artemisia	

Table 3.6a Pollen percentages from basal inorganics

LLYN CORORION POLLEN ASSEMBLAGE ZONE LCA

Depth cm	963	970	974	978	986	994	1002	1009
Taxon								
Betula	21	10	1	0	0	10	7	4
Pinus	16	74	58	33	22	10	10	13
Alnus	0	0	6	0	8	0	3	4
Quercus	2	0	10	0	0	3	3	0
Tree sum	39	84	75	33	30	23	23	21
Corylus	8	0	3	0	0	0	0	0
Salix	3	0	0	0	0	0	0	0
Juniperus	2	0	0	0	0	0	0	0
Shrub sum	13	0	3	0	0	0	0	0
Herb sum	43	0	11	33	28	43	45	36
Spore sum	5	16	11	34	42	34	32	43
No of taxa	16	3	13	7	8	12	12	11
Indeter.	8	13	4	33	65	43	78	66
Pre-Quat.	2	10	+	+	+	+	+	+
Pollen Sum	61	20	71	12	25	30	29	27

Table 3.6b Pollen percentages from basal inorganics

LLYN HENDREF

			LHB					LHA				
Depth cm	724	726	730	734	738	743	752	760	768	776	784	792
Taxon												
Betula	4	2	3	4	10	18	0	0	17	7	9	8
Pinus	0	2	0	2	0	6	7	25	22	31	20	26
Alnus	0	0	1	0	0	+	14	0	0	0	11	22
Fraxinus	5	0	0	0	0	+	0	0	0	0	0	0
Quercus	0	0	+	1	2	1	7	4	0	0	0	4
Tree sum	9	4	4	7	12	25	28	29	39	38	40	60
Corylus	0	1	3	1	0	+	21	0	0	8	9	11
Salix	13	8	3	2	1	1	0	0	6	7	0	2
Juniperus	0	0	0	0	1	2	0	0	6	0	0	1
Shrub sum	13	9	6	3	2	3	21	0	12	15	9	14
Herb sum	65	82	84	76	78	67	35	52	33	24	32	21
Spore sum	13	5	6	14	8	5	16	19	16	23	19	5
No of taxa	12	21	24	28	17	26	10	11	6	17	14	26
Indeter.	21	1	4	+	5	2	48	36	5	18	20	11
Pre-Quat.	+	+	+	1	1	+	+	10	5	10	+	+
Pollen Sum	23	196	191	561	137	580	14	27	18	61	45	195

from the radiocarbon dates. The zones are specific to each site, and there has been no attempt to correlate them with regional pollen assemblage zones (cf. Edwards, 1980). All correlation with other sites has been done within a chronostratigraphic framework provided by the radiocarbon dating.

For each site informal zone descriptions and definitions have been included with a described assemblage, age estimate and description of contacts. These are based on the pollen percentage diagram but the concentration and pollen accumulation data have also been considered. The inorganic portion of the core is not included in the pollen zonation program, but a brief description of the pollen content from these sediments is presented.

3.5 POLLEN ZONE DESCRIPTIONS

3.5.1 LLYN CORORION

Pollen assemblage zone within the inorganic portion of the core.

Eight inorganic samples were prepared and general results are illustrated in table 3.6. Pollen sums did not exceed 73, with maximum concentrations reaching 1000 gr/cm^3. With such small pollen sums the results have limited accuracy and only general trends and common taxa are noted.

LCA GRAMINEAE-ARTEMISIA POLLEN ASSEMBLAGE ZONE

Type Site : Llyn Cororion
Core A 963-1009cm
Estimated Age >9680 BP
Base arbitrary based on first sample taken.

The zone is characterised by tree and herb taxa, with few shrubs and a decreasing spore record. The tree record is dominated by Pinus with maximum frequencies (74%, concentrations 152gr/cm^3) at 970cm. Betula percentages are relatively steady rising at the zone top to 30% (concentration

232 gr/cm^3. There are low and sporadic records of Quercus and Alnus, and an isolated grain of Tilia. Shrub frequencies are minimal with Corylus recorded in the top three samples (<10%, concentration 420 gr/cm^3) with isolated Salix (3%) and Juniperus (1.6%). There is an isolated grain of Hedera helix.

Gramineae and Cyperaceae dominate the herb record and there are steady curves of Ericales undiff. and Artemisia (concentration <50gr/cm^3). Other herbs include; Compositae Liguliflorae, Caryophyllaceae, Chenopodiaceae, Cruciferae, Filipendula, Leguminosae, Trifolium, Polygonum persicaria, Rosaceae undiff., Rumex acetosella and Rumex acetosa. The spore record is dominated by decreasing Lycopodium, Sphagnum, Pteridium and Filicales undiff.

Aquatic species are virtually absent except for one grain of Myriophyllum verticillatum. Pediastrum is present in the top two samples reaching 36% (concentration 626gr/cm^3). Frequencies of indeterminable grains are high and include all categories, with highest frequencies recorded for crumpled grains. Pre-Quaternary counts are high throughout, decreasing in the uppermost level (15%) associated with increasing zygospore counts.

Pollen assemblage zones in the organic portion of the core.

LC1 BETULA-SALIX-JUNIPERUS ASSEMBLAGE ZONE
Type site: Llyn Cororion
Core A 948-936cm
Estimated Age 9680 BP-9600 BP (duration 80 RC. YRS.)
Base defined by onset of organic sedimentation.

Zone one is characterised by high herb and shrub values (maximum 83%) at the base but these decline as tree pollen increases from 15% to 53%. At the zone top there is a slight decrease in tree values (30%) associated with a shrub increase (to 28%). Spore values increase from 1% to 13% through the zone.

The tree record is dominated by Betula which is present from the onset of organic sedimentation and increases through the zone but with a slight reduction (52% to 29%) at 936cm. Pinus is also recorded but at always less than 1.5%. Single grains of Quercus and one grain of Ulmus occur.

Salix and Juniperus are the principal contributors to the shrub record, and there is only a sporadic occurrence of Corylus. Juniperus is at a maximum (36%) at the zone base but as Salix values rise (from 16% to 25%), Juniperus declines markedly.

The herbaceous record is diverse and is dominated by grass and sedges. Near the base, Gramineae has maximum values of 20% and Cyperaceae of 7% but then they fall to low levels (2.5%). There are also continuous curves for Ericales undiff., Compositae Tubuliflorae, Cruciferae, Plantago undiff., Rosaceae undiff., Thalictrum and Rumex undiff. Filipendula cf. ulmaria reaches values of 6.7% and Artemisia is present in low quantities (1%)

The spore record is varied with the Filicales (6%), Dryopteris (9%) and Equisetum being the dominant components. There is also an isolated count for Lycopodium. Myriophyllum alterniflorum (4-7%) dominates the aquatic record, but Myriophyllum spicatum is also present with low values for Potamogeton. The algal record is continuous with low values of Pediastrum and Botryococcus, and indeterminable grains include crumpled, broken, concealed and degraded grains, with a maximum of indeterminables (15%) at 948cm.

Taxa diversity is relatively high with the number of taxa in the pollen sums ranging from 18 and 25.

ZONE LC1 POLLEN CONCENTRATIONS AND ACCUMULATION RATES

The concentration diagram shows that the large initial increase in the Betula percentage curve is an artifact of the percentage method, and concentrations rise steadily from $2.7 \times 10^4 gr/cm^3$ to $1.4 \times 10^5 gr/cm^3$. Salix concentrations are steady in the lower part of the zone and do not appear to be suppressed by increasing Betula. Juniperus concentrations reflect the percentage curve with high concentration values ($1.2x10^4gr/cm^3$) and the influx value is $6.8x10^4gr/cm^2/yr$ at the base, declining as Betula and Salix rise. A slight decrease in Betula concentrations is mirrored by small increases in Salix and Juniperus. Tree concentrations vary between $2.8x10^4gr/cm^3$ and $1.4x10^5gr/cm^3$.

Cyperaceae values decrease from $2.3x10^3gr/cm^3$ to $1.0x10^3gr/cm^3$ reflecting the percentage data. Throughout the zone, Gramineae concentrations remain stable (around $6.0x10^6gr/cm^3$), in contrast to the percentage data which suggests decreasing values.

The total average pollen concentrations range from $1.5x10^5$ to $2.7x10^5gr/cm^3$ (average $2.2x10^5gr/cm^3$). Pollen accumulation rates vary between $2.7x10^4gr/cm^2/yr$. and $4.3x10^4gr/cm^2/yr$ (average $4.0x10^4gr/cm^2/yr$).

LC2 BETULA-SALIX ASSEMBLAGE ZONE
Type site: Llyn Cororion
Core A 936-860cm
Estimated Age 9600 BP-9000 BP (duration 600 RC. YRS.)
Base defined by a sharp reduction in Juniperus and a rapid rise in Betula.

This zone is characterised by high arboreal pollen (maximum 83%) and a consistent herb record (around 32%). Shrub values are generally low but there is a wide variation in percentages and an overall increase towards the zone top. Spores rise to a maximum of 27% at 912cm which is the highest record for the Postglacial at Llyn Cororion, before gradually declining to less than 2% at the upper boundary.

The arboreal pollen spectra is dominated by a rapid rise in Betula. Frequencies always exceed 60%, with maximum values for the Postglacial of 81% and 75% at 892cm and 880cm respectively. Pinus values increase to 5% with peaks in the pollen curve corresponding to peaks in the Betula frequencies. Quercus is present in low quantities (<2%) in most samples and Ulmus occurs as isolated and sporadic grains.

The shrub record consists of Salix with some Juniperus. Salix is suppressed in zone 2 with values declining from 15% at 932cm to <5% at the top. Salix minima coincide with Betula peaks but this may be an artifact of the percentage method. Juniperus is continuous until 916cm, and thereafter only occurs as isolated grains. When Juniperus finally disappears (900cm) the Viburnum curve becomes continuous and follows a similar pattern to Salix. Viburnum frequencies remain between 2 and 5%. Corylus first becomes continuous at 892cm and then rapidly increases; at 860cm values of 29% are recorded. There are sporadic occurrences of Lonicera, Hippophae, Ribes and Sorbus cf. aucuparia.

The herbaceous record is varied but again Gramineae and Cyperaceae dominate. Gramineae fluctuates between 7.5% and 10% with a slight reduction (to 5%) in the upper levels. The Cyperaceae curve fluctuates more with an isolated peak of 4% at 928cm, corresponding to a Salix high. There are records for Artemisia, Cruciferae, Plantago undiff., Rosaceae undiff., Filipendula and Rumex undiff. All these taxa decrease towards the top of zone 2 and virtually disappear by the end.

Spores are generally reduced but the dominant elements are still Dryopteris and Filicales undiff. Dryopteris has an isolated peak of 15% at 912cm followed by a small Filicales increase to 5%. Polypodium occurs in the middle of the zone and low but consistent values are recorded for Equisetum (<2%) along with isolated occurrences of Lycopodium. At the top of the zone the spore record is reduced.

Aquatics are not well represented, and Myriophyllum alterniflorum declines from 7% to 0%. Myriophyllum spicatum and Sparganium type also disappear. Potamogeton has a low and sporadic curve (<1%). The algal record fluctuates between 0% and 6% for Pediastrum; Botryococcus has values of <1%.

Indeterminable grains are increased with values around 10% and include concealed, crumpled and corroded grains; degraded grains are rare. The number of taxa recorded in the pollen sum ranges from 15 to 22.

ZONE LC2 POLLEN CONCENTRATIONS AND ACCUMULATION RATES

The concentration diagram in zone 2 provides a different picture than that suggested by the percentage diagram. The rapid rise in Betula frequencies followed by sustained high values is absent. Concentrations vary between $1.1x10^4gr/cm^3$and $4.9x10^4gr/cm^3$ with a distinct minimum of $2.5x10^3gr/cm^3$ at 912cm. On the zone boundary (860cm) Betula concentrations reach their maximum ($5.1x10^4gr/cm^3$) for the Postglacial, a peak which is not reflected in the percentage diagram.

Salix concentrations remain relatively constant throughout the zone with only a slight decrease at the top. There is a Salix minimum of $3.5x10^3gr/cm^3$ at 912cm. The concentration curve therefore shows that Salix did not decline as Betula increased, but remained a significant component of the vegetation. Corylus concentrations and influxes are similar to the percentage curve with a rapid increase in values towards the zone top (concentrations of $2.5x10^4gr/cm^3$, influx values of $1.0x10^4gr/cm^2/yr$)

The Gramineae concentration curve shows a steady and continuous record. There is no decrease as illustrated in the percentage diagram and concentration values range between $6.7x10^2gr/cm^3$ to $4.9x10^3gr/cm^3$. Cyperaceae values rise to $1.1x10^3gr/cm^3$ at 924cm, coinciding with a peak in the percentage diagram. Total pollen concentrations for zone 2 average at $2.0x10^5gr/cm^3$ and total pollen accumulation values average at $2.9x10^4gr/cm^2/yr$.

LC3 CORYLUS-QUERCUS ASSEMBLAGE ZONE

Type Site: Llyn Cororion

Core A 780-860cm

Estimated Age 9000 BP-8425 BP (duration 575 RC. YRS.)

Base defined by a rapid rise in Corylus, the first continuous Quercus, and the start of a Betula decline.

Tree pollen fluctuates at around 40%, and reaches a minimum of 17% at 836cm. Shrub percentages rise from 32% at the zone base to a maximum of 75% at 836cm, but then decline slightly as trees recover. The herb record increases throughout the zone reaching values of 15%, before a sudden decline in the uppermost level. Spores reach a minimum value (0.2%).

Betula is still the major component of the tree record although percentages are reduced and fluctuate between 15-30%, with minimum values at 831cm (17%) and 812cm (11%). Quercus has gradually increasing values, and a rapid expansion at 788cm (from 1 to 8%). Ulmus values become continuous above 829cm with values steadily rising to maximum values (6%) before 780cm. The Pinus record is characterised by low frequencies (2-3%).

The shrub record is dominated by Corylus, which undergoes a rapid expansion (from 30% to 65%) before reaching maximum values of 73% (831cm). Towards the zone top Corylus values gradually decrease, and Corylus minima are associated with Betula maxima. As Corylus rises, Salix percentages decrease to a steady 7.5%. Juniperus is totally absent, and the record for Viburnum is discontinuous. Sorbus cf. aucuparia has low values throughout the middle of the zone.

The herb record is dominated by Gramineae and Cyperaceae and both curves have a peak (7% and 6% respectively) at 788cm, corresponding to a Salix peak and a Corylus minimum. Generally Gramineae values fluctuate around 2.7% and Cyperaceae frequencies decline to <2%. Cruciferae and Filipendula are recorded sporadically (<1%) and Rubus type, Calluna vulgaris, Rosaceae undiff., Viscum alba and Ranunculus undiff. have isolated records.

Spores attain minimum frequencies and no taxa have a continuous record. There are traces of Equisetum, Lycopodium, Dryopteris and Filicales. The aquatic record has a minimum number of taxa but includes isolated Sparganium type, Potamogeton and Nymphaea alba.

Botryococcus levels remain constant but Pediastrum percentage values show a slight increase to 4% at the zone top. Indeterminable records are dominated by concealed grains although there are also slight increases in degraded and corroded grains.

The number of different taxa identified varies between 10-19.

ZONE LC3 POLLEN CONCENTRATIONS AND ACCUMULATION RATES

The concentration and influx diagram differ from the percentage diagram in a number of ways. The Betula concentration curve shows maximum values are reached in zone 3, not in zone 2 as suggested by the percentage diagram. Concentrations of 5.2×10^4gr/cm^3 and influx values of 4.5×10^5gr/cm^2/yr are recorded at the zone base, with two further peaks at 824cm (5.3×10^4gr/cm^3) and 804cm (5.1×10^4gr/cm^3).

The concentration diagram suggests that Betula initially declined as Corylus values rose but values then recovered. A later reduction in Betula values (812cm) is mirrored by another Corylus concentration peak. Ulmus, Quercus and Pinus concentration curves reflect patterns in the percentage diagram.

The percentage diagram suggests that Salix undergoes a significant decline in zone 3 but this is not reflected in the concentration data. Salix concentrations are slightly reduced but remain steady at around 1×10^3gr/cm^3 for most of zone. Corylus concentrations shows a rapid rise from 2.2×10^3gr/cm^3 to 1.1×10^4gr/cm^3 but maximum values (6.7×10^5gr/cm^3) are not reached until 812cm; values then decrease towards the zone top as Quercus and Ulmus expand.

Herb concentrations are negligible (between 8.9×10^3gr/cm^3 and

$8.8x10^4 gr/cm^3$). Gramineae and Cyperaceae concentrations remain steady and do not reduce as suggested by the percentage diagram. Slight increases are seen in the top four samples, with Gramineae reaching concentrations of $5.9x10^4 gr/cm^3$ and influxes of $9.6x10^3 gr/cm^2/yr$ at 812cm.

Total pollen concentrations for zone 3 average $6.2x10^5 gr/cm^3$ with average pollen accumulation rates of $8.0x10^4 gr/cm^3$.

ZONE LC4 PINUS-QUERCUS ASSEMBLAGE ZONE
Type site: Llyn Cororion
Core A 780-702cm
estimated Age 8425 BP-7745 BP (duration 700 RC. YRS.)
Base defined by a rapid rise in Alnus

This zone is characterised by increasing tree percentages, and declining shrub and herb records. Trees and shrubs reach 93% at the top of the zone but generally fluctuate around 70%. Shrub percentages range between 15% and 40%. Spore values are low and herbs range between 1% and 6%, decreasing slightly towards the zone top.

The tree record is now more diverse and characterised by the expansion of Quercus and Pinus. Betula values remain at around 30% but decrease to 15% at 704cm, corresponding to a large Pinus peak. Ulmus values decrease to between 2% and 6%. Quercus expands rapidly to 28% at the zone base before a sudden drop to 2.5% at 732cm; the latter coinciding with the first major Pinus peak. Towards the top Quercus recovers (to 15%) before a second reduction in values. Pinus gradually rises to 50% at 732cm but the curve has two peaks with a maximum value of 65% just before the top of the zone (706cm). Alnus is recorded in the top four levels but the curve is not continuous and values are always <2%. There are also isolated occurrences of Fraxinus.

Salix has low, consistent values (<5%) and the shrub record is dominated by Corylus, which maintains high values in the lower part of zone 4 (approximately 30%) before decreasing towards the top. Hedera helix is present between 716cm and 706cm (values <0.5%) but thereafter occurs only sporadically.

Gramineae percentages decrease to around 5%. Cyperaceae has values up to 5% before 740cm but then declines. Calluna vulgaris forms a continuous record for the first time but is always <1%, and there are occasional records for Solidago type, Compositae Tubuliflorae, Artemisia, Cruciferae, Viscum alba, Rosaceae undiff, Ranunculus undiff. and Rumex undiff. There is also the first Umbelliferae count, and a large isolated peak of Melampyrum at 704cm (11%), the latter associated with records of Filipendula, Vicia/Lathyrus, Campanula, Artemisia and peaks in the grass and sedge record. At the same level all tree taxa are reduced except Salix, which shows a slight increase.

The spore record is sporadic and discontinuous. Equisetum occurs throughout, and Polypodium and Pteridium increase towards the zone top. There are occasional occurrences of Osmunda, Lycopodium, Sphagnum and Dryopteris. Aquatic taxa are at a minimum for the whole diagram with isolated counts of Sparganium type and Nymphaea (<1%).

The algal record is increased due to a Pediastrum rise, with peaks at 756cm (6%) and 728cm (3%). Botryococcus has a discontinuous curve. Indeterminable grains are consistent with increased corroded, broken and concealed grains (<2%) and a decrease in degraded and crumpled grains.

The number of different taxa identified in the pollen sum varies between 14-21.

ZONE LC4 POLLEN CONCENTRATIONS AND ACCUMULATION RATES

The concentration and pollen accumulation rate diagrams are similar to the percentage diagram. Betula concentrations show an overall decline but with peaks ($2.5x10^5 gr/cm^3$) identified at 764cm and at 748cm. The Ulmus and Quercus concentration and pollen accumulation curves are similar to their percentage diagrams. Ulmus values decrease towards the top of the zone and the *Quercus* curve has a minimum (concentration $1.3x10^4 gr/cm^3$, influx $1.5x10^3 gr/cm^2/yr$) at 732cm, corresponding to a *Pinus* peak. *Pinus* concentrations peak at 732cm ($2.8x10^5 gr/cm^3$) and at 706cm ($2.9x10^5 gr/cm^3$). These are separated by a minimum corresponding to a *Quercus* increase. *Alnus* has negligible concentration values at around $1.8x10^3 gr/cm^3$.

The shrub record has low, steady accumulation rates for *Salix* grains (between $5.2x10^2$ and $1x10^3 gr/cm^2/yr$; concentrations vary between $1x10^4$ and $7x10^3 gr/cm^3$), with a decreasing *Corylus* record. The *Corylus* concentration record is smoother than the percentage curve, suggesting that many of the small *Corylus* percentage peaks are artifacts. A drop in concentration values at 706cm corresponds to the second *Pinus* peak, and there is an overall decline in *Corylus* concentrations ($2.9x10^5$ to $4.3x10^4 gr/cm^3$) from the base upwards.

The Cyperaceae and Gramineae diagrams show slight increases in but Gramineae declines to $3.0x\ 10^3 gr/cm^3$ by 702cm. *Pediastrum* concentrations reach a maximum of $4.5x\ 10^4 gr/cm^3$ at 756cm. The average pollen concentration for zone 4 is $8.5x10^5 gr/cm^3$. Pollen accumulation rates average at $9.8x10^4 gr/cm^2/yr$.

LC5 ALNUS-CORYLUS-QUERCUS ASSEMBLAGE ZONE

Type Site: Llyn Cororion

Core A 702-460cm

Estimated Age 7745 BP-5650 BP (duration 2095 RC. YRS.)

Base defined by the empirical limit of *Alnus*.

Zone 5 is represented by the thickest sequence of sediment, and is the most palynologically stable zone in the core. Spore and herb percentages remain low throughout (<5%); tree percentages are high at between 60 and 80%, and shrubs fluctuate between 20 and 50%. Tree percentages are lower in the zone centre with two apparent minima of 45% and 58% at 528cm and 468cm. The shrubs at these levels show a corresponding increase.

The tree record is dominated by Betula, Ulmus, Quercus, Pinus and Alnus. The Betula record fluctuates but generally percentages lie between 10 and 25%. Minimum values (9%) are recorded near the zone base, coinciding with the Alnus rise, and low frequencies are also recorded at 552cm (11%), 536cm (9%) and 488cm (10%).

The Ulmus curve is continuous throughout with maximum values (5%) at 536cm and 584cm. The Quercus record also maintains high values between 20-30%; maximum values of approximately 30% are recorded at 480cm, 568cm, 608cm, 664cm and 696cm. Pinus frequencies fall to <1% at the zone top, but during the decline there are two phases of slight recovery, at 640cm (19%) and 688cm (29%), which can be correlated with reduced Betula. The first continuous Alnus is recorded and values quickly increase from 1% at 702cm to 16% at 664cm, with a peak of 21% at 488cm. Values are consistently between 15-20% but with occasional low percentages (eg. 11% at 602cm). Towards the zone top Fraxinus and Tilia grains are recorded.

The shrub record is characterised by high frequencies of Corylus but Salix has consistently low values (5%). Three main Corylus phases can be identified; higher values coincide with Betula minima between 620cm-600cm (Corylus 30%), 536cm-528cm (Corylus 43%) and between 488cm-480cm (Corylus 35%). The remainder of the curve fluctuates between 20 and 30% before values decline to 8% at the zone top associated with an Alnus rise. Other shrubs include isolated Viburnum, Ribes and Sorbus cf. aucuparia. A continuous Hedera helix curve occurs between 576cm and 540cm with values of <1%.

The herb record reaches a minimum with respect to taxa diversity and percentages. Gramineae and Cyperaceae curves are discontinuous with values of <1% and there are sporadic occurrences of Ericales undiff., Calluna vulgaris, Rosaceae undiff., Filipendula and Ranunculus undiff. There are also grains of Compositae Tubuliflorae, Leguminosae undiff., Plantago undiff., Caltha type and Melampyrum.

The spore record has a continuous curve for Polypodium (<2%) and increased values of Equisetum, Osmunda, Pteridium, Dryopteris and Filicales. The aquatic record is sparse with low percentages of Nymphaea alba (<0.6%) and occasional Nuphar and Potamogeton. There is also one isolated count of Typha latifolia (528cm) and sporadic Myriophyllum spicatum. Algal values are low with a continuous Botryococcus record (<1%) and virtually no Pediastrum.

The indeterminable grain record has slightly lower values overall but with increased corroded grains compensated for by decreased broken and crumpled grains. The number of different taxa recorded ranges from 12-20 with the majority of levels having less than 15.

ZONE LC5 POLLEN CONCENTRATION AND ACCUMULATION RATES

The concentration and pollen accumulation rate diagrams compare favourably with the percentage diagram and both reflect similar changes in taxon values.

The initial Betula decrease, as Alnus rises, is recorded in the concentration diagram, and values are reduced to $2.9x10^4 gr/cm^3$ with accumulation rates of $3.2x10^3 gr/cm^2/yr$. The Ulmus curve shows little change with concentrations between $8x10^3 gr/cm^3$ and $2x10^4 gr/cm^3$ and the Quercus curve remains stable with few fluctuations, and only a slight decrease as Alnus expands. Pinus concentrations and pollen accumulation rates reflect the percentage curve with a gradual decrease, and, although the "recovery" phases are highlighted by the concentration curve, they appear to be displaced. Alnus concentrations show a more gradual rise than that suggested by the percentage diagram and there are two distinct peaks in the concentration values at $1.4x10^5 gr/cm^3$ (632cm) and $1.0x10^5 gr/cm^3$ (552cm) which are not reflected in the percentage diagram.

The Salix concentration curve reaches minimum values in zone 5, and the Corylus curve has continuing low values with average concentrations between $5x10^4$ and $2x10^3 gr/cm^3$). A late increase in <u>Corylus</u> up to $2x10^5 gr/cm^3$ at 468cm is associated with an <u>Alnus</u> decline and a <u>Betula</u> minimum. For most taxon a slight increase in values can be identified at 632cm, 600cm, 584cm, and 532cm. The coincidence of increased values at this level suggests that sedimentary factors may be responsible for pollen deposition.

Average concentrations for this zone are $2.6x10^5 gr/cm^3$ and average pollen accumulation rates are $2.8x10^4 gr/m^2/yr$ and $3.3x10^4 gr/m^2/yr$. There are two accumulation rate values because the sedimentation rate, as calculated from the radiocarbon dates, changes within the zone (figure 5.2).

<u>LC6</u> <u>TILIA-FRAXINUS-QUERCUS</u> <u>ASSEMBLAGE</u> <u>ZONE</u>
Type site: Llyn Cororion
Core A 460-324cm
Estimated Age 5650 BP-4200 BP (duration1450 RC. YRS.)
Base defined by first continuous <u>Tilia</u>

Tree frequencies are high, but the record is unstable with a temporary drop in values, between 361-328cm, and a minimum value of 44% at 356cm. Shrub values are generally low (15-40%), averaging 30% but with a maximum of 52% corresponding to the tree minimum. Herb values exhibit a rise with an isolated high of 16% at the zone base, but generally values lie between 0-5%. Spore percentages remain low throughout.

<u>Quercus</u>, <u>Betula</u> and <u>Alnus</u> dominate the tree record. <u>Quercus</u> rises slightly to reach a maximum of 40% at 417cm but fluctuates before declining to minimum values of 14% (356cm) and 15% (340cm). <u>Betula</u> frequencies vary but are generally >20%, except for a minimum of 5% (356cm), which corresponds to a minimum in the <u>Quercus</u> record.

The <u>Alnus</u> curve is consistently >15%; peaks coincide with low <u>Quercus</u> values and an exceptionally low value of 0.43% is recorded at 417cm. The <u>Ulmus</u> record remains at around 4% until 417cm when it starts to decline; by the zone top values are 0.1%. The <u>Pinus</u> record is low and discontinuous and by

324cm frequencies are negligible. *Tilia* gradually increases to a broad peak (2.5% at 361cm) before declining to <1% but this is the only zone in which *Tilia* is consistently recorded. *Fraxinus* percentages fluctuate between 0.3 and 1% but with no counts between 356-348cm.

The shrub record shows an increase towards the top; most attributable to *Corylus* which shows large fluctuations throughout. The lowest values occur between 417-376cm and values peak at 356cm (50%). The *Salix* curve rises smoothly, from 0.38% (460cm) to a maximum of 3.7% (324cm) and thereafter remains a minor component of the diagram. Other shrubs occur sporadically, or as isolated grains, and include *Hedera helix* (<1%), *Sorbus* cf. *aucuparia* and the first record of *Ilex aquifolium*.

The herb record shows increased values but few taxa have a continuous record. The record is characterised by Gramineae (1-2%) and Cyperaceae (1-3%). At 455cm Cyperaceae has an isolated peak of 15%. Other herbaceous taxa include Compositae Liguliflorae, Rosaceae undiff. and *Filipendula ulmaria*. *Filipendula ulmaria* has a short continuous curve (<5%) in the middle of the zone.

The spore record is still dominated by *Polypodium* and associated *Pteridium*, *Equisetum* and Filicales. The *Osmunda* record becomes continuous at 340cm and reaches values of 1% at the zone top. The aquatic record is varied with continuous curves of *Potamogeton* (up to 1.4%), and *Nymphaea alba* consistently recorded. *Nuphar* occurs and there are isolated grains of *Sparganium* type.

Botryococcus is continuous with values up to 1.1%, and *Pediastrum* reappears with a sporadic record and values of <2%. Indeterminable frequencies are high with a continuous record of corroded and concealed grains, and occasional crumpled and broken grains.

The number of taxa within the pollen sum varies between 13-

25%, an increase attributable to rising herb records.

ZONE LC6 POLLEN CONCENTRATION AND ACCUMULATION RATES

The concentration curves are also comparable to the percentage records, with synchronous maxima and minima.

Betula and *Quercus* concentration values are relatively constant throughout, but the two minima identified in the percentage diagram are also present in the concentration and pollen accumulation rate record. The next minimum in the percentage curves is recorded at 340cm, but low concentrations are not recorded until 332cm (*Betula* 5.5×10^4gr/cm^3; *Quercus* 6.1×10^4gr/cm^3).

Ulmus concentrations show a decline in values from the beginning of the zone rather than constant values and a later decline, as suggested by the percentage curve. *Ulmus* concentrations decrease from 1.8×10^4gr/cm^3 to 2.0×10^3gr/cm^3 with accumulation rates of 1.3×10^2gr/cm^2/yr at 324cm. *Alnus* concentrations reflect the frequency curve with a minimum at 417cm (1.2×10^3gr/cm^3) and a maximum at 340cm (8.4×10^4gr/cm^3). *Fraxinus* and *Tilia* concentrations are low throughout the zone with *Tilia* pollen accumulation rates not exceeding 9.8×10^2gr/cm^2/yr (392cm).

Corylus concentrations decline between 392cm and 361cm with minimum values of 3.3×10^4gr/cm^3 at 384cm, corresponding with the rise in *Tilia* accumulation rates. As *Tilia* subsequently declines and *Betula* and *Quercus* also decline, *Corylus* concentrations recover.

The herb record is sparse in this zone and both concentrations and accumulation rates for Gramineae and Cyperaceae are low. Other herbs have low and inconsistent records.

Average concentration values for zone 6 are 1.2×10^5gr/cm and accumulation rates are 2.1×10^4gr/cm^2/yr between 466-375cm and 8.3×10^3gr/cm^2/yr between 375-324cm, averaging at 14282 gr/cm^2/yr.

ZONE LC7a FRAXINUS-BETULA-QUERCUS ASSEMBLAGE ZONE

Type site: Llyn Cororion

Core A 324-112cm

Estimated Age 4200 BP-1250 BP (duration 2950 RC. YRS.)

Base defined by end of continuous *Tilia*

This zone is characterised by fluctuating and gradually declining tree percentages. Tree percentages are low (55%) at the zone base (320cm) and then vary between 50% and 80%, but after a small peak (72%) at 224cm, frequencies drop to 49% (112cm). The zone is also characterised by a gradual reduction in shrub pollen with a corresponding increase in the herb record. Shrubs reach a minimum of 6% at 128cm corresponding to herb percentages of 28%. Spores remain relatively constant (<2%) with a slight decline at the zone top.

The tree record is dominated by *Betula*, *Quercus* and *Alnus* and a continuous *Fraxinus* record. *Betula* values record wide variations in values (17% to 42%) with an overall decline through the zone. *Quercus* maintains steady values for the first half of the zone, but gradually decreases from 240cm upwards. Minimum values for *Quercus* (15% to 20%) occur between 200cm and 174cm, coinciding with relatively high *Betula* values. *Alnus* increases throughout the zone; values are relatively low at the base (9%), coinciding with a *Quercus* peak, but frequencies then reach 17%. There is one slight drop in values at 280cm coinciding with *Betula*, *Ulmus*, *Salix* and *Corylus* increased.

This is the only zone where *Fraxinus* has a continuous record. Although percentages are consistently low (<2%), values rise towards the zone top. One slight reduction in *Fraxinus* occurs at 180cm, where increased *Tilia* frequencies are recorded. *Tilia* is virtually absent in zone 7a with only isolated occurrences.

Corylus dominates the shrub record but overall values decrease but with superimposed fluctuations. Peaks are recorded at 216cm (2%), 180cm (2%), 152cm (3%) and 128cm (5%). A large drop in percentages occurs at 272cm with values at zero, coinciding with a Betula and Quercus rise. Values at the top of the zone are 2%.

Salix values are initially 3% but then decline to almost zero at 272cm. Values then recover significantly, reaching 4% (at 208cm), with a sustained high of around 3% at the zone top. Other shrubs include Hedera helix (reaching 1.2% at 112cm),Sorbus cf. aucuparia, Ilex aquifolium, Lonicera and an isolated grain of Sambucus at 192cm. Ilex aquifolium forms a short, low (<1%) continuous record at the zone top.

The herb record is dominated by large increases in Gramineae and Cyperaceae; Gramineae starts to increase at 184cm and then rapidly expands to 10% by 180cm. Cyperaceae shows a gradual increase, followed by a rapid but irregular rise after 174cm. Peaks are recorded at 144cm (12.5%) and 128cm (10%).

The herb record also includes continuous records for Compositae Liguliflorae and Compositae Tubuliflorae, Chenopodiaceae, Plantago undiff., Plantago lanceolata and Rumex undiff. Plantago lanceolata occurs sporadically until 240cm, then increases, reaching 1.2%. Plantago undiff. follows a similar pattern with percentages between 0-7%. Cereals occur consistently. Other herbs include increased Calluna vulgaris, Solidago type, Achillea, Artemisia, Stellaria holostea, Campanulaceae, Leguminosae undiff., Filipendula, Potentilla, Ranunculus undiff. and isolated occurrences of Cannabaceae, Urtica and Melampyrum.

The spore record is also diverse with continuous records for Osmunda, Polypodium, Equisetum and Pteridium (<1%). The Osmunda and Polypodium curves occur in the lower parts of the zone and are then succeeded by Pteridium and Equisetum.

The aquatic record includes Hydrocotyle, Nuphar, Nymphaea (<1%) and Potamogeton (<3%). The latter two dominate but percentages remain low. Algae records are low and no taxon has a continuous record. The indeterminables have smoother curves, and broken and crumpled grains are recorded at the base of the zone. Crumpled grains reappear at 192cm to form a continuous (<2%) curve until the top of the zone. Corroded grains are the principal indeterminable grain with increasing values up to 208cm (3.3%).

Taxa diversity increases in zone 7a with the number of taxa identified varying between 13-27, with larger numbers towards the top of the zone. The majority of samples record over 15 taxa.

ZONE LC7a POLLEN CONCENTRATIONS AND ACCUMULATION RATES

The concentration and pollen accumulation rate diagrams are similar suggesting that sediment accumulation rates were relatively constant. The two diagrams reflect the percentage curves in all major respects.

The generally increased percentage values for Betula are mirrored in the concentration diagram with a maximum concentration ($2.9 \times 10^5 gr/cm^2$) reached at 208cm. Ulmus concentrations and accumulation rates are at a minimum. Quercus concentration values show an overall increase with a minor peak of $6.7 \times 10^4 gr/cm^3$ at 280cm and a minimum value of $1.6 \times 10^3 gr/cm^3$ (240cm) corresponding to a low in the Betula curve. The concentration diagram indicates that Quercus progressively declines throughout this zone, not as suggested by the percentage diagram.

Alnus concentrations remain relatively constant with a small rise to $1.0 \times 10^5 gr/cm^3$ (accumulation rates $6.6 \times 10^3 gr/cm^2/yr$) at 208cm, mirroring small peaks in both Quercus and Betula values, then a steady decline towards the top of the zone. This is in contrast to the percentage curve which suggests increasing values throughout zone 7a.

Salix concentrations decline into the base of zone 7a, and, except for two peaks at 208cm and 160cm, values remain low, a pattern that is also recorded in the percentage values. Corylus concentrations also reflect the percentage curve although the decline of Corylus concentration values is more rapid than is suggested by the percentage values. A sudden drop occurs in concentrations from $1.5x10^4 gr/cm^3$ to $5.1x10^3 gr/cm^3$ at 152cm. Values then remain low with minima at 272cm and 208cm coinciding with lows for all tree taxa.

From 272cm upwards both Gramineae and Cyperaceae concentrations increase associated with counts of Plantago lanceolata, Plantago undiff. and Rumex undiff. Concentrations of spores (Osmunda, Polypodium, Equisetum) decrease from the base of the zone upwards.

Average pollen concentrations in zone 7a are $2.8x10^5 gr/cm^3$ with pollen accumulation rates averaging at $1.8x10^4 gr/cm^2/yr$ for the lower portion of the zone (324-152cm) and $3.8x10^4 gr/cm^2/yr$ for between 152 and 112cm.

ZONE LC7b FRAXINUS-BETULA ASSEMBLAGE ZONE
Type Site: Llyn Cororion
Core A 612-548cm
Estimated Age 1250 BP-780 BP (duration 470 RC. YRS.)
Base defined by first continuous record of a number of herbs including Calluna vulgaris, Compositae Liguliflorae, Ranunculus undiff., and the beginning of the Quercus decline.

Zone 7b has a slight recovery in tree percentages (52% at 72cm) before a decline to 36% at the top of the zone. Shrub values are relatively low and fluctuate around 25%. The zone is characterised by a rapid expansion of herbs at the base (from 22% to 46%) and these remain a major component of the pollen record between 80cm and 72cm. Above this the tree record recovers slightly. Spore values stay at around 2%.

Betula frequencies decline throughout the zone with a slight recovery in values at 72cm (23%). Alnus values reach a peak of 20% at 80cm and decline towards the zone top with two troughs (3% at 104cm and 6.5% at 120cm). Quercus declines at the zone base to a minimum of 7.5% at 88cm but values increase again towards the zone top (10%). Fraxinus has frequencies up to 1.5%, but then decreases. Other taxa have sporadic (Ulmus, Pinus) or isolated (Tilia, Fagus) records, although Ulmus does show a slight increase associated with the Quercus rise towards the zone top.

Salix falls from 5% to 2% but the Corylus record is more complex, with values at a minimum (0.4%) at 72cm followed by a rapid recovery to a peak on the upper boundary (18% at 48cm). By the top of the zone, Hedera helix has disappeared and Ilex aquifolium becomes sporadic. An almost continuous record of Frangula occurs, reaching values of 1.5%.

The herb pollen record is dominated by Gramineae and Cyperaceae. Gramineae values rise to 21% whilst Cyperaceae is highest (10%) at the base. The cereal curve is more or less continuous but the values are never high (maxima 1.7% at 88cm and 1% at 64cm). Significant increases occur in Calluna vulgaris, Compositae Liguliflorae (up to 2%), Compositae Tubuliflorae (up to 0.6%), Artemisia (up to 2.5%), Rumex undiff. (up to 2.8%), Ranunculus (up to 1%) and Umbelliferae (up to 0.8%). There are low, sporadic records for Solidago type, Leguminosae undiff., Rosaceae undiff., Filipendula, Stellaria holostea, Potentilla, Cannabaceae, Urtica, Melampyrum, Rubiaceae, Mentha type and Achillea type.

Filicales undiff. makes up the majority of the spore record but is always <1% . The record is sparse, with low values of Equisetum, Osmunda, Polypodium and Pteridium. Aquatics show a decline with decreased values of Nymphaea alba and Potamogeton (<1%). Sparganium type and Nuphar have sporadic records and Alisma and Hydrocotyle have isolated occurrences.

Algal values reach a maximum in zone 7b. Botryococcus rises slightly to values of 1.2% in contrast to Pediastrum which has a rapid rise at the zone base reaching 56% at 80cm before decreasing to 18% at the zone top; 56% is the maximum Pediastrum value in the whole sequence. There is an increase in crumpled and corroded pollen, the former reaching high values (5%) at 88cm.

The number of taxa counted is between 15 and 31 with the higher values at the top of zone 7b.

ZONE LC7b POLLEN CONCENTRATIONS AND ACCUMULATION RATES

Betula concentrations undergo the initial decline (to 2.5×10^4gr/cm^3) seen in the frequency diagram before a slight recovery, then exhibit continually reduced values. Ulmus concentration values are persistently low (2.7×10^2gr/cm^3) and continue to decline. Quercus concentrations and accumulation rates show a gradual decline with values of 1.4×10^4gr/cm^3 and 1.8×10^3gr/cm^2/yr at the zone top. Alnus concentrations increase (to 3.1×10^3gr/cm^3) and pollen accumulation rates reach 6.5×10^3gr/cm^2/yr before decreasing from 72cm onwards.

Shrubs show continued decreases in both the pollen accumulation rate and concentration diagrams with Salix undergoing a decline to around 3.7×10^3gr/cm^3 and 4.8×10^2gr/cm^2/yr. The Corylus pattern is more complicated, with concentrations decreasing to a minimum (1.0×10^3gr/cm^3) at 72cm, before a slight recovery to 9.7×10^3gr/cm^3. The Corylus minimum is associated with Alnus and Betula peaks, and Corylus subsequently recovers as these two taxa decrease.

The majority of herb records cited in the percentage diagram description have increased pollen accumulation rates and concentrations. Gramineae increases and maintains high values for the remainder of the zone. Cyperaceae rises slightly but then declines in the upper levels.

Pediastrum concentrations mirror the percentage curve with a rapid rise in concentrations to 4.3×10^3gr/cm^3, before declining again at the top of the zone.

Total average concentrations for zone 7b are 1.84×10^5gr/cm^3 with accumulation rates of 2.4×10^4gr/cm^2/yr.

<u>ZONE LC8 CANNABACEAE-GRAMINEAE ASSEMBLAGE ZONE</u>

Type Site: Llyn Cororion

Core A 048-0cm

Estimated Age 780 BP-? BP (duration maximum 780 RC. YRS.)

Base defined by a rapid increase in Cannabaceae.

Zone 8 is dominated by rapid expansion (43% to 81%) of herb pollen at the base; values then fluctuate between 60% and 77% corresponding to tree taxa variations. Tree frequencies decrease initially, to recover slightly towards the end but values still remain low (16-34%). Shrubs reach a minimum with values of <5%, occasionally dropping as low as 1.2% (32cm) and 1.6% (24cm). Spores are low but stable at around 3%.

Tree taxa all show an overall decline in this zone. <u>Betula</u> varies around 7% with a slight increase to 10% at 16cm, associated with a slight rise in <u>Ulmus</u> values (2%), although the <u>Ulmus</u> curve is never continuous. The <u>Quercus</u> curve is similar to <u>Betula</u>, with an overall decrease (to 3%), but with a rise in values (7%) at the zone top. <u>Pinus</u> percentages also show this rise (0.64%). <u>Alnus</u> percentages decrease to <15% but level out to remain at around 5% for the remainder of the zone. <u>Tilia</u> is now absent, and <u>Fraxinus</u> declines.

<u>Salix</u> and <u>Corylus</u> dominate the shrub record but decline upwards. <u>Salix</u> is reduced to less than 3% and then fluctuates between 0.2 and 2%. <u>Corylus</u> undergoes a rapid decrease from 18% to 1% but with a slight rise at 16cm. There are sporadic occurrences of <u>Hedera helix</u>, <u>Sorbus</u> cf. <u>aucuparia</u>, <u>Ilex aquifolium</u> and <u>Frangula</u>.

Herbs dominate the record; their diversity and values both increase. Gramineae frequencies decrease at the start of the zone but then rapidly increase to 35% by the top. Cyperaceae values fluctuate between 0.5% and 7% and peak at 7%, before <u>Calluna vulgaris</u> becomes the predominant component.

The herb record is dominated by a rapid Cannabaceae rise, identified as Cannabis sativa with maximum values of 50% at 24cm. It then declines before a recovery to 27% in the upper sample. Cereals have an almost continuous record with percentages at around 0.4% and with minor peaks of 2.8% at 40cm and 0.8% at 16cm. Compositae Liguliflorae shows a rapid increase to 8% by 16cm. Plantago undiff. and Plantago lanceolata (maximum 6%) also increase. Rumex undiff. is high (7%) at the base, before a slight decline to 5%.

Other herbs recorded include Solidago type, Calluna vulgaris, Compositae Tubuliflorae, Artemisia, Caryophyllaceae, Cruciferae, Leguminosae, Filipendula, Umbelliferae and Ranunculus undiff.. Isolated occurrences of Cirsium/Carduus, Campanulaceae, Jasione montana, Chenopodiaceae, Rosaceae, Liliaceae, Polygonum cf. convolvulus, Urtica and Melampyrum are noted.

There are continuous records of Nymphaea, Potamogeton and occasional counts of Nuphar and Hydrocotyle. The algal record is low with Botryococcus absent and Pediastrum declining to <5% before becoming sporadic.

There is an increase in indeterminables with crumpled grains rising to almost 10% at the zone top. Corroded grains have a continuous curve and broken grains show increased values but remain below 5%.

Taxa diversity is at a maximum with the number of taxa identified between 27-35.

ZONE LC8 POLLEN CONCENTRATIONS AND ACCUMULATION RATES

Concentration and pollen accumulation rate curves again reflect the percentage patterns. Betula and Quercus show concentration decreases (to $1.6x10^4gr/cm^3$) but at 16cm a slight rise to $2.0x10^3gr/cm^3$ is seen. Alnus concentrations decline (reaching $1.5x10^4gr/cm^3$ at 34cm) and then peak at the zone top (concentrations of $4.8x\ 10^4gr/cm^3$) which is not recorded in the percentage values.

The *Salix* concentration curve is the same as the percentage diagram with low but consistent values. The *Corylus* curve shows a decrease with a recovery towards the top.

Gramineae concentrations (up to $8.9x10^4$gr/cm^3) and accumulation rates ($5.5x10^3$gr/cm^2/yr) are high. Cyperaceae is low but persistent with concentrations between $1x10^4$-$4x10^4$gr/cm^3, with a small peak prior to the Gramineae peak at the top of the zone. Cereal concentrations generally decrease upwards.

There are increases in Compositae Liguliflorae and *Calluna vulgaris* concentrations and values for *Plantago* undiff. and *Plantago lanceolata* reach $2.9x10^4$gr/cm^3 and $5.5x10^4$gr/cm^3 respectively at 16cm. *Cannabis* concentrations reflect the percentage pattern with a rapid rise from 0 to $8.3x10^4$gr/cm^3. Values then level off at around $1.2x10^5$gr/cm^3 (a feature not seen in the percentage curve which displays a peak) before a drop in values at 16cm, and another rise (concentrations of $8.4x10^4$gr/cm^3) zone top.

Total average concentrations are $3.46x10^5$gr/cm^3 with accumulation rates averaging out at $2.1x10^4$gr/cm^2/yr.

3.5.2 LLYN HENDREF

Pollen assemblage zones within the inorganic portion of the core

The pollen assemblage from the inorganic portion of the core was not included in the zonation program but two distinct phases within the results were identified (table 3.6). The lower zone is characterised by low pollen sums and concentrations (total concentrations are <1500 gr/cm^3). By contrast the upper zone has higher pollen sums and concentrations reaching 4500 gr/cm^3. Species diversity is higher in the upper zone.

LHA GRAMINEAE-ARTEMISIA POLLEN ASSEMBLAGE ZONE

Type site: Llyn Hendref

Core A 752-800cm

Estimated Age ? >10 285 BP

Base arbitrary, defined by first sample taken.

This zone is characterised by decreasing tree frequencies, increasing herbs and a steady spore record. The shrub record stays relatively constant. The tree record is dominated by Pinus (around 35%, concentrations <100 gr/cm^3) and Betula, which decreases towards the zone top. Quercus and Alnus are recorded but have discontinuous records. Corylus percentages reach 20% (concentrations of <50 gr/cm^3) and there are counts for Juniperus and Salix.

Gramineae dominates the herb record along with low values for Cyperaceae, Artemisia and Chenopodiaceae. Other herbs include Ericales undiff., Compositae Liguliflorae, Caryophyllaceae, Cruciferae, Leguminosae, Plantago, Rumex, Rubiaceae and Ranunculus. Concentrations are low for all these taxa and herb concentrations do not exceed 1000 gr/cm^3. There are isolated counts for Thalictrum and Armeria maritima. The spore record contains relatively high frequencies of Sphagnum, Pteridium, Polypodium and Filicales undiff. There are also counts for Equisetum, Osmunda and Polypodium.

The aquatic record is sparse and only Myriophyllum verticillatum is recorded. Algal percentages increase upwards, all attributable to Pediastrum. The indeterminable record is dominated by crumpled and broken grains and there are high frequencies of pre-Quaternary grains (concentrations <250 gr/cm^3). Zygospores are also recorded.

LHB GRAMINEAE-CYPERACEAE-ARTEMISIA POLLEN ASSEMBLAGE ZONE

Type site: Llyn Hendref

Core A 724-752cm

Estimated Age ? >10 285 BP

Base defined by an increase in aquatic taxa and algal representation.

This zone is differentiated from the lower zone by increased taxa diversity, concentrations and pollen sums. Tree frequencies fall to <5% as herb frequencies expand. Shrub percentages are relatively steady and spores decrease slightly towards the zone top. Total concentrations reach 4800 gr/cm^3.

Betula dominates the tree record but in reduced quantities. Percentages never exceed 15% and maximum concentrations are 340 gr/cm^3. Pinus frequencies rapidly reduce and the curve becomes discontinuous. Quercus and Alnus values are also decreased and there are isolated counts of Fraxinus. Decreased Corylus values are associated with a continuous and increasing Salix curve. Juniperus values are low (<3%, concentrations <10 gr/cm^3) and only occur in the lower half of the zone.

The shrub record is characterised by high Gramineae values (up to 40%, concentrations <20 gr/cm^3), increased Cyperaceae (up to 45%) and continuous curves for Artemisia, Caryophyllaceae, Filipendula, Ranunculus undiff. and Rumex. There are low counts of Calluna vulgaris, Ericales undiff. Solidago, Chenopodiaceae, Plantago and Thalictrum. Isolated counts of the following taxa also occur; Serrulata type, Achillea type, Saussurea, Caltha type, Cruciferae, Vicia/Lathyrus, Potentilla type, Rubiaceae undiff. and Umbelliferae undiff.

The spore representation declines and Filicales now dominates. There are lower counts for Lycopodium, Equisetum, Osmunda, Polypodium, Pteridium and Sphagnum, and Isoetes is now present. The characteristic feature of this zone is the increase in aquatic taxa diversity and frequencies. There are now continuous counts for Myriophyllum alterniflorum, Myriophyllum spicatum and Potamogeton, and isolated counts for Myriophyllum verticillatum, Nuphar and Menyanthes. Total aquatic concentrations reach 100 gr/cm^3). Pediastrum frequencies demonstrate a large rise from 10% to a maximum of 90%.

The indeterminables record is reduced. Crumpled grains dominate but only reach 10% and there is an associated decrease in pre-Quaternary grains (generally <5%, with concentrations of <50 gr/cm^3).

Pollen assemblage zones in the organic portion of the core.

LH1 BETULA-JUNIPERUS POLLEN ASSEMBLAGE ZONE
Type Site: Llyn Hendref
Core A 720-712cm
Estimated Age 10 285 BP-9890 BP (duration 395 RC. YRS.)
The base is defined by the onset of organic sedimentation.

This zone is characterised by initial low tree percentages (25% at 720cm) which rise to 55% in the upper levels. Shrub values are low (11-7%) throughout with minimum percentages at 712cm. Herb percentages fluctuate between 30 and 49%. Spore frequencies vary between 10 and 27%.

The tree record is dominated by Betula pollen with percentages increasing from 21% at the base to 53% at 712cm. Pinus forms a continuous curve but frequencies are <5%. Isolated occurrences of Quercus (0.39%) and Ulmus (0.38%) are also recorded.

The shrub record is a minor component of the pollen diagram and is dominated by Salix and Juniperus. Juniperus values are high at 720cm (5-7%) but decline as Salix values rise. Low Juniperus values (<1%) are then maintained for the rest of the zone. The Salix curve has an initial peak (10%, the maximum recorded for the whole diagram) and then declines (as Betula expands) to around 4% in the upper levels. There is one grain of Hippophae recorded at 716cm.

Herb values are high and dominated by Gramineae and Cyperaceae. Both taxa start with high percentages (27% & 12% respectively) and then gradually decline (Gramineae to 13%, and Cyperaceae to 1.5%) as Betula increases. Other herbs with continuous curves include Calluna vulgaris (always <1.2%), Ericales undiff. (maximum 0.5%), Filipendula ulmaria (maximum 1.1%), Ranunculus undiff., Rumex acetosa, Plantago undiff. and Thalictrum. All, except Filipendula, have relatively high values at the base of the zone, but are reduced to sporadic occurrences by the upper levels. Filipendula has initially low values but peaks at 20% in the penultimate sample. Isolated occurrences of Artemisia, Compositae Liguliflorae, Achillea type, Caryophyllaceae, Chenopodiaceae, Cruciferae, Rubiaceae and Umbelliferae, are also recorded.

Spore values are high. The principal contributors are Filicales undiff. (8%-11%) and Dryopteris (2%-3%) with a low, consistent Equisetum curve (1-2%). There are also sporadic occurrences of Lycopodium, Osmunda, Polypodium, Pteridium and Dipsacus. All spore records gradually decline upwards.

The aquatic record is varied with consistent curves for Myriophyllum alterniflorum, Myriophyllum spicatum (2<%), and Potamogeton (2%). Occasional Typha latifolia and Nuphar are observed. Pediastrum dominates (rising to 22%) the continuous algal curve with only small quantities of Botryococcus (<2%). All categories of indeterminable grains (except degraded) have a consistent curve but values are generally low (<3%). The number of taxa identified is between 19-21.

ZONE LH1 POLLEN CONCENTRATIONS

Betula values start off relatively low ($1.1x10^4 gr/cm^3$) and exhibit a gradual increase, compared to the rapid rise in the percentage diagram, reaching values of $8x10^4 gr/cm^3$ by 712cm. Pinus, Quercus and Ulmus concentrations are all low ($<2.5x10^3 gr/cm^3$) reflecting the frequency diagram.

Salix concentrations are low (average $5.3x10^3 gr/cm^3$) with only a minor decrease as Betula rises. The Juniperus concentration curve reflects the percentage curve with low concentrations ($3x10^3 gr/cm^3$), decreasing to $1x10^3 gr/cm^3$ by 712cm as Betula increases.

Total tree concentrations rise throughout the zone from

$1.3x10^4 gr/cm^3$ to $8.2x10^4 gr/cm^3$, (mean $1.5x10^4 gr/cm^3$). Gramineae values increase upwards, compared with the percentage diagram which records a general decline. Cyperaceae forms a minor component (average $5x10^3 gr/cm^3$) of the herb record.

Average concentration values are 5.3 $x10^4 gr/cm^3$ with pollen accumulation rates of $1x10^3 gr/cm^3/yr$.

LH2 BETULA-SALIX ASSEMBLAGE ZONE

Type site: Llyn Hendref

Core A 692-712cm

Estimated age 9890 BP-9420 BP (duration 470 RC.YRS.)

The base of zone 2 is defined by the first continuous Corylus (ie. the empirical limit).

Zone 2 is characterised by increasing arboreal pollen with a peak of 70% at 704cm, before a decline to 50% by the zone top. Herbs maintain percentages of around 25% and there is a slight increase in shrub (7- 17%) values, at the expense of spores. The latter decline to 2.2% in the penultimate level with a slight recovery (7%) at the top of the zone.

The arboreal pollen spectrum is characterised by rising Betula values (from 56% to 68%); maximum values reach a sharp peak at 704cm and then decline to 56% by the zone top. Pinus values are slightly increased but with a minimum (0.53%) corresponding to the Betula peak. There are low but consistent counts for Quercus (usually <0.2%) and an isolated count of Ulmus in the upper samples.

The shrub record is predominantly Salix with low quantities of Juniperus and increasing Corylus. Salix reaches maximum values of 9% at 698cm. Juniperus has continuous but low values (0.94% to 1.4%), with a minimum coinciding with a Betula peak; Juniperus is totally absent by the top of the zone. A continuous Corylus curve occurs for the first time (values <0.4%) rising to 9% by the top of the zone. There are sporadic grains of Hedera helix, Viburnum and Sorbus cf.

aucuparia.

The herbaceous record is varied but Gramineae and Cyperaceae dominate. Gramineae progressively declines (to 11%) whilst Cyperaceae increases from 3% (712cm) to a peak of 12% (692cm). Other herbs have discontinuous records, and include Calluna vulgaris, Ericales, Artemisia, Rosaceae, Rubiaceae, Plantago maritima and Rumex acetosella. Reductions occur in all other herb taxa; the most significant is Filipendula which drops from 3.2% to 1.4%. Ranunculus and Rumex acetosa become discontinuous and Thalictum and Plantago undiff. are eliminated.

Spore values decrease but the major taxa remain; Filicales undiff. (between 2.5% and 6.4%), Dryopteris and Equisetum. Dryopteris values fall from 1.7% to 0.8% at 698cm, and become discontinuous by the zone top. This is associated with decreased Equisetum which maintains low (<0.6%) frequencies. There are isolated occurrences of Isoetes (698cm), Osmunda (698cm) and Lycopodium (704cm) and a low (<0.8%) but continuous curve for Pteridium.

The aquatic record is dominated by increasing Potamogeton (maximum 5.5% at 698cm) and associated decreases in Myriophyllum alterniflorum and Myriophyllum spicatum. Myriophyllum verticillatum is continuous with maximum values for 0.3% at 704cm. At the top of the zone total Myriophyllum recovers, reaching 5%, and a continuous Nymphaea alba curve is recorded (0.7%). There are isolated counts of Nuphar and Sparganium type.

Pediastrum dominates the algal record, reaching 20% at 708cm, followed by a sharp reduction to 3.9% at 704cm. Maximum frequencies of 28% are attained at 698cm. Botryococcus values decrease to zero.

The indeterminable record shows increases in broken and crumpled grains coinciding with the Pediastrum peak, and a decrease in corroded grains. Indeterminable grain values remain below <7%.

The number of taxa recorded ranges from 20-22.

ZONE LH2 POLLEN CONCENTRATIONS

The concentration diagram highlights trends that are not visible using the percentage diagram alone. The *Betula* expansion is shown to be gradual, rising from 6.5x 10^4gr/cm^3 at 708cm to 3.6x10^5gr/cm^3 at 698cm. Concentrations then sharply decline to 1.4x10^5gr/cm^3. *Pinus* concentrations are initially low (1.2x10^3gr/cm^3) and only rise at 698cm (1.6x10^4gr/cm^3). *Salix* rises to a peak of 6.0x10^4gr/cm^3, at 698cm before declining again towards the zone top. *Corylus* concentrations reflect the percentage curve with a rapid expansion from 4.2x 10^2gr/cm^3 to 2.6x10^4gr/cm^3 at 692cm.

Juniperus values are low (1x10^3gr/cm^3) and steady except for an isolated peak (9x10^3gr/cm^3 at 698cm) prior to elimination. A peak is recorded in the aquatic, spore and algal record at 698cm, suggesting they are a function of sedimentation.

Average concentrations for this zone are 2.9x10^5gr/cm^3.

LH3 CORYLUS-ULMUS-QUERCUS ASSEMBLAGE ZONE

Type Site: Llyn Hendref

Core A 692-596cm

Estimated Age 9420 BP-7850 BP (1570 RC. YRS.)

Base defined by the elimination of *Juniperus* and the rational limit of *Corylus*.

The predominant characteristic of zone 3 is the rapid expansion of shrubs (up to 76%) at the expense of tree and herb taxa, before declining and fluctuating around 50%-60%. Trees initially decline to a minimum (15%) at 676cm but then values recover rising to 52% with an isolated peak at 660cm. Herbs decline rapidly but then fluctuate around 5% to 10%. Spores reach a minimum (0.61% at 680cm) before increasing to between 1% and 3%.

The tree record is characterised by rising values of Ulmus, Quercus and Pinus, but Betula still dominates. Betula shows an initial decline (12% at 672cm) but recovers to a short-lived peak of 53% at 660cm, before declining and fluctuating between 10% and 20%. Ulmus percentages rise, and Quercus is continuous but low (<1.5%), not expanding until 672cm with frequencies then reaching 24% at the zone top. The empirical limit of Ulmus is slightly later at 676cm and values are then maintained at around 2% for the rest of the zone. Pinus increases to a small peak (4.2% at 628cm) but generally remains low (<2%). Alnus is first recorded at 616cm (0.36%).

Corylus exhibits a rapid rise and maintains high frequencies which dominate the shrub record. Values rise to 75% at 672cm and percentages then fluctuate between 32% and 61%, but with an overall decline. There is a corresponding decrease in Salix. Juniperus is eliminated but there are increased frequencies for Hedera helix, Viburnum and Sorbus cf. aucuparia. There are two records for Ilex aquifolium.

Herbs generally decline but remain a significant component of the pollen diagram. Gramineae frequencies lie between 2% and 5% and Cyperaceae values fluctuate between 1% and 3%, and peak at 5.4% at 652cm. Calluna vulgaris is sporadic and there are isolated counts for Cannabaceae, Artemisia, Cirsium, Thalictrum, Melampyrum, Polygonum cf. apatholium, Jasione montana, Mentha type and Umbelliferae. There are frequent records for Chenopodiaceae (<0.2%), Ranunculus and Rumex acetosella but Filipendula values are reduced to <0.6%.

Spores have low frequencies but increased diversity. Equisetum is continuous (<1%) and associated with decreasing Filicales (0.5%). Sphagnum and Dryopteris are sporadic, Osmunda, Polypodium and Pteridium increase from 660cm upwards.

Aquatics are diverse, but Myriophyllum alterniflorum and Myriophyllum spicatum dominate recording 3.3% at the zone base but declining thereafter. Nymphaea alba and Potamogeton increase and are continuous throughout. Sparganium is recorded

(<1.5%) from 652cm onwards. Pediastrum reaches a maximum (12.3% at 684cm) but then declines to a minimum of 0.5% at 608cm. Botryococcus percentages generally increase but values remain low (<1%).

Taxa diversity is low (between 12 and 15 taxa) at the beginning of the zone but increases to 20 by the top of the zone.

ZONE LH3 CONCENTRATIONS

The concentration diagram is similar to the percentage diagram. Betula declines (from $1.5x10^5 gr/cm^3$ to $4.7x10^4 gr/cm^3$) but not as sharply as suggested by percentage values. Ulmus values (between $7x10^3 gr/cm^3$ and $2x10^4 gr/cm^3$) are consistent and accompany rising Quercus values, which peak at $1.7x10^5 gr/cm^3$ at 604cm. The Quercus increase is steady and is coincident with a rise and peak in Pinus which reaches $3.5x10^4 gr/cm^3$ at 604cm.

Shrub curves reflect the percentage diagram. Corylus is the dominant species and concentrations rise rapidly from $1.7x10^5 gr/cm^3$ to $6.4x10^5 gr/cm^3$, but in general, values fluctuate between 1 and $2x10^5 gr/cm^3$. Salix concentrations have three distinct peaks at 684cm ($3.6x10^4 gr/cm^3$), 644cm ($2x10^4 gr/cm^3$) and 598cm ($1.2x10^4 gr/cm^3$) and its gradual decline identified in the percentage diagram is not apparent.

Gramineae and Cyperaceae concentrations are low but consistent throughout, except for an isolated peak in Gramineae ($1.7x10^5 gr/cm^3$) at 608cm. The spore and aquatic curves reflect the percentage data. Average concentrations for the zone are $3.9x10^5 gr/cm^3$.

LH4 ALNUS-PINUS-QUERCUS ASSEMBLAGE ZONE

Type site:Llyn Hendref

Core A 596-552cm

Estimated Age 7850 BP-5735 BP (duration 3015 RC. YRS.)

The base is defined by the rapid expansion of Alnus (ie. the rational limit).

This zone is characterised by increasing tree percentages (to 73% at 568cm). Shrubs and herbs show a corresponding decrease, with shrub percentages between 20% and 40% and herbs at between 1 to 5%. Spore values are steady between 1-4%.

The tree record is dominated by a rapid Alnus rise to 33%. High values are maintained except for an isolated drop to 0.9% at 564cm coinciding with a Betula maximum. Betula initially decreases but then rises again (to 22% at 868cm) before falling to minimum values (4%) at the zone top. Counts for Ulmus are maintained at around 3.5% (maximum 4.7%), and Quercus varies between 13 and 20% except for a minimum (>5) at the zone base. Pinus reaches maximum values (7%) at the base of the zone before declining to 4.5% by 552cm.

The shrub record is still dominated by Corylus although this shows a marked decline in the lower half of the zone. Values of 25-35% are initially recorded before a sharp peak of 57% at the upper boundary. The Salix curve is characterised by low but consistent values (<1.5%).

Gramineae and Cyperaceae fluctuate around minimum values of 0.4% and 1% respectively. Zone 4 is characterised by a general absence of herbs, with Filipendula the only taxon to form a continuous curve (<1%). Sporadic counts for Solidago type, Chenopodiaceae, Epilobium type, Melampyrum and Calluna vulgaris are recorded. Umbelliferae and Compositae Liguliflorae occur at the zone top.

The spore record contains low but consistent Equisetum, Sphagnum and Filicales, and occasionally Lycopodium and Polypodium. Polypodium values increase to 3.3%. The aquatic record declines with low values of Nymphaea alba, Sphagnum and Potamogeton. There are occasional counts for Myriophyllum verticillatum, Myriophyllum alterniflorum and Myriophyllum spicatum, and an isolated peak of Typha latifolia (0.5% at 580cm).

The algal record is minimal with discontinuous Botryococcus, and low but continuous Pediastrum (<2%). All categories of indeterminable grains are sporadic. The number of taxa identified within the pollen sum is between 14-22.

ZONE LH4 POLLEN CONCENTRATIONS

The concentration diagram is similar to the percentage diagram. Corylus is the dominant taxon with maximum concentrations of $1.5x10^5$gr/cm^3 at the zone top. Corylus, Quercus and Betula all show an initial decrease in concentrations as Alnus rises, but they then recover. Alnus rises rapidly and except for a minimum at 564cm ($3x10^3$gr/cm^3), high values are maintained until the zone top. Pinus maintains values of $1x10^4$gr/cm^3 until the penultimate level where values are zero. Average concentrations for the zone are 2.7x10gr/cm^3.

LLYN HENDREF POLLEN ASSEMBLAGE ZONES: LH5-LH7

Zones 5, 6 and 7 were identified by computer and described before the receipt of radiocarbon dates. Further work indicates that the upper portion of the stratigraphic column is disturbed and the zonation scheme may therefore have limited application. Due to uncertainty about the upper zones it was decided to include descriptions of each zone, both for descriptive purposes and for the sake of completeness.

If the sequence is heavily disturbed, then percentage and concentration values have relatively little meaning and only the presence of particular taxa is of interest. Few figures have been included in the zone descriptions except to indicate dominance or consistently high records. The estimated dates have been obtained from the depth-age curve (fig.5.2), but date reliability is questionable (section 5.4.2).

LH5 GRAMINEAE-CYPERACEAE-ALNUS-CORYLUS ASSEMBLAGE ZONE

Type site: Llyn Hendref.

Depth 552-432cm

Estimated age 4920 BP-4600 BP (duration 320 RC. YRS.)

The base is defined by simultaneous changes in all pollen

curves and the introduction of a large number of herbaceous taxa.

The majority of the sequence appears to be disturbed, with the exception of samples 548cm, 798cm, 796cm, and 764cm. The base of this zone has been defined by an interpreted unconformity or hiatus, indicating the beginning of disturbed sedimentation; an hypothesis also supported by radiocarbon dating, stratigraphy and macrofossil analysis (section 7.1).

Zone 5 is dominated by herbs and trees. Shrubs fall to 12%, herbs reach a maximum of 57% at 584cm and tree taxa gradually increase to 48% by 432cm. Spores show an overall increase towards the zone top, where percentages of between 8% and 11.5% are maintained

The tree record is dominated by Alnus (up to 28%) with sub-dominant Betula, Quercus and Ulmus. Pinus is sporadic and small quantities of Fraxinus are recorded. There are isolated counts of Fagus. Corylus dominates the shrub record although values are moderate (between 12-26%) and are associated with rising Salix.

Above the hiatus the herbaceous record shows high taxa diversity. Gramineae and Cyperaceae dominate, with maximum values of 29% and 16% respectively. The introduction and maintenance of continuous curves for the following taxa are also recorded; Calluna vulgaris, Compositae Liguliflorae, Plantago undiff., Umbelliferae, Plantago lanceolata, Potentilla type and Ranunculus. The curves are all relatively 'smooth' but frequencies remain <2%. There are increased occurrences of Ericales undiff., Cirsium, Solidago type, Chenopodiaceae, Cruciferae, Rosaceae, Rubiaceae, Rumex undiff. and Jasione montana. Artemisia, Caltha type, Achillea type, Caryophyllaceae, Leguminosae undiff., Trifolium, Ononis type, Plantago maritima, Polygala vulgaris and Polygonum apatholium are recorded as isolated counts.

Spore records increase with maximum values of Filicales undiff. (4%) and continuous counts for Polypodium, Pteridium and Sphagnum. These are associated with low, sporadic Equisetum, Isoetes and Dryopteris. Aquatics are generally low but there are increased occurrences of Myriophyllum alterniflorum and Myriophyllum spicatum, but only isolated Myriophyllum verticillatum. Potamogeton values are low, and Sparganium, Nymphaea alba and Nuphar are all sporadic. For the first time there are Hydrocotyle counts.

Algal counts recover in zone 5 with increased Pediastrum values (around 5%) and low consistent Botryococcus (0.5%). Broken and crumpled grains (<19%) form the majority of indeterminables. Corroded grains register between 1 and 5%. The number of taxa identified ranges between 24 and 35.

ZONE LH5 POLLEN CONCENTRATIONS

All recorded taxa show decreased concentrations at the base of zone 5. Most concentration curves show identical changes suggesting that sedimentary factors are responsible for fluctuations.

Overall Betula and Ulmus concentrations increase, but these are low at 550cm, before peaking at 516cm and 472cm. A separate peak in Betula ($3.4x10^4gr/cm^3$) is recorded at 518cm followed by a later maximum of Ulmus ($1.3x10^3gr/cm^3$) at 480cm. The Alnus curve has high values at 516cm ($7x10^4gr/cm^3$) and 488cm ($7x10^4gr/cm^3$), and unlike Betula, maintains high values at the zone top.

Pinus concentrations are consistently low and Salix values are reduced, but the curve has an identical pattern to that of Betula and Alnus. Corylus values are high and the curve shape matches the other major taxa.

Gramineae and Cyperaceae dominate the herb record with high values at the base of the zone, coincident with low tree and shrub concentrations. The curves then follow the general trend of the tree taxa. Other herbaceous taxa have low concentrations and also follow a common pattern.

LH6 ALNUS-CORYLUS ASSEMBLAGE ZONE

Type Site: Llyn Hendref

Depth 432-056cm

Estimated Age 4600 BP-3800 BP (duration 800 RC.YRS.)

The base of the zone is defined by the first continuous Ulmus and Pinus above the unconformity.

Most of the sequence appears to be disturbed with the possible exceptions of levels 512cm, 504cm, 664cm, 672cm, 680cm, 796cm, and 798cm. Zone 6 is characterised by relatively 'steady' percentage curves. Tree taxa register around 45%, shrubs 11-35%, and herbs around 20%. Spore frequencies reach a maximum of 16% and maintain high values (12-19%).

Alnus, Quercus and Betula dominate the tree record. Betula values remain steady between 4% and 14%. Quercus increases to 15% before levelling out at 10%. The Alnus curve is very similar to those of Betula and Quercus. Ulmus reaches 2% and Pinus becomes continuous (<1.3%) before declining to zero at the zone top. Fraxinus is recorded sporadically, and there are low (<0.5%) counts for Tilia.

Corylus again dominates the shrub record with values consistently >15% but often reaching 30%. Salix values are low (1.5%) and the curve eventually becomes discontinuous. Associated shrubs include Hedera helix with sporadic counts for Sorbus cf. aucuparia, Ilex aquifolium, Lonicera and Viburnum.

The herbaceous record is dominated by Gramineae and Cyperaceae, but taxa diversity is high. Continuous curves are recorded for Calluna vulgaris, Plantago lanceolata, Compositae Liguliflorae and Plantago undiff. Cereals and Cannabaceae are sporadically recorded. Ericales undiff., Artemisia, Cirsium, Achillea type, Caryophyllaceae, Chenopodiaceae and Cruciferae all have intermittent curves, and Potentilla, Plantago maritima, Ranunculus undiff. and Filipendula are persistent. Plantago lanceolata reaches 2.6%, and Ranunculus reaches 6% at

72cm.

The spore record is dominated by Filicales undiff. and Polypodium, each fluctuating between 4% and 10%. Pteridium and Sphagnum are prominent, and Isoetes and Equisetum increase, associated with isolated counts of Osmunda, Lycopodium and Dryopteris.

The aquatic record is generally sparse. Potamogeton and Nymphaea alba dominate but values do not exceed 1%. Both Myriophyllum spicatum and Myriophyllum alterniflorum co-exist and there are sporadic records of Myriophyllum verticillatum, Nuphar, Typha latifolia, Hydrocotyle and Sparganium type. Pediastrum values show large fluctuations (between 1% and 25%) but Botryococcus percentages remain below 0.5%.

The indeterminable record is again dominated by corroded and crumpled grains but with increased concealed grains. Broken grains have a discontinuous record. The number of recorded taxa varies between 24-34.

ZONE LH6 POLLEN CONCENTRATIONS

The concentrations of all taxa are relatively steady with tree taxa all exhibiting the same general pattern. Betula concentrations vary between 1.2×10^4gr/cm^3 (380cm) and 1.1×10^5gr/cm^3 (340cm). Quercus concentrations also have a minimum at 380cm (1.9×10^4gr/cm^3) and a peak at 340cm (1.1×10^5gr/cm^3). Values then fluctuate between 2×10^4gr/cm^3 and 5×10^4gr/cm^3, with further peaks at 228 and 116cm coincident with other taxa. The Alnus curve is almost identical but concentrations are generally higher.

Both Ulmus and Pinus concentrations are low throughout with negligible concentrations of Ulmus between 292-228cm. Higher values in the upper part of the zone coincide with peaks in the other taxa. Fraxinus and Tilia concentrations are low and sporadic.

High but variable Corylus dominates the shrub record (concentrations between $3.8x10^4gr/cm^3$ and $1.6x10^5gr/cm^3$) with maximum values occur at 340cm. All high concentrations coincide with those in all other taxa suggesting a dependence on sediment deposition. Salix and Hedera helix have low concentrations ($<3.0x10^3gr/cm^3$).

Gramineae and Cyperaceae illustrate a similar concentration pattern as the lower 250cm of the Betula curve, ie. they initially decrease but then peak at 340cm. Concentrations then fluctuate before a decline after 72cm. Peaks in Ranunculus, Jasione Montana, Plantago maritima, Cannabaceae, Rosaceae, Pediastrum and indeterminables occur at 324cm, 228cm, and 120 cm. Average pollen concentration for zone 6 is $1.4x10^4gr/cm^3$.

LH7 CANNABACEAE-ALNUS ASSEMBLAGE ZONE
Type Site: Llyn Hendref
Depth 56-0cm
Estimated age 3800 BP- ? (duration <3800 RC. YRS.)
The base is defined by the empirical limit of Cannabaceae.

Without exception the whole sequence appears to be disturbed. Zone 7 is characterised by steady and slightly increased tree taxa (average 41%) and constant shrub frequencies (approximately 16%). Herb percentages increase from 30% to 35%, and spores decline from 13 to 7%.

Betula values are relatively constant at 8% and are associated with higher but steady frequencies of Quercus (10%). Pinus values are low in contrast to Alnus values which fluctuate between 20%-30% except for lows at 48cm (15%) and 24cm (15%). Corylus is the dominant shrub (12-19%) and there are increased Salix values. Salix percentages average at 0.5%, and from 40cm upwards form a continuous record.

The zone is defined by the rising curve of Cannabaceae, which reaches maximum frequencies of 1.5% at 8cm. Gramineae and Cyperaceae remain major components, with the former rising to 20% by the top of the zone. Compositae Liguliflorae, Solidago type, Plantago lanceolata, Calluna vulgaris and Filipendula all have continuous curves. There are isolated counts for Campanula, Urtica, Melampyrum, Achillea type, Artemisia, Chenopodiaceae, Caltha type and also sporadic occurrences of Caryophyllaceae, Cruciferae, Potentilla type, Rumex undiff, Rubiaceae and Cirsium.

The spore record remains important with Equisetum, Isoetes and Sphagnum having fluctuating curves of <3%. Osmunda, Dryopteris, Polypodium, Pteridium and Filicales undiff. are also present. The latter often dominates with frequencies up to 8%. Polypodium values reach 3% and Pteridium maintains frequencies around 1.4%.

Aquatics are relatively sparse, with low percentages of Potamogeton and Myriophyllum alterniflorum. A continuous record of Nymphaea begins at 24cm but values remain low (<1%). There are occasional Myriophyllum verticillatum, Nuphar and Sparganium grains. Pediastrum values rise to 23% before declining to 16% at 8cm and rising again to 48% at the top of the zone. Botryococcus values are consistently <1%. Zone 7 is characterised by continuous but low curves of broken, crumpled and corroded grains. The number of taxa identified varies between 29 and 34.

ZONE LH7 POLLEN CONCENTRATIONS

The concentration curves reflect the major percentage trends. Betula concentrations increase slightly (average $2.3x10^4gr/cm^3$) and Ulmus values remain low ($1.4x10^3gr/cm^3$). Quercus values fluctuate between $1x10^4gr/cm^3$ to $5x10^4gr/cm^3$ and Pinus has low but increasing values reaching a maximum at 16cm. Alnus concentrations dominate ($1.5x10^3gr/cm^3$ at 40cm) before declining to $3.9x10^4gr/cm^3$ at the zone top. Salix concentrations follow the percentage trends, and Corylus maintains concentrations of $4.7x10^4gr/cm^3$ with major fluctuations reflecting the Betula curve.

Gramineae and Cyperaceae concentrations are high and have identical curves. A small peak is recorded at 40cm and then values level out. Concentrations of other herb taxa are low.

The Cannabaceae maximum of $5.4x10^3gr/cm^3$ is at 8cm. Spore concentrations remain consistent at around $2.5x10^4gr/cm^3$.

LLYN HENDREF POLLEN ACCUMULATION RESULTS

From the onset of organic sedimentation to 598cm, the pollen accumulation rate and concentration diagrams are similar suggesting that variations in pollen concentrations and accumulation rates reflect vegetational changes. The influx curves appear to be independent and the estimated sedimentation rates suggest that this was a relatively stable phase of the lake's history (section 7.1). Throughout this period total influx values increased from $1x10^3gr/cm^2/yr$ to $1.1x10^4gr/cm^2/yr$ reflecting forestation of the surrounding landscape.

Between 598cm and 552cm, pollen influxes are reduced to minimum levels with the average total pollen accumulation rate at $6x10^3gr/cm^2/yr$. The sharp decrease is not reflected in the concentration diagram which retains relatively high values ($2.7x10^5gr/cm^3$). This suggests that the concentration values are artificially high due to decreased sedimentation rates. It is unlikely that the minimum influx rates reflect true vegetational change as this is hypothetically a period of maximum forestation with an expansion of Alnus and Corylus (section 7.3). The low pollen accumulation rates during this period could be due to preferential organic erosion, a changed sedimentary regime, or radiocarbon dating problems. A similar situation was identified at Crose Mere (Beales, 1980). All influx values fell simultaneously and the mean pollen influx was reduced to $1x10^4gr/cm^2/yr$. It is believed that the inwash of older sediment was responsible for producing erroneous dates, which in turn affected the calculated sedimentation rate and pollen accumulation rates.

Above the hiatus at Llyn Hendref, synchronous changes in the concentration and pollen accumulation rate curves suggest that pollen input depended on sedimentary factors. Identical changes in many taxa suggest that pollen was deposited in association with redeposited sediments. Superimposed on this fluctuating regime would be pollen concentration changes due to vegetational change. It is difficult to distinguish contemporaneous pollen variation from fluctuations due to redeposited pollen.

Between 551cm and 432cm the average total pollen accumulation rate is $1.4x10^5$gr/cm^2/yr, decreasing gradually to $8.4x10^4$gr/cm^2/yr. These are the highest accumulation rates recorded for the Postglacial at this site. This period is characterised by continuously changing sedimentation patterns, probably due to resuspension and redistribution, which can result in increased pollen influx (Davis, 1967a). A similar situation is again recorded at Crose Mere (in LPAZ CM9; Beales, 1980) where sedimentation rates are high (0.21cm/yr) and influx values simultaneously rise. Beales (1980) suggests the increase is artificial and due to sediment redistribution.

At 56cm the concentration and influx diagrams diverge slightly with concentration values remaining relatively constant but influx values decreasing. The mean influx value is $4.6x10^3$gr/cm^2/yr and sedimentation rates are reduced to 0.02cm/yr. Changes between the influx and concentration diagrams are no longer synchronous, suggesting that factors other than the sedimentary regime are controlling pollen input. The decreased sedimentation rate should theoretically increase concentration values, but their consistency suggests that actual pollen input decreased, perhaps indicating a reduction in vegetation cover.

The synchronous changes in the pollen accumulation rate and concentration diagrams are probably attributable to sediment erosion and redistribution. Sediment focusing due to erosion and redeposition exaggerates total pollen input, and fluctuations in pollen accumulation rates may be influenced by short term changes in sediment accumulation. Many of these variations will be on too short a time scale to identify with infrequent radiocarbon dates.

In view of the apparently continuously changing sedimentary regime of Llyn Hendref it is difficult to interpret much of the upper portion of the diagram in terms of vegetational change.

3.5.3 COMMENTS ON POLLEN ACCUMULATION RATE CALCULATIONS

Pollen accumulation rates for Llyn Cororion are generally higher than those at Llyn Hendref, supporting Davis' (1967a) statement that "pollen input per unit area over a small lake may exceed significantly that over a lake of greater dimensions". This is probably because smaller lakes are more efficient at trapping pollen due to their limited outflows. The data from Llyn Cororion illustrates that in lakes with a relatively stable regime and constant sedimentation rates, influx and concentration diagrams are similar, and can be interpreted as reflecting changing vegetation. In this case palaeoecological interpretation can be undertaken from the percentage diagram using the concentration diagram as an aid to analysing species interaction.

The Llyn Hendref data illustrate the problems associated with palynological work in unstable or disturbed environments. Pollen concentrations do not reflect vegetational change and are dependent on highly variable sedimentation rates which cannot be detected using radiocarbon dates. Pollen accumulation rates at this site are largely a reflection of sedimentary regime and are not as useful as those calculated for Llyn Cororion. Although much of the concentration and accumulation rate data cannot be used in the conventional way they do serve to illustrate periods of irregular sedimentation and sediment redistribution. Without this data, the percentage diagram could have been mis-interpreted in the absence of the knowledge that frequency shifts do not reflect vegetational succession.

In view of high between lake variability in influx rates (Davis, 1966), and the problems associated with calculated sediment accumulation rates, Llyn Hendref and Llyn Cororion are not compared with other studies.

3.6 POLLEN WASHINGS

3.6.1 INTRODUCTION

Plant macrofossil analysis is an alternative approach to the reconstruction of temporal changes in vegetation, but the depositional and preservational processes of macrofossils differ from that of pollen; hence data interpretation has different assumptions and limitations. In peat deposits macrofossils tend to be autochthonous, and, although in lake deposits there may be a streamborne macrofossil component, most macrofossils in the lacustrine environment are locally derived (Birks and Birks, 1980). Unlike pollen, macrofossils indicate the actual presence of a taxa at a site, and can often be identified to species levels. This is important for taxa such as Pinus where the pollen percentages required for local stands to be inferred are ambiguous, and may not be constant. Macrofossil remains are also important with taxa such as Juncus which are not recorded in pollen diagrams. Macrofossil remains tend to be sporadic, and rarely occur in high concentrations, making interpretation of changing frequencies difficult.

Detailed macrofossil analysis requires different site selection procedures and sampling techniques to those used in palynology. The optimum location for recovering macrofossils is towards the edge of a lake site as marginal deposits tend to be richer in plant remains (Seddon 1962), but most cores for palynological studies are taken from the central area of lakes and tend to contain little coarse organic material. Identifiable remains are often recovered from pollen washings and can be used to obtain complimentary data on both the inorganic and organic content of the core. The results cannot form a macrofossil study in their own right, but for relatively little extra time much information can be obtained.

3.6.2 METHOD

Residues collected on the 118 micron mesh during pollen preparation were studied under a binocular microscope at a magnification of X25. All components were noted and divided into three main categories; recognisable remains, unidentifiable organics, and the inorganic component. The latter two groups were then further subdivided into a fine and coarse component. The division between fine and coarse minerogenic material was taken at the division between medium and coarse sand, (approximately 0.6mm) and where possible lithology of the larger fragments was ascertained. Abundances of unidentifiable components were recorded on a four point scale (fig. 3.3).

Macrofossil analysis was therefore limited to the small sediment samples associated with pollen preparation. Identification was restricted to a few taxa, due to lack of reference material. Identification was undertaken using photographs (Godwin 1975), drawings (Burrows 1974,) and detailed notes and sketches (taken by the author under the guidance of Mary Pettit, University of Cambridge). Only presence or absence of a taxa was recorded and results are shown in figures 3.3 and 3.4. Relative frequencies of the inorganic component can be integrated with loss-on-ignition results and sedimentary data to indicate periods of intense erosion and unstable soils. Identifiable plant remains complement pollen data and provide information about the vegetation in the immediate vicinity of the basin.

3.6.3 RESULTS

LLYN CORORION

The minerogenic portion of the core (1009-963cm) yielded relatively large quantities of inorganic material, with the quantity of coarse mineral material increasing towards the graded gravel (fig. 3.3). Lithologies were dominated by slate, quartz, quartzite and sandstone fragments derived from outwash

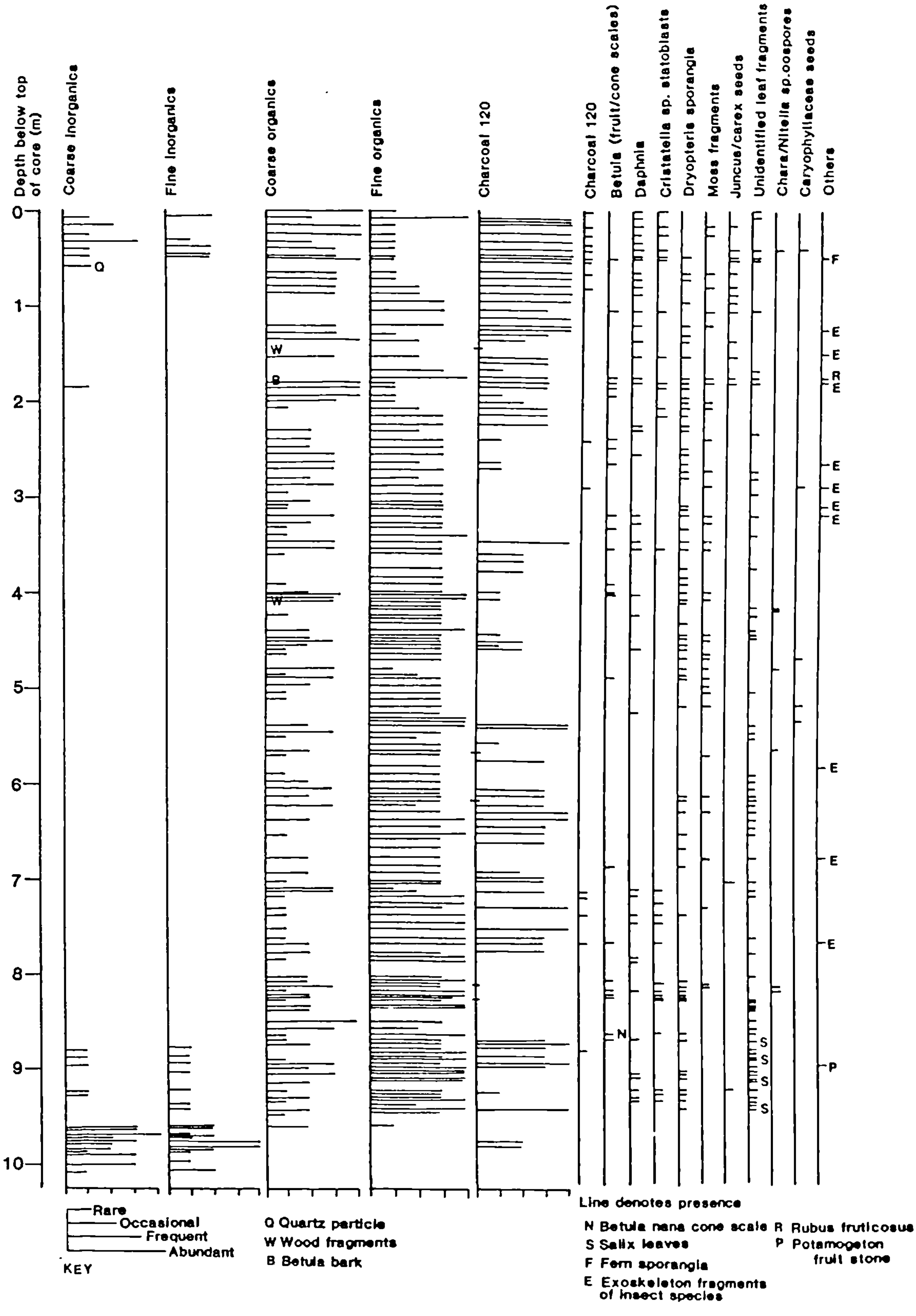


Figure 3.3 Llyn Cororion: Pollen washing residues and charcoal analysis

deposits within the catchment. One sample (963cm) contained coarse organic material and rare fine organic sediment, a feature also recorded in the loss-on-ignition data. The boundary between the inorganic and organic portions of the core is abrupt, with organic rich lake muds lying directly on gravels, (plate C).

In the organic portion of the curve, mineral material (both coarse and fine sand) occurs up to 880cm, coinciding with high inorganic measurements from the loss-on-ignition curve. From 48cm upwards, which marks a rapid Cannabaceae rise, every sample yields both coarse and fine mineral material. Fine inorganics are recorded as either rare and occasional and coarse material fluctuates between rare and frequent. These upper samples also contain abundant coarse organic material. The increasing mineral content is also reflected in the loss-on-ignition data and indicates accelerated erosion during deforestation (section 6.1).

Betula cone scales, leaves and fruits are recorded but only one specimen is positively identified to species level; a *Betula nana* cone scale at 965cm. This indicates that the shrub form of *Betula* did occur at Llyn Cororion in the early Postglacial. The appearance of many of the *Betula* grains in the lower part of the core did suggest the possibility of the presence of *Betula nana* but no systematic separation was attempted. *Betula* remains occur throughout the core and increases in *Betula* pollen percentages are matched by increased macrofossils (eg. between 180-200cm and at 800cm). Betula macrofossils confirm the local presence of birch carr around the lake basin.

Dryopteris fern sporangia are one of the most commonly occurring macrofossils and are recorded throughout the core except for a gap between 615-520cm, which is matched by an absence of *Dryopteris* spores in the frequency diagram. It is interesting to note that the early Postglacial *Dryopteris* spore records do not have a corresponding macrofossil record. Moss fragments are recorded from 816cm upwards with initial sporadic occurrences, and then frequencies increase upwards with a concentration between 445cm and 520cm.

Juncus and Carex seeds have a distinct occurrence, with a concentration of remains in the top two metres of the core (from 225cm upwards). This corresponds to increasing Cyperaceae pollen frequencies and could indicate the gradual spread of carr and swamp vegetation around the margins of the lake.

Isolated Caryophyllaceae seeds were recorded at 535cm, 520cm, 470cm, 280cm and 140cm. Only the latter level has an associated pollen record and the rest therefore verify the presence of a taxa that is not recorded in the pollen record. Other positively identified macrofossils include a Potamogeton fruitstone at 904cm associated with a percentage peak in the Potamogeton spore record suggesting the presence of a fringing macrophtye community (section 6.2). A Rubus fructicosus stone is identified at 180cm but there is no corresponding pollen record. Godwin (1975) noted that the stones are freely distributed by birds so it may not indicate the presence of this species close to Llyn Cororion.

Cristatella has a relatively consistent record from the base to 716cm but thereafter is only one isolated occurrence at 352cm before frequencies increase again. The Daphnia record is similar but is absent between 716-526cm. Gaps in the records of these two macrofossil types correspond well with low or zero records of Pediastrum suggesting that their occurrence depends on relatively high lake productivity. Throughout the core a selection of insect exoskeleton fragments were recorded but these were not identified to species level; most were mite carapaces.

Unidentified leaf fragments decrease upwards, with a small gap in the record between 764cm and 720cm, corresponding to increased charcoal fragments. Charcoal occurs in two distinct portions of the core with the first occurring between 770-715cm. Below this, at 882cm, there is the isolated occurrence of charcoal fragments and a few fragments are noted at 790cm and 740cm. Above 580cm there are continuous records of charcoal. Associated with increased charcoal washings is the onset of declining Betula, Salix, Alnus and Fraxinus and increased percentages of Corylus pollen. Detailed interpretation of the charcoal results is included in section 6.3.

At the base of the organics, an isolated fragment of 'shell' was recovered and due to its unusual structure it was sent for identification at the British Museum. It was identified as a heavily worked and weathered 'carinal compartmental plate of a balanoid cirripede (barnacle)' (Morris, pers. comm., 1987). The origin of this is unknown, but from the state of preservation and the distance of the site from the shoreline, suggests that it was derived from reworked glacial material within the catchment. No other shell material was found in the core.

LLYN HENDREF

The basal sediments at Llyn Hendref are laminated and disturbed (plates D1, D2 and fig. 3.1). Below 750cm only inorganic material was identified with a high frequency of fine sand particles (residues from sand laminations). At 784cm a small pebble of mica schist was identified and coarse grained quartz rich sand was recorded at 743.5cm and 782cm. Above 745cm the organic record increases, and although medium sand still dominates, both coarse and fine organic fragments are now recorded, a trend which is also recognised in the loss-on-ignition results. There is also an increase in coarse inorganic material with calcareous nodules recorded at 744cm and quartz pebbles at 731cm and 720cm.

The boundary between the organic and inorganic portion of the core is taken at 720cm but separation is difficult because of the gradational nature of the contact. From 712cm upwards the coarse organic component increases and organic remains then dominate for the rest of the core. Inorganic material occurs

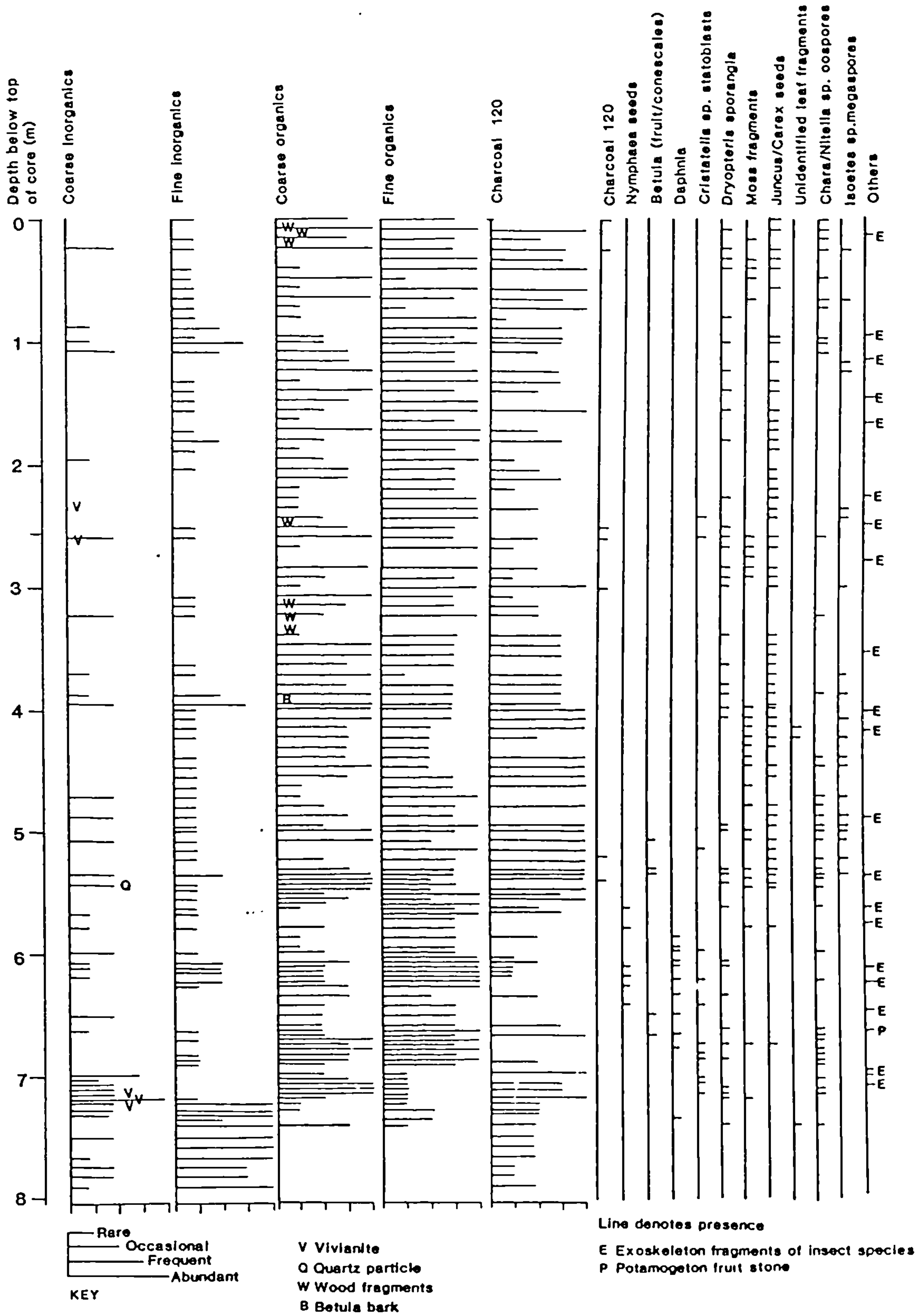


Figure 3.4 Llyn Hendref: Pollen washing residues and charcoal analysis

sporadically throughout the core, usually as medium micaceous sand. Fine inorganic material occurs around 625cm, 538cm, 396cm, and 100cm, with sporadic occurrences between 675cm and 205cm before increasing again towards the top. Coarse mineral material (quartz pebbles) is most frequent at the base of the sequence and then decreases upwards. Vivianite occurs in abundance at the top of the minerogenic sequence and then sporadically between 200-300cm.

Betula fragments (fruits and cone scales) are recorded between 668cm and 508cm, but frequencies are sporadic and there is no direct relationship between the presence of macrofossils and the pollen record. The macro remains verify the presence of birch trees within the catchment, but not necessarily local presence as they may have been stream derived. Birch wood is recorded at 534cm, 396cm, 245cm and also scattered between 323-345cm and between 116-134cm.

Dryopteris sporangia occur throughout the core and are recorded before the onset of organic sedimentation (742cm) at a level of reduced minerogenic input. Moss fragments are also widely distributed, with the first isolated record at the onset of the organic sedimentation. It is then recorded more frequently above the hiatus (552cm). Above this there are two distinct gaps in the record, between 292-400cm and 164-260cm, but the significance of these are not understood.

Juncus and Carex seeds have a distinctive distribution. Two isolated examples are noted at 678cm and 580cm but above the hiatus at 852cm there is an almost continual record to the core top. This corresponds with the percentage diagram which has relatively low frequencies of Cyperaceae below 552cm and then shows a rapid increase in values above this level. This supports the hypothesis that there were major vegetational and hydrological changes in the lake catchment (section 7.3).

Isoetes megaspores were not systematically identified to species level but the majority of the spores resembled Isoetes echinospora. Below the hiatus there are no records but above 552cm they occur regularly with a gradual decrease upwards. Gaps in the record are matched in the pollen diagram by an absence of Isoetes miospores. Isoetes is a submerged aquatic preferring water poor in dissolved salts and often occurring on peaty substrates (Clapham et al., 1987) and so its presence above the hiatus suggests a change in lake water quality.

Nymphaea cf. alba seeds also have a distinct distribution, occurring only below 552cm. The first seed is noted at 644cm and then there are sporadic occurrences up to 552cm. The macrofossil record is not as consistent as the pollen percentage record. Nymphaea is found in emergent aquatic environments and usually occurs in mildly acidic waters at depths between 50cm-300cm (Clapham et al., 1987). The sudden disappearance above the hiatus supports the idea of changing water depths and/or trophic status of the lake.

Characeae and Nitella oospores occur throughout the core with one isolated occurrence at 745cm before the onset of organic sedimentation. In the organic portion of the core their occurrence is concentrated in the first sixty centimetres, and then between 552 and 372cm and above 100cm. Daphnia and Cristatella statoblast, are most frequent below the hiatus except for sporadic records of Cristatella at 538cm, 240cm, and 260cm. There is no observed relationship between Daphnia, Cristatella and Pediastrum.

Leaf fragments occur occasionally (742cm, 416cm and 424cm), and there is an isolated Potamogeton fruitstone at 680cm. The latter is associated with relatively high percentages of Potamogeton pollen indicating abundant pondweed within the lake (section 7.3). Insect exoskeleton particles are frequent throughout but were not identified to species level. Charcoal occurs in the pollen washings at 100cm, 260cm, 268cm, 300cm, 540cm and 556cm.

3.7 PRE-QUATERNARY SPORES

3.7.1 INTRODUCTION

Previous work has demonstrated that glacial tills may contain large quantities of pollen and spores from either interglacial deposits or pre-Quaternary sources. Birks (1970, 1973) recorded pre-Quaternary microfossils in Lateglacial deposits from the Isle of Skye and they have also been identified at sites in Wales including Llyn Goddionduon (Ince 1981). There has been little discussion about derived spores in sediments at Welsh sites and identification is rare beyond assignment to 'pre-Quaternary'.

It is unlikely that the bedrock at Llyn Cororion or Llyn Hendref would yield derived spores but Irish Sea till is a potential source having scoured source areas dominated by Carboniferous lithologies, including coal deposits (Walsh et al., 1982).

3.7.2 METHOD

During routine pollen counting of the Llyn Cororion basal sediments, a number of trilete spores and tricolpate grains were encountered. These had distinctive morphology and were darkly stained; their amorphous and degraded state suggested a derived origin. The grains were systematically counted, and different groups were distinguished, of which examples were sent to British Petroleum p.l.c. to be identified by B. McPhilemy. Similar types at Llyn Hendref were encountered and their identification was based on comparisons with the Llyn Cororion examples, and by reference to Smith and Butterworth (1967). In the absence of a reference collection, the results illustrated in table 3.7 are limited. Counts are given for each taxa at every level, and detailed descriptions of the different types can be found in Smith and Butterworth (1967). Total percentages for the pre-Quaternary counts are also listed, but the high values are over-emphasised by the low local pollen input.

3.7.3 RESULTS

Many grains were assigned to Lycospora sp. but were too deteriorated or amorphous to allow accurate identification. These grains tended to be between 32 and 37 microns in size with a triangular-obtuse outline, an equatorial thickening (varying in width) and a distinct trilete scar (plate F). One recognisable and well preserved species was Lycospora pusilla, a taxa characteristic of the Carboniferous (range Visean to Stephanian). Other taxa identified included Leiotriletes, and a smooth monolete form assigned to Laevigatosporites which is typical of the Westphalian (Smith and Butterworth, 1967). Specimens of Densosporites were also noted and these have a similar range to Lycospora pusilla (Visean-Stephanian). Densosporites is abundant in Carboniferous coal seams and is characterised by its rounded form and a thickened 'cingulum'. The assemblages are difficult to interpret as many taxa are not identifiable to species level and have long time ranges with similar morphotypes up to the present day (McPhilemy pers. comm., 1988). This makes it difficult to assign them to a particular geological stage but integration of the data suggests that the spores are Carboniferous in age.

The ranges of the taxa are illustrated in fig. 3.5. The presence of the species Tripartites vetustus suggests a source of late Visean to early Namurian age but it occurs with Laevigatosporites which did not appear until later, in the Westphalian. The association of these two spores indicates that reworking of the deposits has occurred either during the Westphalian (Tripartites vetustus is relatively common in reworked Westphalian deposits; McPhilemy, pers. comm., 1988) or in the Quaternary during ice transport and deposition.

3.7.4 INTERPRETATION

Ice movement indicators (striae and erratics) across Anglesey show that Northern Ice crossed Liverpool Bay and impinged on the island from the north-east (Greenly, 1919; Walsh et al.,

Table 3.7 Pre-Quaternary Spores identified at Llyn Cororion and Llyn Hendref

Site — Sample level (cm below top of core)

LLYN CORORION	963	970	974	978	986	994	1002	1009
Lycospora sp.	11	5	5	30	11	20	67	31
Lycospora pusilla				7	22	3		16
Leiotriletes sp.					6		3	1
Laevigatosporites								1
Leistuletes sp.								1
cf. *Reinschospora sp.*						1		
Densosporites					2	2		1
Tripartites vetustus						1		
Trilete undiff.	3	36	36	20	4	9	30	10
Unknown		3	1	5		3	6	
Total Pre-Quat.	14	47	47	62	45	39	106	61
Pre-Quat (%TLP)	7	13	4	33	64	43	78	66
Zygospores	1	2						

LLYN HENDREF	724	726	730	734	738	742	743	752
Lycospora sp.	3				1		2	12
Lycospora pusilla			2					2
Leiotriletes sp.			1					1
Densosporites			1					3
Trilete undiff.	4	4	6	4	5	6	6	4
Unknown			3			2		
Total Pre-Quat.	7	4	12	4	6	8	8	22
Pre-Quat. (%TLP)	21	0.5	4	0.4	5	1	2	48
Zygospores.					2	5		

LLYN HENDREF (cont.)	760	768	776	784	792	800
Lycospora sp.	11	8	21	4	18	16
Lycospora pusilla			2			10
Leiotriletes sp.		6	1	2	2	2
Densosporites		1	4			2
Trilete undiff.	4	3	3	5		
Total Pre-Quat.	16	18	31	15	20	30
Pre-Quat. (%TLP)	36	5	17	20	11	29
Zygospores.	3	1	7			4

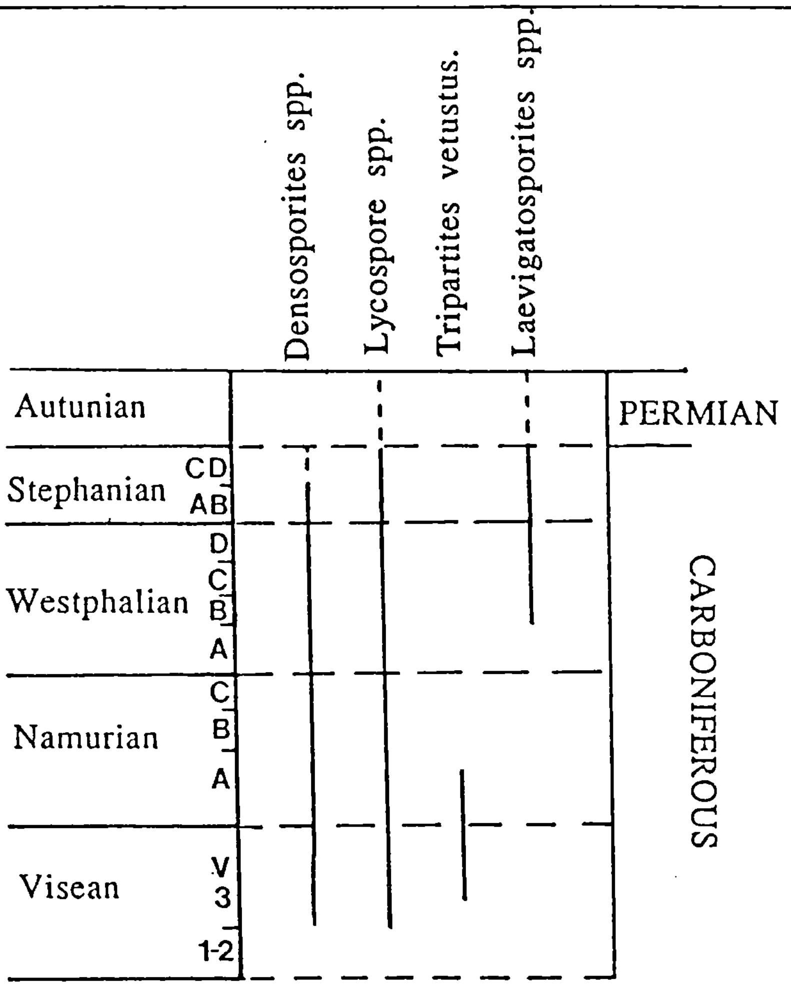


Figure 3.5 Age range of selected Carboniferous miospores, (modified from Clayton et al., 1977).

1982). Borehole data from Liverpool Bay has identified a number of Carboniferous outcrops offshore. The most likely source for derived Carboniferous spores is from either outcrops of Westphalian rocks (mudstones with thin coaly layers and plant material) to the north of Anglesey, or a small isolated inlier (fissile dark grey mudstone of Namurian age) to the south-east of the Isle of Man (Wright et al., 1971). Glacial and glacio-fluvial sediments deposited by Irish Sea ice and now exposed at Lleiniog (SH619787) have been described by Walsh et al. (1982), and include large volumes of coal fragments which vary in size from silty films to cobbles. The palynological assemblages included *Reticulatisporites*, *Laevigatosporites* spp., *Endosporites* and *Sphaerotriangularis*, indicating a source rock of Westphalian A or B age, most likely those off the north coast of Anglesey.

It is therefore apparent that Irish Sea till and associated sediments contain many derived Carboniferous spores and reworked grains. The assemblages of pre-Quaternary spores at Llyn Hendref are relatively easy to explain as the site lies within the domain of Irish Sea ice deposition. During periods of intense erosion, the spores would be transported to the lake by solifluction, slopewash and stream input. As the landscape stabilised and soils developed, erosion decreased and the frequency of the derived spores is reduced.

The derived spores at Llyn Cororion possibly had a similar source. Llyn Cororion lies within the zone of confluence between the local Welsh and Irish Sea ice sheets (section 1.3.4) and deposits in this area may have characteristics common to both sources. During impingement of Irish Sea ice onto the coastal plateau, sediments characteristic of northern derivation may have been deposited and later included within local deposits during periods of Welsh ice dominance. If this was the case then it could be expected that the resultant sediment would contain minerals and derived Carboniferous spores usually associated with Irish Sea drifts.

An alternative hypothesis is that the spores were derived as a windblown component during a period of lower sea levels and severe climate. Carboniferous spores have been described from the site of Llyn Goddionduon (Ince, 1981), where, given the altitude and situation of the site, a wind-borne source for the spores is the most likely explanation. During the Loch Lomond Stadial, lower sea levels left large areas of bare drift, and unconsolidated material was exposed to wind action. Wind was an effective geomorphic process in the Loch Lomond Stadial (Lowe and Walker, 1984), and increased continental and cyclonic conditions (Rind *et al.*, 1986) resulted in greater frequency and strength of winds, particularly in the north-west of Britain. Precipitation rates were reduced and increasing aridity and frost action produced large quantities of material available for aeolian activity. The exposed sediments would quickly have had finer components removed (clay minerals, spores, pollen) and redeposited on the land surface to be later transported to the lacustrine environment or directly deposited into lakes.

CHAPTER 4

PHYSICAL AND CHEMICAL METHODS

4.1 LOSS-ON-IGNITION

4.1.1 INTRODUCTION

Loss-on-ignition is one of a number of methods used to estimate the water and carbon content of materials. In loss-on-ignition, gases evolved during ignition are measured volumetrically, chromatographically, or as a simple weight loss (Dean, 1974). The weight loss at 550°C is taken to be a measure of combusted organics and the loss at 950° is proportional to the volume of carbon dioxide released from carbonate minerals (Dean, 1974). The advantage of this method is that a large number of samples can be processed simultaneously. Dean (1974) concluded that although the results were comparable with other techniques, some limitations should be recognised. Despite the simplicity of the method, there has been no standardisation of the temperature and time length for sample treatment (table 4.1).

WATER CONTENT

Most workers dry samples at around 100°C for between 1-24 hours, although it has been noted that at temperatures above 85° oxidation and charring of peat may occur, resulting in a greater weight loss than anticipated. Skempton and Petley (1970) burnt peats at various temperatures and found an insignificant difference in loss between samples burnt at 60°C or 100°C. Provided that samples are all burnt at the same temperature, and for long enough to reach a constant weight, results will be comparable.

ORGANIC CONTENT

Gibbs (1977) recommended that organic samples should be burnt

Table 4.1 Variations in the temperatures and time length used in loss-on-ignition

Author	Temperature °C	Time
Water Content		
Dean (1974)	90-100	1 hr.
Galle and Runnels (1960)	105	1 hr.
Hakansson and Jansson (1983)	105	6 hr.
Skempton and Petley (1970)	105	12 hr.
Organic Content		
Dean (1974)	550	1 hr.
Skempton and Petley (1970)	550	3 hr.
Ball (1964)	370-380	16 hr.
Arman (1971)	440	5 hr.
Gibbs (1977)	1050	30 secs.
Galle and Runnels (1960)	550	25 mins.
Carbonate Content		
Dean (1974)	1000	1 hr.
Galle and Runnels (1960)	950-1000	1 hr.
Bengtsson and Enell (1986)	925	4 hr.

at 1050°C for short periods of time as at temperatures below this, samples may not be fully oxidised and the organic content underestimated. Gibbs (1977) states that at 550° C the loss-on-ignition only yields a quarter of the true organic weight, resulting in a subsequent overestimation of the carbon dioxide content at 950°C.

The major disadvantage of burning organics at high temperatures (above 600°C) is that volatiles (eg. hydration water from kaolinite) are released and a combination of organic and volatile loss is recorded. This is most significant for material with a high clay content (Mackereth, 1966). Al-Khafaji and Andersland (1981) recommended that ignition for carbon content should be at 400°C, but for a longer time period (eg. 12 hours). Ball (1964) suggested that a temperature of 375°C for 16 hours would minimise water loss from clay, but at such low temperatures it is possible that organics remain unburnt.

Assuming a proportionality factor, the correlation between loss-on-ignition and organic carbon content has shown to be good for non-calcareous highly organic sediments (Hakansson and Janssen, 1983) but cannot be assumed to hold for inorganic sediments due to loss of structural water at lower temperatures. The residue after burning at 550°C is the inorganic component, a mixture of amorphous and crystalline compounds, mineral matter and calcium carbonates.

CALCIUM CARBONATE

The calculation of the carbonate content relies upon the evolution of carbon dioxide from the sample at temperatures between 550°C and 950°C, and on the assumption that the total weight loss is attributable to the loss of CO_2. The biggest problem at these temperatures is the loss of clay lattice water and other volatiles. Loss-on-ignition results only estimate total carbonate content because it is difficult to distinguish between different carbonate minerals (Dean, 1974). If the weight loss at 950°C is assumed to be due to CO_2

evolved from calcium carbonate, then correction factors can be used to calculate the actual calcium carbonate content.

Hosang and Locker (1971) have called for the loss-on-ignition method to be standardised, but this is difficult as each type of sample material requires different temperatures, times and correction factors depending on its physical properties. The loss-on-ignition method is relatively quick, inexpensive and simple to execute and for a series of samples an appropriate temperature and time duration should be chosen. These should be clearly stated and should remain constant throughout the experiment, and the final results should be interpreted bearing in mind possible errors.

4.1.2 METHOD

The procedure adopted closely follows that of Dean (1974) and is illustrated in figure 4.1. The results were processed using LOI.FOR (written by the author for the University College of Wales VAX), and no correction factors have been applied.

Results are illustrated in figs. 4.2 and 4.3. An assessment of dry weight and water content gives an indication of the amount of compaction that the sediment has undergone. Loss-on-ignition has been used here as a crude indication of inorganic and organic content, which has then been used as indirect evidence of erosion rates and soil stability within the catchment (cf. Mackereth, 1966).

4.1.3 LOSS ON IGNITION RESULTS

LLYN CORORION

WATER CONTENT AND DRY WEIGHT

The basal mineral material has a high dry weight (maximum 1.48g at 978cm) and low water content (30% on average) due to low porosity, compaction and the inherently high density of clay (Hakansson and Janssen, 1983).

Figure 4.1 Loss on ignition method

Place 1cm^3 of sediment in a pre-weighed crucible

↓

Ignite at 105°C for 16hrs

↓

Re-weigh sample → Loss = Water content
Residue = Dry weight

↓

Ignite at 550°C

↓

Re-weigh → Loss = Organic content

↓

Ignite at 950°C → Loss = CO_2 evolved/unburnt organics
Residue = Inorganic content

Water content calculated as a % of wet weight
Organic content, inorganic content and loss at 950°C calculated as % of dry weight.

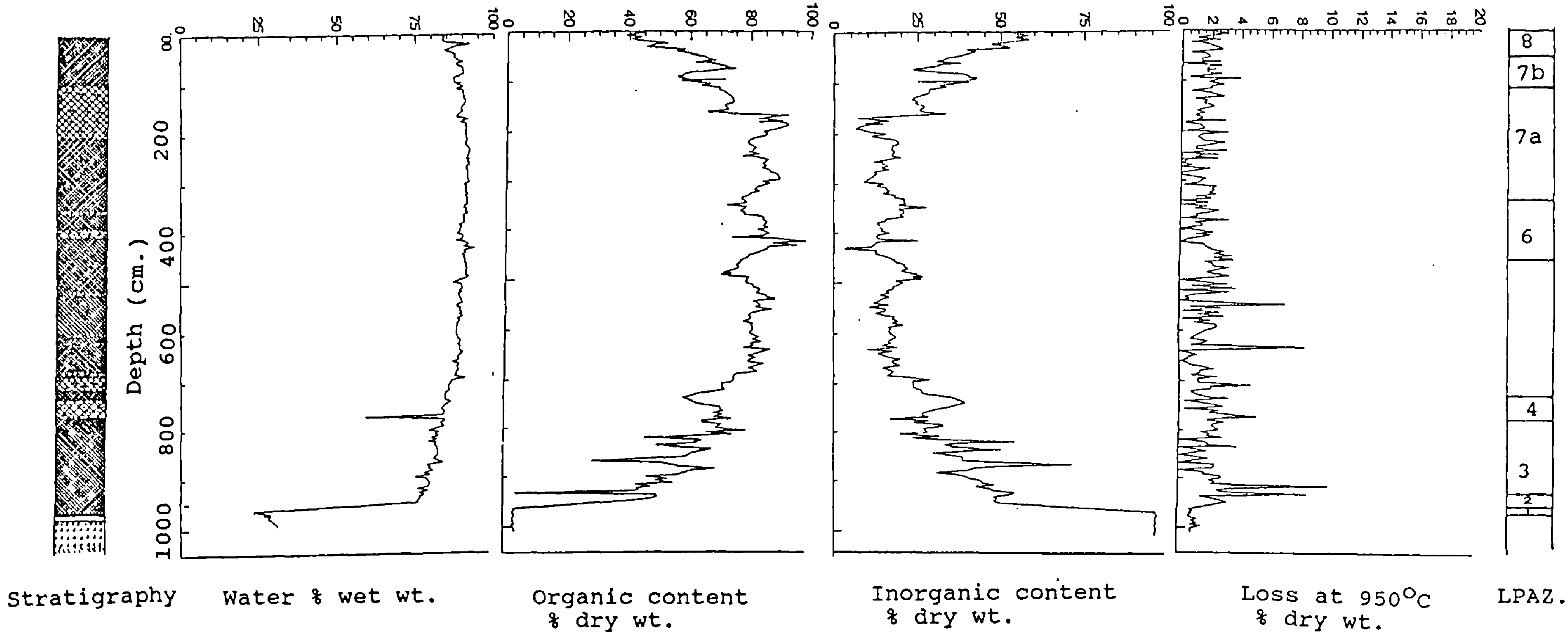


Figure 4.2 Llyn Cororion: Loss on ignition results

At the onset of organic sedimentation (948cm) the water content rapidly increases to 76% and the dry weight decreases to around 0.1g/cm^3. The water content continues to rise and fluctuates around 90% for most of the core. In the upper metre, there is a noticeable rise in density (to 1.9g/cm^3) and a corresponding decrease in water content (to 83%). The density curve and water content are clearly related to the organic and inorganic content of the sediment (fig. 4.2); water content almost matches organic content with lower values at the base where the minerogenic content is still high and there has been compaction.

Increased density in the top metre of the core is explained by the higher mineral content. A decrease in the water content is unexpected as shallow burial and minimum compaction would theoretically result in a higher water content. Two possibilities to explain this are; 1) water loss occurred during core extrusion in the field and 2) the increased inorganic content and the fine size of organic detritus reduced porosity.

ORGANIC AND INORGANIC CONTENT

The basal mineral material contains 1-3% loss-on-ignition at 500°C and although most loss will be due to organic material, some may be due to volatiles or structural water loss (section 4.1.1). The minerogenic content to 950cm is high (89-97%) but then gradually decreases upwards.

The high inorganic content suggests that vegetation cover was low, and soils were immature, unstable, and susceptible to erosion. At the onset of organic sedimentation organic values rise rapidly to 41% before increasing (fluctuating between 32-69%) to a maximum of 72% at 720cm. The inorganic content falls to 55% at the onset of organic sedimentation followed by a large decrease to 15% by 668cm.

Between 720cm and 400cm organic values remain relatively stable at 75%-80% with a slight decrease in values between 492-484cm to 70%. This then recovers and rises to a peak at 408cm (86%). From 400cm to 164cm the organic percentages remain high but with frequent fluctuations (between 75-98%). For the same portion of the core the inorganic component remains at low values (between 15-20%) with slightly increased percentages at 348cm (27%), 492-484cm (23%) and 248cm (19%). Troughs in the minerogenic content are coincident with a high organic content.

At 164cm both curves change, the organic percentages rapidly decrease and at the top of the core reach 45%. The decline is relatively steady except for a sudden minimum of 54% at 74cm. The mineral content increases in the top portion of the curve with values reaching 61%. Again the rise is gradual with a maximum at 93-68cm (42%) followed by a trough at 72-74cm (25%).

The Llyn Cororion curves are typical for Postglacial lake sediments (cf. Mackereth, 1965, 1966) which show similar organic profiles irrespective of their ecological status. The increase in organic sedimentation at Llyn Cororion around 9680 BP signifies the increase in vegetation cover and rising lake productivity, but mineral input was still relatively high suggesting that soil stabilisation was gradual. Vegetation then stabilised, canopy density increased and organic soils accumulated. Interception of rainwater and the protective effects of undergrowth reduced erosion rates and soils gradually matured. The net result was one of maximum organic deposition, although the continued inorganic input (10%) suggests localised erosion persisted but had reached some kind of equilibrium.

The subsequent decrease in organics is associated with the main phase of deforestation within the catchment area (cf. Pennington and Lishman, 1984). Woodland clearing induced increased erosion and soil destabilisation. Increased surface run-off transported the weathering products to the basin. The slightly increased organics towards the core top are associated with a period of high internal productivity, possibly related to increased nutrient supply provided by the inorganic material.

LOSS AT 950°C

The loss recorded in the basal inorganics is low (0-1%) but at the inorganic/organic boundary it rises to 3%. Values then fluctuate between 0% and 4% for the rest of the core with higher values nearer the core base.

Weight loss at 950°C is often attributable to evolution of CO_2 but tests showed that the $CaCO_3$ content of the sediment was negligible. It is possible that the weight loss was due to structural water loss from clay minerals but this appears to be unlikely as minimum weight loss occurred where the clay content was greatest. The most probable source for weight loss is unburnt organics which remained after the 550°C ignition. This would explain the low losses in the basal sediments and the higher losses at 932cm 900cm and 772cm, which correspond to lower weight losses at 550°C.

LLYN HENDREF RESULTS

WATER CONTENT AND DRY WEIGHT

The basal materials have a high density (between 1.7-0.9g/cm^3) but are variable, reflecting the transitional nature of the inorganic/organic boundary. The water content is between 30-40% with slightly higher values indicating permeable silt and sand bands (eg. at 916cm, water content is 55% and density is low). Water content gradually increases towards the top of the inorganic sediments corresponding to a density decrease associated with increasing organics and silts. The low water content and high density result from clay compaction. However, an organic band (82%) at 716cm is identified by a high water content and low density.

At the onset of organic sedimentation the dry weight decreases

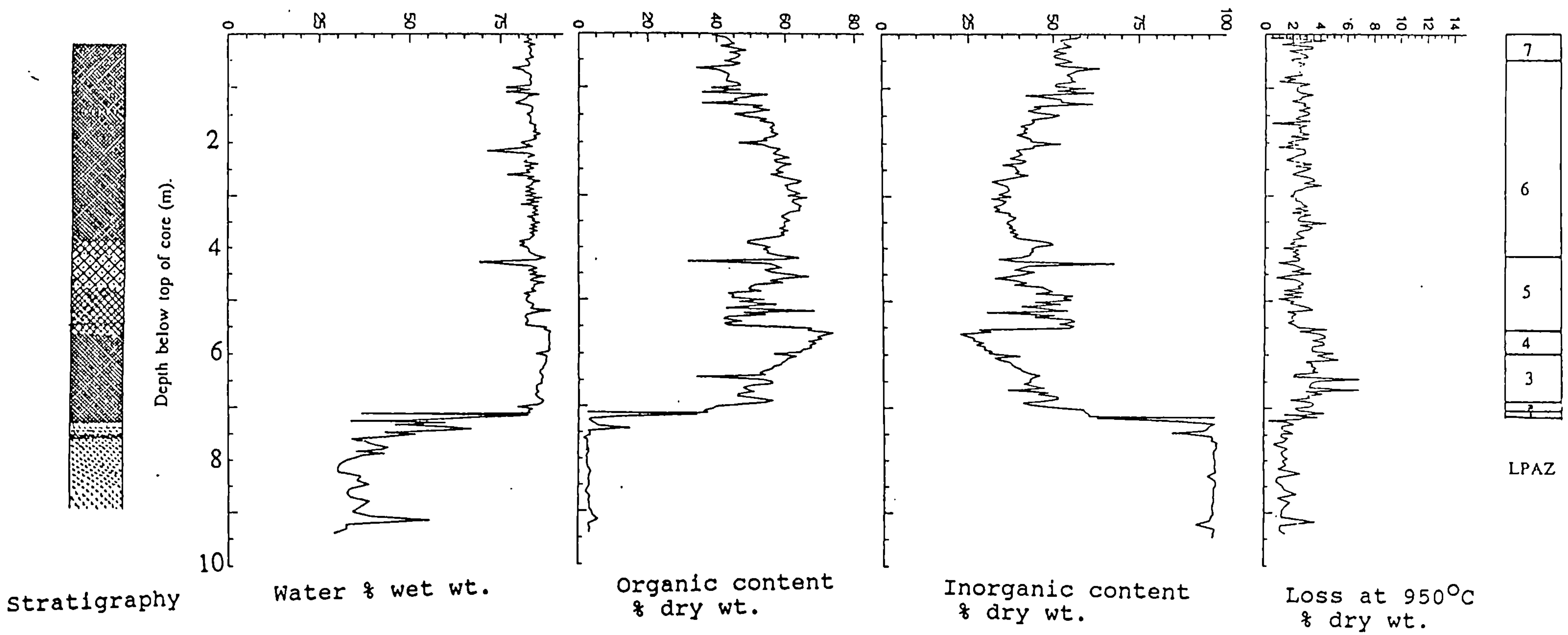


Figure 4.3 Llyn Hendref: Loss on ignition results

to 0.5 g/cm^3 but then remains relatively stable at around 0.18 g/cm^3 except between 712-552cm when density is less than 0.15g/cm^3 reflecting a low minerogenic input. Above 552cm most results lie between 0.15-0.27g/cm^3 with maximum values reflecting minerogenic rich material.

The water content rises rapidly at the base of the organics (to 82%) and then fluctuation between 79-89% up to 552cm. Water percentages then drop slightly to 76-85%. The water content does not have an obvious relationship to the organic/inorganic content but corresponds well to changes in stratigraphy with finer lake muds containing less water. A higher minerogenic component in the top part of the core appears to have also resulted in a general reduction in water content; perhaps as a result of poor sorting or finer organic material inducing better compaction, a lower water content and higher density values.

ORGANIC AND INORGANIC CONTENT

The organic and inorganic curves do not follow the 'typical' Postglacial sequence as seen at Llyn Cororion. The basal minerogenics have a low organic content (1-5%) but with peaks of 11% and 17% at 743.5cm and 742cm respectively, corresponding to organic rich layers. The inorganic content is high at between 87-97%. An unexpected minimum of 90% at 916cm is due to contamination during coring (section 7.1).

At the onset of organic sedimentation minerogenics decrease to 59% at 712cm and then fluctuates between (59% and 22%). Organic percentages show a corresponding increase, initially rapid to 27% followed by a period of gradual increase to a maximum of 73% at 560cm. This reflects forestation and increased productivity within the catchment, and reduced soil erosion. Minimum values are recorded at 45% (680cm), 41% (664 cm) and 34% (644cm), each coincident with inorganic peaks.

The change in both inorganic and organic curves at the base of zone 5 are obvious and reflects changes in the sedimentary regime. Organic values decrease from 67% to 43% with a corresponding high in minerogenic material. The organic content fluctuates between 42% and 57% until 472cm, after which percentages begin to rise again until a maximum of 66% at 304cm. High values are recorded between 356-352cm (61-67%) and at 320cm (64%), separated by an anomalous low of 31% at 428cm. The inorganic percentages show the opposite pattern (figure 4.3) and are thought to represent an unstable sedimentary regime (section 7.1). Above 300cm, inorganics increase to a maximum at the core top reflecting deforestation and soil erosion. These effects were superimposed on the continually changing sediment regime and input from resedimentation.

LOSS AT 950°C

Minimum weight loss (0.5-2.7%) occurs in the basal minerogenic sediments and increases in the overlying organic sediments. For the organic sediments, the curve can be divided into two; 1) between 720cm and 552cm the loss is generally higher and varies between 1.5% and 5% and 2) above 552cm, weight loss is generally lower (0.5-3.5%) and decreases upwards. There is no evidence of calcium carbonate contamination and with a minimum loss in the minerogenic portion of the curve, losses are unlikely to be due to evolution of CO_2 or structural water. The presence of unburnt organics is the most reasonable explanation and is supported by the fact that the greatest losses at 950°C occur in the portion of the curve that contains maximum organics.

CHEMICAL ANALYSIS

INTRODUCTION

Chemical analysis of Lateglacial and Postglacial lacustrine sediments was pioneered by Mackereth (1965, 1966). Lake sediments are a complex matrix of sediment from the catchment (allochthonous sediment) and vegetation, algae and precipitates from within the basin (autochthonous sediment). Mackereth

(1966) suggested that sediments were predominantly derived from the drainage basin, and unstable autochthonous material was rapidly oxidised at the mud surface and unlikely to be preserved.

Lake sediments are therefore essentially a sequence of mineral soils and stable organic material eroded from the catchment area. A complete and undisturbed sequence can therefore be analysed, and chemical and mineralogical changes can be interpreted as representing variations in rates and intensity of erosion, and in soil composition of the surrounding area. Subsequent work in Northern Scotland (Pennington et al., 1972) and the Lake District (Pennington and Lishman, 1984) verified these conclusions, and have shown that changes in sediment chemistry correspond well to biostratigraphic variations.

Particulate mineral and element sources are both varied and complex; Oldfield (1977) concluded that with some elements (eg. phosphorus, iron, silicon) it is often difficult to verify the exact source but the derivation of sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) is easier to identify. Mackereth (1966) suggested that Na, K and Mg were predominantly associated with allochthonous mineral material, and were not usually formed by chemical or biological precipitation. Once deposited, they remain relatively immobile with only minor quantities exchanged across the sediment-water interface or incorporated into sediment by sorption. Organic matter can complex or sorb inorganic ions from solution but only in small quantities (Engstrom and Wright, 1984) and so measured concentrations of these three elements should theoretically reflect allochthonous input.

The calcium content of lake sediments is more complex. It has been shown to be directly proportional to organic content (Mackereth, 1966; Engstrom and Wright, 1984), but can also be precipitated chemically. Calcium content may therefore reflect changes in organic input into the lake basin. Calcium can also be derived from allochthonous mineral sources but only during periods of intense and rapid erosion of raw soils as it is relatively soluble and is leached away during weathering of stable soils.

Mackereth (1966) concluded that during periods of relatively stable soils, high vegetation cover and low erosion rates, there would be leaching of mineral matter in situ and elements in solution would be lost from the system. Subsequent erosion of the soil would result in the deposition of inorganic material depleted in alkalis (Cowgill and Hutchinson, 1970). During times of intense erosion, leaching would be restricted, and raw soils rich in Na, K, Ca would be transported directly to the lake basin. Concentrations of Na, Ca, K are therefore a direct reflection of the hydrological conditions and soil composition within the drainage basin.

The relative solubilities of the elements (Ca > Na > Mg > K; Likens et al., 1977) is taken into consideration in this project, as is the tendency of certain elements to concentrate in clay minerals (eg. K; Oldfield, 1977) and hence occur in higher proportions when the inorganic fraction is clay rich. Unless there is evidence to the contrary, it has been assumed here that the rate of material transported to the lake is primarily determined by the rate of erosion. Diagenetic changes are assumed to be limited and bioturbation, chemical interaction with water and vertical ion movement are also assumed to be insignificant (Engstrom and Wright, 1984).

Crabtree (1965) produced a detailed and comprehensive chemical record of limnic sediments and valley peats in North Wales. Results were integrated with diatom and pollen studies, and it was concluded that the data reflected erosion intensity within the catchment. Guppy and Happey-Wood (1978) studied the sediment chemistry of Llyn Peris and Llyn Padarn, in the Llanberis valley, and were able to relate chemical stratigraphy to climate change and industrial activity. Elner and Happey-Wood (1980) utilised diatom, pollen and chemical analysis to elucidate the history and evolution of Llyn Peris. A good correlation between sediment chemistry and diatoms was found, and changes were attributed to mining activity within the catchment area, particularly copper mining. Botterill (1988) produced the first chemical study on Postglacial mire sediments from Anglesey with the integration of peat chemistry and mineral content which were then correlated with vegetation change, hydrological conditions and erosion rates within the drainage basin.

Most chemical techniques are time consuming and hazardous, and Bengtsson and Enell (1986) present two alternative methods both using strong acid leaching, which allows the determination of element concentrations from the acid soluble phase of a sediment. Similar methods have been adopted by Elner and Happey-Wood (1980) but they are not suitable for elements that cannot be easily associated with one sedimentary component (eg. Si). Organic matter is effectively destroyed but it is not possible to break down the mineral component with the result that certain elements (eg. K) cannot be measured in total concentration (Engstrom and Wright, 1984).

4.2.2 METHOD

Temporal variations in potassium, calcium and sodium are examined in this study. These elements are theoretically relatively easy to ascribe to a single sedimentary component and are potentially the most useful for identifying changes in erosion rates within the catchment. The method used in this project is similar to the one suggested by Bengtsson and Enell (1986) involving two stages of acid digestion (fig. 4.4).

A blank sample was produced with each set of samples to detect contamination and for calibration. Samples were processed on a Gallenkamp flame photometer, and standard solutions were used to construct calibration curves for each element. Figures from these were used to convert the machine reading to actual concentrations. Final concentrations (PPM) were calculated by;

$$\text{Element concentration in dry sediment (PPM)} = \frac{[\text{Concentration} \times \text{Volume} \times \text{Dilution}]}{\text{Dry sediment weight (g)}}$$

Figure 4.4 Sediment preparation for chemical analysis

Place 5g sediment in pre-weighed beaker

↓

Dry at 100°C for 12hrs.

↓

Add 20cc conc. analar nitric acid
Cover beaker with watchglass

↓

Heat on hotplate at 110°C for 30 mins.

↓

Remove watchglass
Dry sample until surface is 'gleaming'
but it is no longer a liquid

↓

Repeat 2 and 3

↓

Stir 50cc of 0.001 M HNO_3 into dry
sediment. Warm to 50°c for 15 mins.

↓

Filter solution through filter paper
(Whatman No 540) into 50ml volumetric flask

↓

Make up volume with distilled water

↓

Clean glassware thoroughly with 10% HNO_3
to prevent contamination

The data was processed using Fortran programs (CHEM.FOR and PLOT.FOR, written by the author), on the University College of Wales VAX. Results have been plotted as concentrations (PPM) against depth (figs. 4.5 and 4.6). A stratigraphic column, organic content and local pollen assemblage zones have been included for comparison.

The method adopted is relatively cheap and quick but does not give total elemental concentrations. Nitric acid is ineffective at dissolving silicates but it was assumed that the concentrations extracted remain proportional to the total mineral content throughout. Interpretations is based on trends and relative changes with little emphasis on absolute values.

The problems of interpreting concentration data are similar to those confronted in pollen analysis where variations in sediment accumulation rate affect final values. An increase in lake productivity or organic input will 'dilute' the minerogenic component producing an apparent decrease in element concentration. It is possible to remove the influence of a variable (eg. the organic component) by calculating the elemental concentration per gram mineral material (eg. Mackereth, 1966; Davis and Norton, 1978).

4.2.3 RESULTS AND INTERPRETATION

LLYN CORORION

SODIUM

A comparison of the mineral content and the sodium concentration curve indicates little direct connection between the two (cf. Mackereth 1965, 1966) so alternative sodium sources need to be considered.

Sodium concentrations in the basal minerogenics are low (between 98PPM and 105PPM) suggesting that the mineral

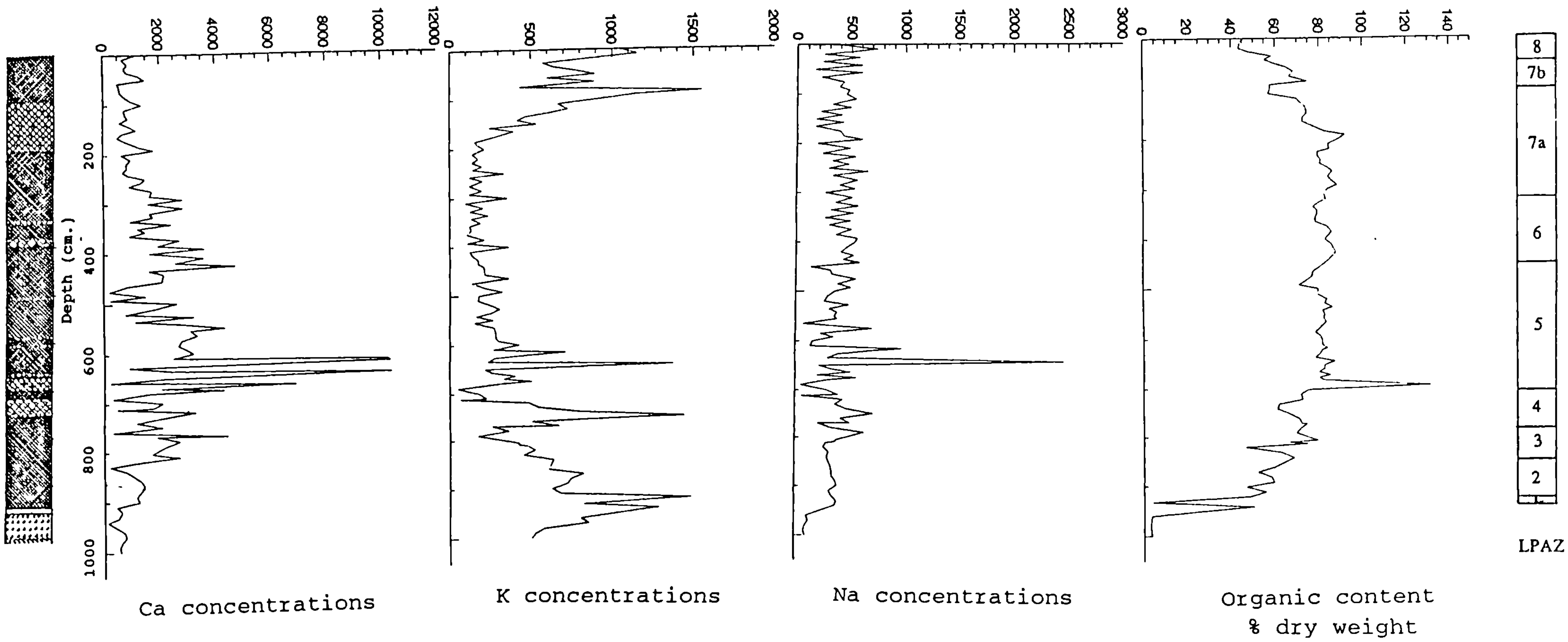


Figure 4.5 Llyn Cororion: Element concentrations

material was derived from an inherently sodium-poor source (supporting the XRD results, section 4.4.4). It is possible that the underlying glacial sediments contain a significant proportion of rock flour, and were therefore rich in clay-sized quartz. Mineral input was therefore a minor source of sodium and provided only a background component which varied as inorganic input and sedimentation rates changed. Fluctuations are unlikely to represent a changing sediment source as most inwash was locally derived and they could reflect experimental error or fluctuating sedimentation rates.

Precipitation may be a possible source of sodium; Llyn Cororion lies on a coastal plain but at a break of slope where precipitation rates are high due to topographic rainfall (Ball, 1963). The contribution of sodium from rainfall is impossible to quantify (given this data set) and both frequency and concentrations will have changed throughout the Postglacial. Precipitation as a major source of sodium is only considered when no alternative explanation for the observed fluctuations can be identified. The data indicates that allochthonous organic material was the main sodium source in the lake sediments. Concentrations rapidly rise at the inorganic-organic boundary (948cm) and many of the major fluctuations in the curve mirror the organic content.

Zone 1 (948-936cm) is characterised by a rise in sodium concentrations (to 365PPM) associated with the onset of organic sedimentation. High percentages of <u>Salix</u> and fen vegetation are recorded (section 6.3) and at the base of the sequence numerous <u>Salix</u> leaves were identified. <u>Salix</u> preferentially stores sodium within its leaves (up to 0.4 g/kg being recorded; Allen <u>et al.</u>, 1974). The high concentrations (between 261-385PPM) are therefore related to the spread of carr vegetation.

Sodium concentrations in zone 2 are relatively steady (between 312PPM and 386PPM) compared with the organic content which gradually increases and the apparent decrease in estimated sedimentation rates (section 5.5.2). These latter two factors would increase sodium concentrations but were probably offset by diminishing mineral input. A slightly higher value (385PPM) at 900cm is associated with an isolated sand band. Fluctuations in zone 2 are minor but could be related to a combination of factors including changing carr vegetation, varying sedimentation rates and fluctuations in mineral input.

In zone 3 (860-780cm) concentrations are generally steady (between 263 and 382PPM), but one significant peak (633PPM at 790cm), is reflected in the loss-on-ignition curve (fig. 4.5). There are rising Salix percentages and increased algal production which may have enhanced sodium concentrations. The sedimentation rate in zone 3 is low but the effect of this on concentrations is difficult to assess given possible fluctuations in other variables.

Sodium concentrations in zone 4 (780-702cm) are generally high (between 56 and 719PPM) with increased values associated with a rise in coarse organic detritus and increasing Betula values. Zone 5 (702-460cm) shows a wide variation in concentrations, between 47PPM and 973PPM, with lower values recorded at the zone top and peak concentrations (2463PPM) recorded at 542cm. Organic input is high and sodium input from mineral material is likely to have been at a minimum. Sedimentation rates remain steady and minor fluctuations in sodium concentrations are probably associated with changing carr vegetation. The fluctuations recorded in the top half of zone 5 are directly comparable to variations in the organic curve. Maximum values are associated with high (86%) organic deposition and layers rich in leaf debris (Betula and Salix) and Dryopteris sporangia. Values reflect increased carr vegetation and deposition of coarse organic material.

In zone 6 (460-324cm) concentrations are steady, varying between 135PPM and 569PPM and reflecting the consistent organic content. Slightly higher concentrations are associated with layers of leaf fragments (eg. 531PPM at 427cm) or an increase in the coarse organic component (unidentified ligneous and herbaceous material). Sodium input from mineral material would have been minimal, as inorganic input is low and material would have been depleted in sodium due to continuous leaching.

Zones 7 and 8 (324-0cm) have a relatively steady concentration curve (between 166PPM and 654PPM), averaging at 426PPM. From 85cm onwards the organic curve progressively declines reflecting deforestation (section 6.3), and it is believed that eroded mineral material now became a major source of ions. The contribution of sodium from vegetation diminished with decreasing carr vegetation and progressive deforestation but this was offset by the rising input of inorganic sediments. Erosion of soils was now extreme (section 7.1) and unleached subsurfaces, relatively rich in sodium were exposed and removed. Some fluctuations within this period are positively attributed to increased leaf content (eg. 478PPM at 92cm), and sand rich layers (eg. 413PPM at 142cm).

POTASSIUM

Potassium concentrations produce a curve similar to other Welsh data sets; they are typically high in the basal organic sediments, decrease throughout the Postglacial and then rise again after 5000 BP. Superimposed on this general pattern are lower than expected values in the basal inorganics, and a large peak within zone 5. A comparison of the loss-on-ignition curves and potassium concentrations indicate that the major source of potassium at this site was allochthonous mineral material with minor quantities derived from organic sources.

Concentrations in the basal mineral material range between 498PPM and 798PPM with higher values recorded just below the inorganic\organic boundary. The concentrations are relatively low compared with the early Postglacial, but the ratio of potassium to sodium is relatively high suggesting enrichment in the former element. Local slates are dominated by quartz, chlorite and illite; the latter a possible source of potassium.

The gradual rise in potassium concentrations (from 498PPM to

798PPM) towards zone 1 appears to be unrelated to organic content and is possibly connected with a change in source material, decreasing sedimentation rates or variations in grain size; Pennington (1974) noted the tendency for potassium to be concentrated in clay-sized particles. The clay content generally increases towards the top of this particular sequence, perhaps contributing significant quantities of potassium.

In zone 1 (948-936cm) concentrations are initially high, rising to 1476PPM before fluctuating between 604PPM and 816PPM. High values are associated with increased organic input and possibly low sedimentation rates. Mineral matter probably contributes a major portion of the potassium but higher values could also be related to increased Salix, Cyperaceae and the development of fringing aquatic vegetation (Allen et al., 1974). The potassium values also appear to be directly related to algal production but the exact relationship is unclear.

Zones 2 (936-860cm) and 3 (860-780cm) are characterised by a decline in potassium values which accurately reflects the gradual decrease in inorganic material. In zone 2, concentrations vary between 604 and 1476PPM but generally fall below 800PPM. Concentrations in zone 3 are lower, between 359 and 634PPM with a minimum of 169PPM at 790cm. Fluctuations appear to be directly correlated with variations in mineral input.

Zone 4 (780-702cm) is characterised by fluctuating values. Concentrations of 258PPM are recorded at the base, rising to 1438PPM at 750cm before declining to 179PPM at the zone top. There is also a relative enrichment of potassium compared with sodium. The peak is associated with a change in stratigraphy (lake mud now contains more ligneous material) and a corresponding maximum in mineral material. Decreased values correspond to increased organic input and it is possible that the low recorded in all the elements at 712cm is the result of sediment redistribution.

Zone 5 (702-460cm) concentrations have a pattern similar to that of sodium, and it appears that some fluctuations are related to organic content. Concentrations of 47PPM are recorded at the base, corresponding to increasing coarse organic debris. Values then fluctuate between 47PPM and 1368PPM but these are extreme, and values generally vary between 213PPM and 527PPM. The ratio of K:Na is decreased (1:1) emphasising the increasing organic input into the lake. The maximum value of 1368PPM is associated with leaf fragments and an increasing Corylus record but a simultaneous change in all concentration records at this point suggests the peak is associated with a sedimentation change or water level fluctuations.

Zones 5 and 6 (460-324cm) have low steady values (between 106PPM and 361PPM, generally decreasing throughout the zone) reflecting a period of maximum forestation (section 6.3) and soil stability. Leaching of soils was slow and steady, so mineral matter deposited within the lake was depleted in base elements.

In zones 7 and 8 (324-0cm) potassium concentrations increase from 93PPM to 723PPM (zone 7) to a maximum of 1047PPM at the top of zone 8. This corresponds to a changing stratigraphy and increased inorganic input. Fine sand and silt are increasingly common, related to progressive deforestation and subsequent soil erosion. Eventually base-rich (unleached) substrates were exposed resulting in increased deposition of mineral material.

The sediments show an increasing enrichment in potassium until the ratio of K:Na reaches 3:1 as inorganic input increases. Minor fluctuations in the potassium content may be attributable to vegetational changes or sedimentation variations. Crabtree (1965) recorded high potassium values associated with reedswamp vegetation (especially Juncus squarrosin). Increased concentrations of potassium are recorded at 150cm 92cm and 50 cm; all are associated with the possible presence of Juncus and therefore reedswamp vegetation.

CALCIUM

The basal sediments have low calcium values (between 557PPM and 693PPM) which decrease (91PPM) at the onset of organic sedimentation suggesting a mineral source poor in calcium, one of the characteristics of locally derived till. The clay assemblage has minerals devoid of calcium so the small concentrations recorded here may be derived from Irish Sea till incorporated into local till, from calcite veins within the slates or from occasional shells and reworked forams in the till. Mineral material from the catchment therefore provides minimum quantities of calcium.

For much of zones 2, 3 and 4 the calcium curve fluctuations reflect changes in organic content (fig. 4.5). Concentrations vary between, 192PPM (at 830cm) and 4464PPM (at 770cm) with mean values at around 320PPM. The development of a Salix carr (including Pteridium and Dryopteris) and the onset of fringing reedswamp would lead to increased calcium deposition as many of these taxa have a high calcium uptake. The slightly lower sedimentation rate would also account for some increase in concentrations. Zones 3 to 7a have the same calculated sedimentation rates and the concentration values are therefore comparable. In zones 3 to 6 variations in calcium concentrations reflect organic content hence possibly also vegetational changes at the site. There is little evidence of autochthonous mineral precipitation although occasional Nitella and Chara oospores indicate that, at times, the lake water was relatively calcium rich.

Maximum calcium values (up to 10 399PPM, fig.4.5) are recorded in zone 5 associated with simultaneous changes in the other elements (and hence possible sediment redistribution), and a leaf-rich layer. From zone 7 upwards, calcium concentrations remain relatively steady (between 300PPM and 500PPM) despite decreasing organic content. There is a progressive depletion in calcium compared with potassium as the mineral content increases. Decreasing organic content would be expected to produce a corresponding fall in calcium concentrations, but this is offset by the input of relatively raw mineral material. As erosion intensity increased, the proportion of calcium retained within the soil rose and it was finally incorporated into the lake sediment.

Peaks in the concentration curve (eg. 1810PPM at 192cm and 1161PPM at 150cm) correspond to increased sand input as seen in the stratigraphy. This suggests that the sediment source now included progressively less-weathered mineral soils, with composition tending towards that of raw soils (Pennington and Lishman, 1984). Pennington and Lishman (1984) have suggested that increased calcium values in late Postglacial sediments may be attributable to increased autochthonous organic material. Pediastrum values at Llyn Cororion are high in zone 7b and it is possible that this maintained calcium values.

LLYN HENDREF

The sequence below 552cm (zones 1 to 4) is in stratigraphic order but above 552cm much of the core appears to be disturbed (section 7.1) and it is virtually impossible to assign the elements to one particular source. The results and interpretation for zones 5 to 8 are therefore of limited value.

SODIUM

The sodium values at Llyn Hendref vary considerably, and the direct relationship between inorganic input and sodium concentrations recorded by some authors (eg. Mackereth, 1966; Pennington, 1978) is not immediately apparent. A comparison of the loss of ignition curves for Llyn Hendref and the sodium concentration curve shows that the predominant source of sodium was not unleached soils. Minerogenic input may provide some sodium to Llyn Hendref but only as a background component.

It has been suggested that sodium may be deposited by

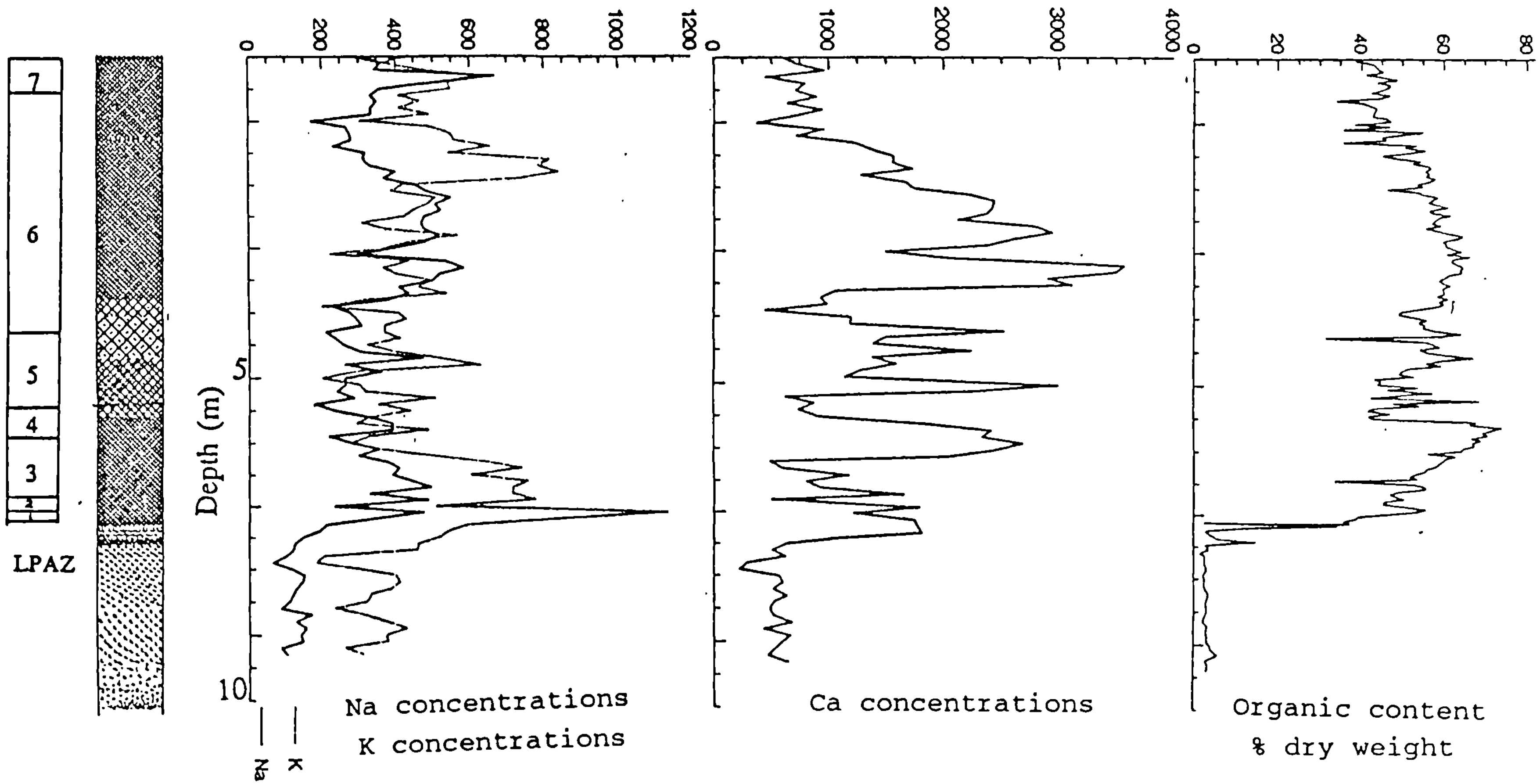


Figure 4.6 Llyn Hendref: Element concentrations

precipitation at coastal sites (Mackereth, 1966) and was a possible sodium source at Loch Lang (Bennett et al., 1990a). Llyn Hendref is a lowland site, relatively close to the coast and exposed to south-westerly winds. Precipitation could therefore be a potential sodium source but this is a difficult hypothesis to test as changes in precipitation are impossible to estimate without using circumstantial evidence (eg. vegetation).

At Llyn Hendref sodium concentrations appear to be closely associated with organic input and lacustrine vegetation. The link between sodium concentrations and allochthonous organic material has been noted by Botterill (1988). The preferential uptake of sodium by some plants has been documented (Tallis, 1973) and Crabtree (1965) illustrated the association of high sodium content with reedswamp and peat formation. Tallis (1973) measured elemental concentrations for various types of aquatic vegetation and noted that semi-swamp carr had ten times the concentration of sodium compared with open water.

Sodium concentrations in the basal minerogenic deposits are low (<200PPM, range 84PPM to 207PPM). Other sites in Wales (eg. Llewesig; Crabtree, 1965) tend to exhibit high sodium concentrations for Loch Lomond Stadial sediments indicative of rapid erosion under a severe climate. The basal stratigraphy at Llyn Hendref (table 3.2) is similar to other Welsh sites, and a high sedimentation rate is inferred from the long sequence of inorganics recovered. Low sodium content could indicate rapid deposition of severely leached mineral material (unlikely when compared with other sites) or a source material that is inherently sodium poor. XRD results suggest that the mineral assemblage is depleted in sodium rich silicates and so the latter explanation is most likely. It is possible that surrounding glacial sediments are rich in 'rock flour' (clay-sized quartz) and are therefore be inherently base-poor but clay rich.

The low sodium concentration values at the base of the core are therefore a reflection of a base-poor source. Increasing sodium values (from 98PPM at 790cm to 207PPM at 730cm) at the top of the minerogenic sequence could be due to decreasing sedimentation rates (section 7.1) or gradually increasing organics.

Sodium concentrations increase towards the inorganic/organic boundary (from 200PPM to 472PPM) confirming that it is associated with allochthonous organic input although increased internal productivity may have also been a source. In zone 1 (720-712cm) concentrations are relatively high (up to 472PPM at 710cm) associated with willow scrub development and increased organic input. Salix and Filipendula ulmaria, both high in this zone, preferentially uptake and store sodium in their leaves (up to 0.4g/kg dry weight) and some species of sedge (Cyperaceae) contain up to 1.2g/kg (dry weight) of sodium (Allen et al., 1974). The rapid sodium increase therefore reflects increased organic input associated with the spread of Salix carr.

In zone 2 (712-692cm) concentrations are reduced (to 230PPM) and radiocarbon dates suggest slightly increased sedimentation which would effectively reduce the elemental concentration. In zone 3 (692-596cm) the sodium content is initially increased to 493PPM, despite an increasing sedimentation rate, before fluctuating between 274 and 444PPM; the lower values towards the zone top. Sodium values appear to be linked with aquatic vegetation development and increased organic input. This is a phase of continuing organic input and the introduction of Corylus signifies increasing canopy cover (section 7.3). The beginning of this zone marks maximum macrophyte development with vegetation fringing much of the lake.

From 600cm upwards sodium concentrations start to decrease; this is surprising in view of the increasing organic input, and it is possible that the sodium values were affected by a changing vegetation assemblage. Taxa which concentrate sodium (eg. Salix, Filipendula), were replaced by species that are relatively sodium poor (eg. Alnus). A distinct concentration low (295PPM at 620cm) is associated with a decreased organic input, increased charcoal records and the beginning of the alder curve. Lower concentrations may also be due to decreased input of allochthonous mineral material as soils within the catchment stabilised and erosion decreased. The minerogenic input is likely to have been depleted in sodium as leaching was effective.

In zone 4 (596-552cm) concentrations stabilise between 215PPM and 388PPM, mineral input was minimum and the lake was gradually infilling. The Na:K ratio shows that the lake sediments were preferentially enriched with sodium (1.5Na:1K) suggesting that increased sodium could be derived from precipitaticn. An increase in precipitation is often inferred at the onset of the Alnus rise (Godwin, 1975) but the evidence for this in inconclusive at Llyn Hendref. The source of sodium for this zone therefore remains obscure. Lake level fluctuations and associated changes in sedimentation may have caused the observed concentration fluctuations.

It is likely that the upper portion of the core is disturbed (section 7.1) making it difficult to correlate sodium concentrations with a particular source. The hiatus, identified in the stratigraphy and pollen record, is not apparent in the sodium curve. Correlations are tenuous and it is impossible to ascertain any direct relationships. A comparison of the organic content and sodium concentrations (fig. 4.6) suggests that this is the strongest link. In zone 5 (552-432cm) concentrations remain at around 250PPM (varying between 175-471PPM) despite an apparently increased sedimentation rate. The core immediately above the hiatus consists of coarse organic debris which may have contributed to the sodium input and higher concentrations appear to be associated with birch bark fragments.

Zone 6 is characterised by a broad concentration peak, (fig. 4.6) followed by a trough, but again it is difficult to identify the sodium source. A comparison of the organic content and the concentration curve show that both are similar, with the broad peak matched by an increased organic content.

Maximum sodium concentrations are associated with sedge rich layers containing wood fragments suggesting that coarse organic detritus is the major sodium source. In zone 7, concentrations again mirror the organic curve and peak concentrations are associated with increased ligneous material and pieces of birch wood.

POTASSIUM

The potassium source at Llyn Hendref is difficult to verify. Changing potassium concentrations are usually taken to indicate high erosion rates and the deposition of unleached sediments (eg. Mackereth, 1966). At Llyn Hendref, potassium appears to be derived from a combination of sources, but generally was associated with organic material. At Loch Lang, Bennett et al. (1990a) found that sodium, calcium and potassium had a strong affinity for organic sediments.

The basal mineral sediments show uncharacteristically low potassium concentrations (between 179 and 591PPM) for sediments of Loch Lomond Stadial age, (eg. Tre'r Gof, Botterill, 1988) which usually contain much unleached clay. This suggests that the sediment is derived from a base poor source material.

The XRD results show that the clays are depleted in potassium rich minerals and are dominated by Mg- or Fe-rich assemblages (eg. the chlorite is Fe-rich). Illite is characteristic of 'Northern' tills and its formation would predate deposition. The potassium concentrations in the basal minerogenics therefore indicate the 'background' concentration that could be expected from allochthonous inorganic material.

Lower values (179-201PPM) recorded at 790-780cm possibly result from variations in the sedimentary regime as other elements are simultaneously affected. The presence of sand bands indicates fluctuations in sedimentation rate. From 770cm onwards concentrations increase, with a rapid rise (from 591 to 1132PPM) at the onset of organic sedimentation (720cm). The ratio of K:Na remains constant (3:1) until the lower boundary of zone 1 when the ratio drops to 2.5:1 indicating preferential enrichment of sodium.

Increasing potassium concentrations at the onset of organic sedimentation could be due to a gradual decrease in sedimentation rates (as suggested by the simultaneous increase in all elements) or the development of willow scrub (section 7.3). Relatively high concentrations of potassium are found in taxa such as Salix (1.6g/kg dry weight of leaves), Equisetum, Pteridium and Carex (Allen et al., 1974; Tallis, 1973). High potassium concentrations also appear to be linked to Pediastrum maxima. Within Llyn Hendref, factors controlling algal productivity (eg. mineral input, nutrient status) also appear to have influenced the potassium concentrations. The concentrations in zone 1 (720-712cm) are a maximum (1132PPM) for the Postglacial.

Low values (505PPM) are recorded for zone 2 despite its high organic input, possibly the result of an increased sedimentation rate. At the beginning of zone 3 (692-596cm) values rise to a peak (754PPM) at 660cm before decreasing to 274PPM. at the zone top. The sedimentation rate increases and varying concentrations are associated with increasing organic input and development of fringing swamp. Juncus macrofossils are present; these preferentially absorb potassium (Crabtree, 1965). Corylus also contains relatively high concentrations of potassium (Allen et al., 1974) and this zone is characterised by increasing Corylus frequencies. Potassium input from organic material is therefore related to changes associated with the fringing aquatic and carr vegetation.

A gradual decrease in concentrations throughout zone 3 may be related to decreased quantities of deposited mineral material. The loss-on-ignition results show that the inorganic component of the sediment is consistently decreasing and the deposit will accordingly be depleted in base ions. Decreasing values may also be related to changing sedimentation rates not detected with sparse radiocarbon dates. This is difficult to verify although the minimum (493PPM) at 620cm, simultaneously recorded for all the elements, is likely to be due to resedimentation processes.

In zone 4 potassium concentrations are relatively steady (between 290 and 485PPM), coincident with maximum organic input. A peak (485PPM) at 580cm is associated with the spread of Sphagnum into wetter areas of bog. The association between potassium and Sphagna has been noted by Tallis (1973). The progressive enrichment of Na compared with K could be due to either increased precipitation or accumulation of plant debris that is preferentially enriched in Na, eg. Salix leaves.

The possibility that the upper core is disturbed has been mentioned. In zone 5 (552-432cm) concentrations vary from 193PPM (500cm) to 518PPM (470cm) and do not reflect the unconformity or increased mineral content. This suggests that the mineral material was heavily leached and depleted in base-rich ions. The source of the potassium remains obscure and the effects of a fluctuating sedimentation rate are difficult to detect.

In zone 6 (432-056cm) the potassium concentration curve initially coincides with the organic content but above 600cm the relationship is not so obvious. Lower concentrations appear to coincide with increased coarse organic detritus but there is no obvious explanation for the higher values towards the zone top. An increased mineral input, now of relatively unleached material, may explain decreased sodium concentrations and increased potassium values.

In zone 7 (0-56cm) concentrations range from 360-628PPM but the reason for the increase is difficult to ascertain. Organic values are slightly raised but as it appears that most of the potassium is derived from inorganic sources, this should make little difference. The similarity of the potassium and sodium curves suggests that sedimentary factors are responsible for the fluctuations.

CALCIUM

In the basal inorganics, the concentration are comparatively high (between 221 and 1820PPM, but generally <500PPM). The XRD results show that calcium enriched clay minerals are absent but calcium could be derived from Irish Sea tills which contain calcium carbonate derived from Carboniferous deposits within the area (section 3.7). At 750cm there are calcareous nodules within the lake mud and the calcium concentrations are increased (to 641PPM), indicating that under suitable conditions (reduced lake levels?) calcium carbonate may have been chemically precipitated.

Increasing calcium concentrations above 790cm may be associated with increased organic input and the spread of carr vegetation. The data suggest that calcium is associated with the occurrence of *Dryopteris*, and *Chara* and *Nitella* oospores. High values of the latter have been used (Macan and Worthington, 1972) to indicate the presence of calcium rich ground water or sediments, and this relationship is supported by the Llyn Hendref results.

The high values (1746PPM) continue into zone 1 (720-712cm) associated with expansion of *Salix* and high values of *Filipendula*. Both have high uptakes of calcium (7.4g/kg and 8.5g/kg dry weight of leaves respectively, (Allen *et al.*, 1974). Reduced values (1220PPM) in zone 2 are probably due to fluctuating sedimentation rates although an increased Ca:K ratio suggests an overall increase in Ca, possibly associated with developing macrophyte vegetation.

Zone 3 concentrations are complex with values exhibiting wide fluctuations. Concentrations vary between 493PPM and 2433PPM, the higher values occurring at the top of the zone; the results are similar to those produced by Crabtree (1965). The high values at the zone base may be attributed to the onset of peat development. Mire plants tend to uptake calcium (Crabtree, 1965), and the element is also concentrated in 'woody' material (Botterill, 1988). The beginning of zone 3 is characterised by a rapid Corylus expansion, increasing canopy cover and associated organic accumulation within the catchment. The leaves of Corylus have a relatively high calcium content (6.9 g/kg. dry weight leaves, Allen et al., 1974).

Relatively high values are continued throughout zone 3 reflecting high organic input into the lake and developing aquatic macrophytes. Fluctuations could reflect stream activity, variations in ground water supply or lake levels. Low values (493PPM) at 620cm are interpreted as being due to sediment disturbance. This is supported by decreases in the other elements and by the increase in inorganic material >118 microns (fig. 3.4).

From 610cm upwards there is a return to high calcium levels corresponding to increased carr vegetation, and particularly the presence of Dryopteris. The lake was gradually infilling, aquatic vegetation increased and there was a change from macrophyte vegetation to reedswamp vegetation (section 7.2). There was now peat growth within the basin which would produce a preferential enrichment of calcium (Allen et al., 1974). The calcium input from minerogenic sources was decreasing due to reduced mineral input and leaching of soils in the drainage basin.

Values in zone 4 (596-552cm) are steady (between 2331 and 2688PPM), except for the disturbed level at 560cm when minimum values (1831PPM) are recorded. Sedimentation rates are low which may partly explain the higher concentrations. However, organic sedimentation is now at a maximum and the aquatic and carr development is extensive. Alnus glutinosa is enriched in calcium (Allen et al., 1974) compared with potassium and sodium (10 g/kg. dry weight of leaves) and the high values of calcium correspond to the rapid expansion of Alnus around the lake basin. This is one possible explanation for the rapid enrichment of calcium compared with other elements.

Above 552cm, the calcium concentration curve is very similar to that of sodium, suggesting that they were derived from the same source. Both curves show some affinity to the organic content suggesting that this was the primary source for these elements. Peaks in the calcium curve are associated with coarse organic detritus and birch bark, and lower values are recorded when vivianite and quartz rich bands are present.

4.3 CHARCOAL ANALYSIS

4.3.1 INTRODUCTION

The role of fire in vegetational change and its effects on ecosystems have been well documented by Heinselman (1981), Fissell (1973) and Swain (1973). Heinselman (1981) concluded that fire is a major factor in reducing organic material and increasing nutrient recycling, resulting in increased species diversity in post fire sequences. The post-fire release of nutrients and increased carbon was also noted by Dodson and Bradshaw (1987), and is often matched by high *Pediastrum* frequencies associated with increased eutrophication, productivity and charcoal deposition within a basin, (Clark *et al.*, 1989).

Natural fires assist in the spread of opportunistic, shade intolerant taxa (eg. *Fraxinus*) and some taxa (eg. *Pinus banksiana*) require fire for efficient propagation (Heinselman, 1981). The proposed role of fire in the promotion of *Corylus* has been discussed by Rawitscher (1945) and Dimbleby (1961) suggested that hazel dominance in Mesolithic times was a direct result of anthropogenic use of fire. Others (eg. Rackham, 1980) have not found conclusive evidence to link the establishment of *Corylus* with fire occurrence.

The coincidence of charcoal frequencies and the rational limit of *Alnus* has been noted (eg. Smith, 1984) and Chambers and Price (1985) suggested that the spread of *Alnus* (a light-demanding species) may have been facilitated by the burning of closed forest. An *Alnus* rise associated with clearance and burning has been recorded at Moel-y-Gerddi (Chambers and

Price, 1985), Newferry and Seamer Carr (Smith, 1984), and Chambers and Elliott (1989) state that fire 'was a likely precursor to the expansion of alder populations at some inland sites'.

In Wales there are a number of sites with charcoal records but few have undergone systematic charcoal analysis. Chambers and Price (1988) record charcoal through a peat profile at Moel-y-Gerddi but no quantitative results are presented. From charred seeds found at the site, Kelly (1985) inferred that Neolithic people had managed fire as a means of ground clearance. At Cefn Gwenffrwd (mid-Wales), a charcoal layer associated with the *Ulmus* decline and an increase in herbaceous taxa has been interpreted as Neolithic influence (Chambers, 1982b).

There are numerous examples of charcoal associated with Neolithic activity but the possibility of accidental burning or deliberate fire use in pre-Neolithic times is often underestimated (Smith, 1970). Fire in Mesolithic times may have had a widespread effect, and Dimbleby (1963) suggests that increasing soil acidity may have been aggravated by periodic burning. With few archaeological records, and only minor fluctuations in the pollen record, it is difficult to deduce the cause of forest fires (natural or anthropogenic) during the Mesolithic. Recent work (Bennett *et al.*, 1990b) suggests that charcoal records from pre-5000 BP could represent domestic fires and are best interpreted as a 'record of intensity of occupation beside lake shores'. After 5000 BP fire was increasingly used for land clearance.

Natural forest fires also occurred and fire frequency has been used to indicate palaeoclimates (eg. Swain, 1973) Increased fire occurrence may reflect decreased precipitation, increased temperatures (eg. Clark *et al.*, 1989) or availability of biomass. Reconstruction of the fire regime (fire type, intensity, size and frequency) of an area is important when considering vegetation dynamics and successions, and interactions between climate, man and vegetation (Patterson *et al.*, 1987). The fire history of an area can be reconstructed using a number of complementary techniques including pollen analysis, macrofossil records and charcoal.

Microscopic charred particles are of interest to the palynologist as they are often encountered during routine pollen analysis. To examine the role of fire within an ecosystem it is necessary to identify, count and quantify the charcoal content of a sample and then interpret the results within what is known about charcoal taphonomy. A wide range of analytical techniques are used, and results can be presented in a variety of ways.

4.3.2 CHARCOAL TAPHONOMY

The final quantity of charcoal at a site has to be assumed to be proportional to the original quantity produced. An understanding of charcoal taphonomy is critical as there are many variables which influence the final volume of charcoal deposited within the lake basin, many of which are difficult or impossible to quantify (eg. fire intensity, local climate). This section briefly considers processes involved in charcoal production, dispersal and sedimentation.

Charcoal is well preserved in lake sediments, but unlike pollen it is produced at irregular intervals and has a large size range (Patterson et al., 1987). The volume of charcoal produced during a fire depends on a number of factors, including the material undergoing combustion, (oak wood produces more charcoal than birch; Patterson et al., 1987) the duration, temperature and intensity of the fire and site conditions (eg. hydrology). Information on the relationship between fire size and type, and vegetation, is sparse.

Charcoal dispersal is also little understood and the time lag between production and incorporation into the sediment is difficult to measure. Theoretical models of charcoal dispersal under a variety of meteorological conditions are based on the pollen dispersal models of Tauber (1965), (Patterson et al., 1987). They predict the quantity and size of charred particles that could be expected at increasing distance from the fire source, under calm conditions and under the influence of a unidirectional wind; the models highlight the large number of variables involved but are highly idealised.

The potential charcoal source area could be estimated using the model of Jacobson and Bradshaw (1981, appendix A4), but similar limitations apply. Drainage patterns are an important consideration as fire has a considerable effect on catchment hydrology. Run-off and erosion are enhanced by burning, resulting in increased charcoal and minerals input into the lake. Once deposited within a lake, charcoal is subject to similar sedimentary processes as pollen, including winnowing, focusing, erosion and redistribution. It is rare that lake sediments are specifically collected for charcoal analysis but chose of study site has been discussed by Tolonen (1986).

4.3.3 CHARCOAL SAMPLING AND IDENTIFICATION

Preparation procedures are often the same as those adopted for pollen preparation with the final slides used for both analyses. The main problems in charcoal analysis are sampling interval, identification and counting procedures. Sample thickness and frequency, and sediment accumulation rate, are important variables, and fluctuations in these can result in different interpretations from the same sediment (Patterson et al., 1987). At a site with a rapid sedimentation rate charcoal occurrence will be more sporadic for a given number of fires compared with a location that has a slow sedimentation rate. In the former case, the lack of close sampling may mean that fires are "missed" altogether (Clark et al., 1989). Temporal resolution of charcoal data therefore depends on sample thickness and the time span it represents. This emphasises the need for continuous sampling at minimum thickness, which unfortunately is often impractical for palaeoecological studies as sampling interval is usually determined by the pollen content.

Charcoal identification is complex (Winkler, 1985) with a gradation between charcoal and partially charred vegetation, and also confusion with opaque minerals (eg. pyrite), and 'soot' produced by burning fossil fuels. Pyrite crystals can be removed by using nitric acid (Waddington, 1969) and reference material can be used to distinguish decomposed vegetation (Tolonen, 1986). 'Soot' is a problem relevant to recent deposits (<100 yrs. old) and can be in itself useful for studying air pollution history. The measurement and quantification of charcoal fragments into meaningful figures can be effected in a number of ways. Most workers count actual numbers of particles and classification is by size (Waddington, 1969; Swain, 1973) and area (Clark, 1982).

Results can be expressed as a percentage of the total pollen sum or as a ratio of the total pollen (C/P ratio; Swain, 1973). With the addition of exotic markers, concentrations can also be calculated (Davis, 1967) and sedimentation rates enable influx values to be estimated (Swain, 1973) although these are subject to the same limitations as pollen data. Clark et al., (1989) discuss problems associated with quantifying charcoal fragments in pollen preparations and Tolonen (1986) concludes that area determinations give the best estimate of charcoal content. To exactly quantify the actual charcoal content a number of techniques have been developed including image analysis, electron microscopy and chemical methods.

4.3.4 CHARCOAL ANALYSIS METHOD

Macroscopic charcoal (>118 microns) was identified in the pollen washings from a number of samples at Llyn Cororion and Llyn Hendref (figs. 3.3 and 3.4), but no charcoal was initially identified in the slide preparations. To complement the macroscopic evidence, the digestion/combustion method of Winkler (1985) was attempted on the Llyn Cororion core. This method has the advantage that it does not rely on accurate identification of charcoal, and it produces an estimate of total charcoal content. However, it has the disadvantage that charcoal content is underestimated if the inorganic component is high. In addition the results are not comparable with microscopic techniques if stratigraphy is constantly changing.

A total of sixty samples from the core were processed (method fully explained by Winkler, 1985) but the results were found to be unsatisfactory. The method was time consuming, due to small oven size, and therefore resolution was poor. Replicate samples also produced results with large errors making it difficult to establish the significance of particular trends. Possible errors may have been due to the presence of graphite in the samples, inaccuracy of the furnace temperature, variations of temperature within the furnace and perhaps weighing errors (the latter thought to be minimal). Finally, incomplete digestion of organic material may have occurred so that weight lost during heating overestimated charcoal content.

After the trial run for the Llyn Cororion core it was decided that the method was unsuitable for this work. When dealing with a long core it was too time consuming to produce data with a fine temporal resolution and with a high degree of accuracy. It was then decided that microscopic techniques should be adopted.

It was not until towards the conclusion of the project that charcoal analysis was attempted. The point count method of Clark (1982) was investigated but proved too time consuming for the 410 slides that required counting. For this project, it was felt that evidence for the presence of fire within the catchment was the most important factor, and given the difficulties mentioned above, fire size, intensity and locality are not consistently estimated.

Six equally spaced transects across each slide were traversed, and all charcoal fragments encountered within the field of view were noted. A Leitz microscope with a magnification of x400 was used. All exotic Lycopodium spores were also counted and the final figures were used to estimate the charcoal concentration for that particular sample.

Charcoal concentration =

$$\frac{\text{Charcoal counted} \times \text{Exotic counted}}{\text{Exotic added} \times \text{sediment volume}}$$

This method was relatively quick, but all size classes have an equal weighting (cf. Clark, 1982). Most fragments measured 10 to 30 microns with Llyn Hendref sediments containing larger fragments.

Concentration values are difficult to interpret due to the variety of taphonomic processes affecting the final count, and so it was felt that abundance changes and general trends were more important. Concentrations were therefore divided into five categories:

Category	Concentration	
+	$1x10^3$-$3x10^3$fragments/cm^3	trace
1	$3x10^3$-$7x10^3$fragments/cm^3	rare
2	$7x10^3$-$10x10^3$fragments/cm^3	occasional
3	$1x10^4$-$3x10^4$fragments/cm^3	frequent
4	> $3x10^4$ fragments/cm^3	abundant

This is a crude but simple way of illustrating major changes in charcoal abundance and the results are illustrated on figs. 3.3 and 3.4. These results are adequate for this project although for archaeological purposes more detail may be required. The results here are used only as complimentary data, with the assumption that the estimated concentrations reflect the frequency and intensity of forest fires within the catchment.

4.3.5 RESULTS AND INTERPRETATION

LLYN CORORION

The importance of stream input into Llyn Cororion is believed to be limited and the main mode of charcoal transport would have been wind, or, in the case of local fires, by direct transfer from tree to water. Fragment size is therefore likely to be generally smaller than that at a site with inflowing streams (eg. Llyn Hendref). The pollen source area at Llyn Cororion is generally local/extra-local (appendix A4) and if there is abundant charcoal but little associated expression in the pollen diagram, it suggests that the fire occurred outside the pollen source area or was due to local domestic fires (cf. Bennett et al., 1990b).

Charcoal is present throughout the Postglacial, and substantially increases in both frequency and abundance in the last 2000 years. It is rare or absent between 885cm and 750cm, 540cm and 460cm and 320cm and 270cm. Although this may simply reflect the counting method, the close sampling interval suggests it is a real pattern. During such phases fire may have been rare within the catchment, or conditions (eg. hydrology, prevailing wind direction) unfavourable for charcoal deposition. Changing charcoal concentrations are unlikely to be the result of varying sedimentation rates, as these are believed to have been steady (section 5.5.2).

The basal slides (1002cm-948cm) contained an abundance of rounded black opaque particles, possibly coal fragments introduced during loess deposition, or from reworking of older deposits (section 3.7.4). The first definite charcoal fragments are identified at 944cm, suggesting fire occurrence, although this appears to have had little effect on the substrate or vegetational succession. Records above this (928cm) are low, and indicate that although fire did occur, it was of limited local significance. This does not exclude the possibility that relatively large fires were occurring on the periphery of the drainage basin; slightly increased Pinus concentrations at these levels could support this in indicating the opening up of the canopy with more efficient transport of windborne pollen.

Between 902cm and 860cm charcoal counts are relatively high (frequent or abundant). Loss-on-ignition results do not suggest erosion of exposed substrates, although it is noted that there is an increase in inorganic material >118 microns in size (fig. 3.3). A slightly reduced sedimentation rate in zone 2 may partly explain high charcoal concentrations, but their high values suggest that fire was frequent between 9500 years BP and 9000 years BP. The major vegetational change during this period is a Corylus increase (empirical limit at 890cm and rational limit at 876 cm). High charcoal frequencies do not directly relate to increased Corylus and low, isolated quantities during the Corylus maximum, suggest that if fire was important in Corylus establishment, it was not necessary for its maintenance.

Charcoal is rare between 860cm and 776cm (equivalent to pollen zone 3). It is interesting that there is a coincidence of charcoal and the Ulmus empirical limit at 816cm, but values are low and isolated. In contrast, zone 4 (780-702cm) is characterised by a continuous and high charcoal record with evidence that fire affected the vegetational succession near the lake. Fires were apparently more frequent and intense with macroscopic remains (eg. 772cm) indicating that burning occurred locally. It is possible that the charcoal increase was linked to a reduction of precipitation and increased dryness although anthropogenic factors cannot be discounted (section 6.3). An increase in Fraxinus is associated with many of the high charcoal frequencies, reflecting colonisation of gaps created by fire. There is also an association between the empirical limit of Alnus and the occurrence of charcoal (cf. Chambers and Elliot, 1986)

Zone 5 (702-460cm) sediments contain upwards decreasing charcoal concentrations. Concentrations rise between 664cm and 608cm but only at the zone base is there an associated increase in minerogenics. Although vegetation change can be distinguished at all charcoal levels, it is difficult to ascertain the relationship between the two as some vegetational change may be successional, and totally unrelated to fire. The charcoal record suggests that fire occurred frequently within the catchment, although intensity, fire type (crown or ground) and extent are impossible to estimate. Salix (and occasionally Corylus) increase, and some samples show increases in herbaceous taxa (eg. 664cm) including Chenopodiaceae, Thalictrum and Rumex. An increase in crumpled grains suggests local erosion of soils. Increased representation of Hedera helix may indicate improved flowering under a thinner canopy, and Calluna vulgaris values suggest that in some areas heathland was encouraged by repeated burning. It appears that after fires, vegetation recovered with Betula and Sorbus aucuparia colonising gaps.

The tree sum oscillates repeatedly, reflecting a number of burning-regeneration episodes. Fires may have become less frequent towards the top of zone 5 with just two levels containing 'abundant' charcoal (542cm and 540cm) If these do represent fire occurrence, there appears to have been minimal vegetation damage; a slight increase in Fraxinus indicates possible opening up of the canopy. It is possible that the charcoal was from domestic fires (cf. Bennett et al., 1990b).

Sedimentation rates in zone 6 (460-324cm) remain steady (section 6.1), so the charcoal results are interpreted as a reflection of fire activity rather than changing sedimentary conditions. At the zone base, charcoal coincides with increased mineral input into the lake and also the beginning of Tilia pollen representation. All tree taxa appear to be affected by sporadic fires, although Betula and Fraxinus are quick to recolonise open areas. Fluctuations in Corylus concentrations are possibly due to canopy thinning, and improved flowering.

Between 356cm and 272cm charcoal is absent but then concentrations and frequencies increase and there is macroscopic charcoal between 80cm and 0cm interpreted as a rise in anthropogenic activity. Clearance within the woodland was now permanent, with limited regeneration, and the spread of heathland (Calluna and Ericales). Erosion increased resulting in high mineral input and increased internal lake productivity (as indicated by Pediastrum values).

LLYN HENDREF

The charcoal source area at Llyn Hendref is difficult to interpret because of high stream input; fires on the catchment periphery may contribute high quantities of larger-sized charcoal fragments, and yet be poorly represented in the pollen diagram. With the problems of resedimentation above the hiatus (section 7.1), only the charcoal record below 552cm can be said to reflect fire frequency within the catchment.

In the basal sediments it was difficult to distinguish derived coal clasts from charcoal. The platy shape of the particles, with well rounded corners, suggests that the majority were derived from the local glacial sediments as coal fragments. The first definite charcoal record occurs in zone 1 at 720cm, with frequent or abundant quantities recorded intermittently up to 700cm. Sedimentation rates were relatively slow, resulting in an apparent increased charcoal concentration and if charcoal is indeed derived from forest fires, it had little effect on the vegetation.

At 708cm, (LH2), the pollen diagram shows the possible effects of fire disturbance; there is a decrease in tree pollen concentrations associated with an increase in *Sorbus aucuparia*, perhaps indicating openings within the woodland. *Corylus* is now consistently recorded, and *Quercus* values increase slightly. The woodland recovered, *Betula* frequencies rise rapidly, although increased *Calluna* values may indicate that some burnt areas were colonised by heathland taxa.

Abundant charcoal is recorded at 698cm (LH2) but the possibility that this is the result of resedimentation cannot be discounted. All tree pollen increase synchronously and high Ericales, degraded Filicales and the presence of indeterminables, especially crumpled and corroded, suggest that higher charcoal frequencies derive from the erosion and redeposition of littoral sediments.

Abundant charcoal is also recorded at 692cm (top of Lh2) and this appears to reflect actual fire occurrence. Tree taxa concentrations decrease and there is a rapid increase in Corylus, Viburnum and Sorbus aucuparia. High Rumex values are also recorded. The woodland then regenerated with increasing Betula, Corylus, Quercus and Calluna values.

Fire frequency throughout zone 3 is sporadic but an isolated but significant fire event appears to have taken place at 668cm producing the highest charcoal concentrations within this zone. Corylus and Ulmus are the only affected tree taxa. Associated with decline of these taxa are increases in Sorbus aucuparia and herbs such as Plantago undiff., Umbelliferae and Potentilla. Indeterminable and minerogenic content increase, suggesting soil erosion within the catchment.

Charcoal concentrations at the top of zone 3 do not appear to have been produced by large scale burning. Organic input into the lake continued to increase and tree concentrations stayed relatively constant suggesting that vegetation was only affected on a local scale. Betula percentages sporadically decrease, and a decline in Ulmus is registered at 636cm. The latter is associated with an increase in Sorbus aucuparia, Calluna vulgaris, Achillea type, Potentilla and Rumex signifying some kind of disturbance; it is not possible to infer the cause of fire. Charcoal peaks at 616cm and 556cm are believed to be due to resedimentation (section 7.1). The fire record in the early Postglacial at Llyn Hendref is therefore sporadic, and the possibility of resedimentation makes interpretation awkward.

The charcoal record above 552cm is virtually impossible to interpret as a series of individual events due to the high probability of sediment disturbance. Charcoal abundance and frequency is higher above the hiatus but it is not possible to estimate when fire frequency first increased. The evidence suggests that it was after 5735 years BP, and a comparison with other sites would suggest that fire became increasingly important in the Bronze age (section 7.3). The increasing presence of both microscopic and macroscopic charcoal suggests that fires became widespread and that charcoal transport and deposition was more effective in the late Postglacial.

4.4 X-RAY DIFFRACTION

4.4.1 INTRODUCTION

The clays at the base of both cores were subjected to x-ray diffraction analysis. This was an exploratory study to see if extra information could be gained on the provenance of the basal sediments. The origin of clay minerals is complex (Brown and Brindley, 1980; Hall, 1987), but basically there are three potential sources; 1) synthesis from dissolved products, 2) occurrence as a secondary product resulting from the alteration of primary minerals by the addition or removal of elements eg. the alteration of biotite to vermiculite and 3) as primary detrital material removed from argillaceous rocks and unconsolidated sediments (eg. muscovite and chlorite)

During the Loch Lomond Stadial, the predominant source of lake clays would have been thin immature soils and extensive tracts of exposed Late Devensian tills and outwash deposits. Physical weathering was intense and erosion rates were high with the fine fraction of glacial sediments susceptible to aeolian activity and slope processes. In North Wales the provenance of glacial deposits is complex, due to the high diversity of geological formations and the interaction of the Welsh and Irish ice sheets. Welsh deposits are predominant along the coastal plain, and Irish Sea ice deposits dominate on Anglesey, but within the zone of confluence, approximately along the line of the Menai Strait (section 1.3.4) the deposits are mixed. The sediments of the two ice sheets can be distinguished by their clay mineralogy and heavy mineral assemblages (Younis, 1983) but this is often complicated due to the incorporation of local material and post-depositional clay mineral diagenesis.

Irish Sea till is characterised by a clay mineral assemblage of illite, chlorite, vermiculite and interstratified clays (illite-vermiculite). The presence of carbonates, derived from shelly material, kaolinite and a typical red/brown colour are characteristic of this sediment derived from Triassic deposits in the Liverpool Bay area. In contrast, Welsh till is usually grey, and contains no kaolinite or carbonate. Illite, vermiculite, quartz, interstratified clay minerals and a high chlorite content are common.

Llyn Hendref lies outside the limits of the Welsh Ice sheet in an area dominated by Irish Sea till. Llyn Cororion lies within the zone of confluence of the two ice sheets and has been mapped both inside (Whittow and Ball, 1970) and outside (Saunders, 1968) the Welsh ice limits. In reality, the ice limits would have changed both spatially and temporally throughout the Late Devensian. Only one lake site in North Wales (Llyn Peris; Tinsley and Derbyshire, 1976) has previously been analysed by XRD on the basal inorganic sediments.

4.4.2 X-RAY DIFFRACTION METHOD

The slide preparation method was standard and is illustrated in figure 4.7 and the results are expressed as a series of diagnostic curves (fig. 4.8). Clays are layered minerals with characteristic basal spacings which alter by expansion or collapse on chemical saturation and/or heating (Battey, 1981). Individual clay species can therefore be identified depending on the behaviour of the basal spacing under different conditions. The results are purely descriptive and unquantified and identification was based on data from Brindley and Brown (1980).

Three samples from the basal inorganics of each site were processed to assess any potential down-core variation in mineralogy. The surface of the core was carefully cleaned to prevent contamination and a 2cm slice extracted from the following levels:

Figure 4.7 Sample preparation for X-Ray Diffraction

Sediment treated with dithionite and NaOCl — Removes Fe oxides

↓

Separate clay fraction

↓

Disperse sample in 5% Calgon
Make up to 1 litre with distilled water
Shake well

↓

Suspension left to settle — Time determined by Stokes Law (20 hrs. for 25cm)

↓

Remaining suspension decanted and divided into two — (suspension contains clays <2 microns)

↓

1) Sample further subdivided | 2) Sample left untreated

↓

a) Saturate sample with K / b) Saturate sample with Na

↓

Wash with distilled H_2O to remove excess electrolyte

↓

Centrifuge

↓

Produce a clay residue

↓

Mix clay with 5ml distilled H_2O

↓

Pipette suspension onto a glass slide
Dry at room temperature

↓

Result - Oriented specimens which intensify the 001 diffraction maxima.

Llyn Cororion	973cm	990cm	1008cm
Llyn Hendref	720cm	830cm	950cm

4.4.3 DIAGNOSTIC TREATMENTS

For each sample three slides were initially analysed; an untreated sample and samples treated with magnesium and potassium. The potassium and magnesium saturated samples were then processed for further diagnostic tests. The potassium saturated samples were heated for one hour at 550°C and the magnesium samples were treated with ethylene glycol vapour at 60°c for 12 hours.

When it became apparent that kaolinite might be present it was necessary to attempt to distinguish between Fe-rich chlorite and kaolinite, both of which have a basal spacing at 7.0A which collapses on heating. The method described below (developed by Lim et al., 1981) treats the potassium-saturated sample with dimethyl sulphoxide (DMSO) and shifts the basal spacing of kaolinite from 7.0Å to 11.2Å.

Each sample (40mg dry weight) was ground with 100mg CsCl for three minutes in an agate mortar. Another 100mg of CsCl were added prior to another three minutes grinding. The material was placed in a centrifuge tube with 2ml of 85% hydrazine monohydrate. The mixture was shaken and then warmed in an oven at 65°C for 12 hours.

The suspension was then centrifuged and washed once with 8NKoAC and then again with 4NKoAc. The sample was resuspended in 2ml of DMSO and warmed for 20 minutes at 90°C before centrifuging, decantation and a second saturation in 2ml of DMSO. It was then left overnight at 90°C. The sample was then washed with 99% methanol, and a slurry prepared using equal volumes of water and sediment prior to slide preparation.

XRD analysis was carried out using a Philips PW.1011n generator, producing Mn filtered Fek radiation with a tube voltage of 56KV and a tube current of 16mA. A Philips wide range goniometer (PW1049) was used to measure the diffraction angle and intensities, with a scanning rate of 1°20 per minute from 2°-35°2θ for untreated samples and from 2°-15°2θ for the rest of the samples. A slit system of 1°/0.1mm/1° was used. Intensities were recorded on a strip chart recorder with a damping time constant of 2 seconds and a running rate of 1cm/minute (ie. 1° 2θ/cm) and a c.p.s rate of 2000. Traces of successive samples were superimposed using a zero offsetting unit, to enable quick visual comparisons. The following traces for each sample were obtained:

1)untreated	2° to 35°	2θ
2)K saturated	2° to 20°	2θ
3)K saturated 550°C	2° to 20°	2θ
4)K saturated DMSO	2° to 20°	2θ
5)Mg saturated	2° to 20°	2θ
6)Mg saturated EG	2° to 20°	2θ

4.4.4 X-RAY-DIFFRACTION RESULTS

The results are shown in figures 4.8 and are summarised in table 4.2.

COMMENTS ON MINERALS IDENTIFIED

CHLORITE

The chlorite within all samples is iron-rich producing a weak order reflection at 14Å (001) and 4.7Å (003) and an intense peak at 7.2Å (002) and 3.55Å (004). The 14A peak is unaffected by treatment but is diminished slightly after heating to 550°C. The 7Å peak is relatively sharp in all traces but is diminished in intensity and broadens when saturated with K+, and disappears on heating. This heat instability makes differentiation from kaolinite difficult and for most samples, except two from Llyn Cororion, it suggests that the chlorite crystalinity is poor.

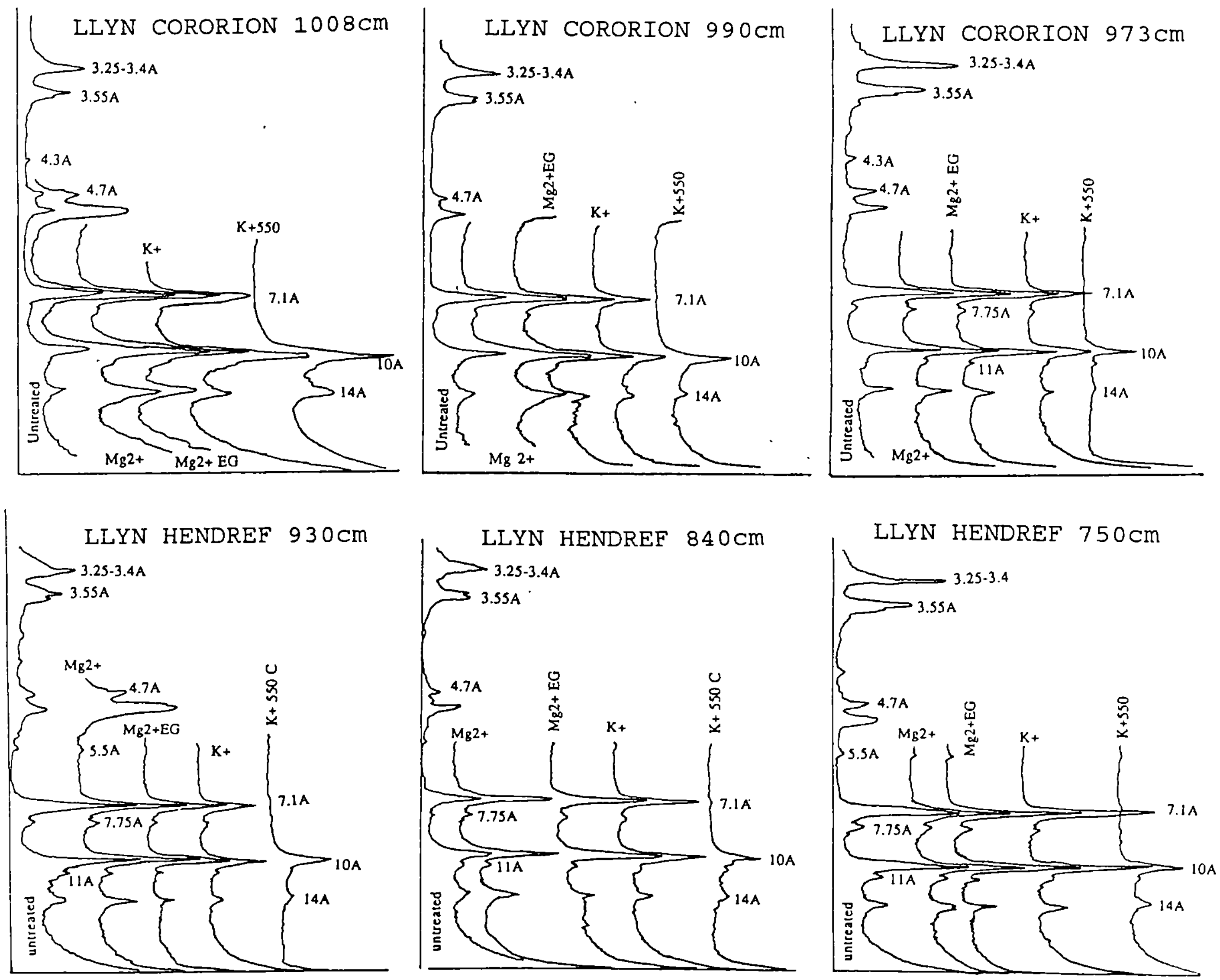


Figure 4.8 XRD traces for Llyn Cororion and Llyn Hendref

Table 4.2 XRD results for Llyn Cororion and Llyn Hendref

	SITE					
	LLYN HENDREF			LLYN CORORION		
SAMPLE DEPTHS (CM)	750	840	930	973	990	1008
HYDROUS MICA	+	+	+	+	+	+
CHLORITE	+	+	+	+	+	+
KAOLINITE	+	+	+	+	+	+
VERMICULITE	+	+	+	+	+	+
SMECTITE	?	+		?	+	
INTERSTRATIFIED (ILLITE/VERM.)	+	+	+	<+	<+	?
11A PEAK	+	+	+		<+	<+
QUARTZ	+	+	+	+	+	+
FELDSPAR	+	+	+	+	+	?
HAEMATITE	+	+	+		+	

+ Denotes presence
<+ Denotes presence of a subdued peak
? Denotes uncertainty over presence

HYDROUS MICA

The presence of hydrous mica is indicated by the 001 reflection at 10Å and a corresponding 002 peak at 5Å. The intensity of the 002 peak is greater than the first order reflection suggesting that dioctahedral mica (muscovite) is more common than trioctahedral species.

VERMICULITE

The presence of vermiculite is suggested by the increased ratio of the 14:10Å peak height (intensity) of the Mg2+ and K+ saturated samples. A reflection at 16Å-17Å highlighted on the DMSO trace could be due to vermiculite. It therefore seems to occur as a discrete phase but may also be present as an interstratified mineral.

KAOLINITE

There is a reflection at 7Å which could be either chlorite or kaolinite. The 7Å peak diminishes with K+ saturation, and disappears on heating, a characteristic of kaolinite. However the same can occur in Fe-rich chlorites. The sample treated with DMSO produces both an 11.2Å and a 7Å peak which is usually taken to indicate that both kaolinite and chlorite are present. Here the situation is more complex because an unidentified mineral also occurs at 11Å at both sites. The 11.2Å peak produced after DMSO treatment may be attributable to this mineral.

At Llyn Cororion two of the samples do not contain the unidentified 11Å peak, yet there is still an intensified 11A peak after DMSO treatment. This, and the presence of an easily identified double peak (Wilson, 1987) at 3.55Å (Fe-rich chlorite?) and 3.57Å (kaolinite?), suggests that kaolinite is present. The resolution of the 004 chlorite peak and the 002 kaolinite reflection into a double peak suggests that the minerals are well crystallised (Younis, 1983).

SMECTITE

Smectite occurs in sample 840cm from Llyn Hendref and in sample 990cm from Llyn Cororion. Smectite is distinguished by a peak of 15Å on Mg saturation and a peak of 12Å on K saturation. This expands to 17-18Å when treated with ethylene glycol.

ACCESSORY MINERALS

Quartz produced a distinct reflection at 4.3Å and at 3.35Å for both sites. At Llyn Hendref a minor peak at 3.2Å suggests the presence of Na and K feldspars. A small peak at 3.65Å may represent haematite (in all samples from Llyn Hendref and in sample 990cm from Llyn Cororion).

UNIDENTIFIED MINERALS

3.29Å: This is a small peak identified on all the Llyn Hendref samples and on the 990cm sample from Llyn Cororion. Origin unknown.

Interstratified minerals: It would appear that these occur at both sites although more prominently at Llyn Hendref. Llyn Cororion samples generally produce a 'cleaner' trace suggesting more crystalline minerals and less background noise from interlayered material. The most dominant inter-stratified mineral is stratified hydrous mica and vermiculite.

4.4.5 INTERPRETATION

Except for minor differences the samples from both sites are composed of similar clay mineral assemblages. Dominant minerals are chlorite, hydrous mica, vermiculite, kaolinite and interstratified hydrous mica/vermiculite.

LLYN CORORION

The clay assemblage at Llyn Cororion is as expected for Welsh tills except for the presence of kaolinite. Kaolinite suggests that the parent materials for the lake sediments were not purely local tills, as these do not contain kaolinite. There are two possible explanations; 1) the deposits within the drainage basin are a mixture of sediments from two different sources, Welsh and Irish Sea tills, producing a mixed clay mineral assemblage and 2) the kaolinite was a windblown deposits, derived from offshore areas during a period of reduced sea level (as suggested in section 3.7.4). Wind was an effective geomorphic agent in the Loch Lomond Stadial (Lowe and Walker, 1984) and would have entrained clay grade material. Smectite in sample 990cm may have been derived from Northern drift but the possibility that it resulted from the contemporaneous weathering of volcanic ash cannot be discounted.

Tinsley and Derbyshire (1976) identified kaolinite in the minerogenic sediments extracted from the Llyn Peris-Padarn basins, two sites within the limits of the Welsh ice sheet There the presence of kaolinite was interpreted as indicative of 'a clastic origin attributable to the grinding action of ice' but the possibility that it was windborne should not be discounted. Other clay minerals identified at Llyn Peris-Padarn confirm the results from Llyn Cororion.

The lowermost sample from Llyn Cororion (990cm) is slightly different from the upper material and is similar to the Llyn Hendref results. The two top samples from Llyn Cororion contain more interstratified material and generally have broader and less well defined peaks, suggesting poorer crystallinity. Haematite is only present in the lower sample, taken from the 'pink' portion of the core.

LLYN HENDREF

The results show a typical clay assemblage expected from Irish

Sea tills. Erosion of these deposits within the catchment and deposition in the lake has had little effect on clay mineralogy, and post-depositional diagenesis has not occurred. The kaolinite may be wind-blown but could also have been derived locally. Younis (1983) noted kaolinite in one soil sample overlying the Mona Complex Schists, perhaps derived from in-situ bedrock weathering during periglacial or interglacial episodes. Smectite was again either derived from till in the catchment or as a weathering product of ash.

4.4.6 SUMMARY

The clay mineral assemblages from the two sites are similar, and suggest that the primary source of fine-grained inorganics during the Loch Lomond Stadial was tills within the catchments. At Llyn Hendref a minor component of the clay input may have been derived from in-situ weathering of bedrock and at both sites there may have been deposition of windblown material including volcanic ash. The mineralogy generally reflects the source rock of the sediments; chlorite and hydrous mica dominate, derived from argillaceous rocks, phyllites and schists. The minerals are all either Fe or Mg-rich with a lack of Na bearing clay species.

CHAPTER 5

RADIOCARBON DATING

5.1 INTRODUCTION

Since Smith and Pilcher (1973) demonstrated the time-transgressive nature of vegetational change, radiocarbon dating has become a critical part of palynological work. It is now no longer possible to correlate sites using traditional pollen zones, (section 3.4.1) and in order to compare sites accurately, it is necessary to have a radiocarbon chronology for comparable biostratigraphic events. In this project, radiocarbon dates have been used for four main purposes:

1. Dating of important vegetational changes within the local area;
2. Correlation and comparison of sites;
3. Calculation of sedimentation rates;
4. Construction of pollen accumulation rate diagrams.

The results from Llyn Hendref and Llyn Cororion are critical in the vegetational history of lowland North Wales. Llyn Cororion is the first site to be studied on the Arfon Platform, and the dates are important in charting vegetational change on the coastal plateau. Pollen diagrams have been produced for Anglesey, (Cors Goch, Seddon, 1958; Tre'r Gof, Botterill, 1988) but Llyn Hendref provides the first early Postglacial sequence from a lake site with relatively good biostratigraphic resolution. Before interpretation, it is necessary to be aware of the limitations, problems, assumptions and errors associated with radiocarbon dating.

5.2 SOURCES OF ERROR

5.2.1 STATISTICAL UNCERTAINTIES

Limitations associated with radiocarbon dating include those associated with the statistical uncertainty resulting from the random nature of radioactive decay, the error in counting the decay rate of modern reference standards and fossil samples, and the background noise (Chappell, 1978). The error is usually 2-3% of the sample age and is usually quoted as one standard deviation of a normal distribution curve. This implies that the quoted date has a 68% probability of falling within the age range stated. The error should always be quoted separately from other limitations. Other sources of error are associated with the nature of the material, depositional environment and sampling procedures.

5.2.2 CONTAMINATION

In limnic sediments contamination of the sample by material either enriched in or depleted in C14 is common (Olsson, 1986a). The addition of older carbon (eg. soils, peats) or inert carbon (coal, carbon rich rock-flour, graphite) will result in an over-assessment of the true age. The redeposition of inert carbon, in limnic environments, is a particular problem in newly deglaciated areas, where comminuted material may contain sediments derived from coal outcrops. Even in non-carbonaceous terrains, inert carbon may be released by intense glacial erosion (Sutherland, 1980). This has been identified as a source of error at Llyn Gwernan (Fowler et al., 1986). The error is greatest when the fossil carbon is incorporated into organic-poor sediments (Olsson, 1972), and West (1977) estimated that the addition of 5% 'dead' carbon could produce a date 400 years older than the true date.

'Hard water' error produces an over-estimate of the true age of a sample due to lowered 14C/12C ratios (Shotton, 1972). It occurs in areas of calcareous bedrock or soils, or newly deglaciated areas when ground water rich in dissolved inert carbon enters the hydrological system. During photosynthesis, submerged aquatics incorporate 14C deficient carbon and become out of equilibrium with the atmosphere (Pennington and Bonny, 1970). Hard water error has been identified as a source of error at Late-glacial sites in Ireland (Craig, 1978).

Inwashed allochthonous terrigenous material has a similar effect but is most likely to influence late Postglacial sediments, resulting from increased deforestation and erosion rates. Contaminating material is often difficult to identify unless its input is accompanied by a stratigraphic change (Bradshaw and McGee, 1988). Another possible cause of sediment mixing is resuspension and redeposition of littoral sediments (Hilton et al., 1986). This results in older material being incorporated into younger sediments with an age error depending on the frequency and extent of the reworking; this may have been significant at Llyn Hendref.

Contamination by 'modern' carbon during sediment deposition, or during coring or laboratory work, is a potential problem. The addition of 5% modern carbon would reduce an actual age of 600 radiocarbon years to 160 radiocarbon years (West, 1977). Contamination by modern rootlets is suspected for young dates on sediments from Glanllynnau (Simpkins, 1974). Age estimates can also be reduced by contamination with humic acids. Mobile humic acids may leach downwards through a profile and be redeposited. This effect is most pronounced in Sphagnum bogs and is less likely in the water-logged sediments of a limnic environment (Bennett, 1983a).

Olsson (1986b) produced curves to predict the age differences produced by varying concentrations of carbon-depleted or enriched contaminants, but it is often difficult to quantify the volume of contaminant. To minimise errors due to contamination a number of procedures can be adopted during pre-treatment.

Modern rootlets, macrofossils and charcoal are removed by hand and samples cleaned to remove surface contamination. The possibility of hard water error can be reduced by working in areas away from limestone or avoiding marl sediments. Samples are pre-treated to eliminate carbonates and residues are fractionated so that components can be dated individually, to attempt to identify sources of error. Shelly material is acid leached, and the samples are divided into two fractions which are dated separately (Olsson, 1986b). This reduces the error due to CO_2 penetration or contamination caused by the uptake of older carbon dissolved in the water. Lake muds and peats can be leached in hot acid to remove carbonates and extract humic acids which are dated separately from the insoluble fraction. The latter is treated to remove absorbed CO_2 before dating. Without fractionation, and with dates determined from bulk analysis or on only one component, age estimates have to be interpreted using depositional environment details.

5.2.3 ISOTOPIC FRACTIONATION

Isotopic fractionation (the preferential enrichment of one C isotope compared with another) occurs because organisms vary in their uptake of 12C, 13C and 14C. The ratio of the uptake of one isotope over another is dependent on physiological processes and the temperature and pH. of the depositional environment (Olsson, 1986b). It also occurs during laboratory processing. The induced error can be corrected because the isotopic enrichment of the 14C/12C ratio is double that of the 13C/12C, ratio and the latter can be measured in the laboratory and used for calibration (Harkness, 1979).

Samples usually exhibit a negative enrichment when compared with the primary standard (PDB limestone), so the mean isotopic composition of wood has been chosen as an alternative reference. This has a value of S13C = -25o/oo, which is close to values obtained for lake and peat material (Harkness, 1979). A sample which yields values of S13C = -30o/oo has a 5o/oo depletion in 13C and therefore the measured 14C activity has increased by 10o/oo which is equivalent to 83 years (Harkness, 1979), a correction which is added to the non-normalised results.

For the majority of plant materials, S13C values lie within the range of -20o/oo to -30o/oo, and correction is not necessary as the age adjustment is less than the statistical uncertainty of the age range (eg. for lake mud with a value of

-26o/oo the age correction would be -15 years). The natural variation in S13C for lake mud lies between -35 o/oo and -18o/oo (Olsson, 1986b) but within one core the range of values is usually small.

The possible errors associated with isotopic fractionation should be kept in mind when comparing samples from different sites and from different depositional environments. Lowe and Gray (1980) noted that most authors do not state S13C values for dated samples, so it is not always possible to assess possible age deviations due to this effect.

5.2.4 RADIOCARBON YEARS AND CONVENTIONAL CALENDAR YEARS

One of the basic assumptions behind radiocarbon dating is that the specific activity of 14C in the major carbon reservoirs have remained constant (Harkness, 1979). However, radiocarbon dating of dendrochronological sequences have shown that there have been long term variations in the 14C/12 C ratio of CO_2 in the atmosphere (Olsson, 1986b) which have resulted in a divergence between radiocarbon dates and calendar years. The time scale of radiocarbon dates is therefore non-linear and between 5000 BP and 8000 BP, radiocarbon dates are 600 to 800 years too young (Chappell, 1978). The two scales converge at about 9500 BP (Hibbert and Switsur, 1976).

Superimposed on the long term variations are short term natural changes in the 14C/12C ratio, although these have been obscured by anthropogenic factors (Harkness, 1979). Increased burning of fossil fuels since the 1850's has resulted in a reduced 14C/12C ratio (the Suess effect), which has since been offset by the testing of nuclear weapons.

Dates determined from radiocarbon measurements and normalised to S13C = -25o/oo are called 'radiocarbon dates' and are quoted in years 'before present' relating to AD1950. If these are corrected for variations in the 14C/12C ratios and converted to calendar years they are called 'calibrated dates' (Olsson, 1986b). The majority of authors quote radiocarbon dates but calibrated dates are often used for archaeological purposed (eg. Chambers and Price, 1988), and are important when comparing dates with historical records.

5.2.5 SAMPLE SIZE

Some uncertainty associated with radiocarbon dates results from the sample size used. In the Lateglacial Interstadial, sedimentation rates were relatively slow and a thick sediment sample may represent an age span greater than the statistical error (1S) quoted for the radiocarbon measurement, (Lowe, 1981). Age estimates obtained from such samples will reflect the average age of the whole sample and not a specific vegetational event (Gray and Lowe, 1977). To minimise this reduction in resolution, it is necessary to determine the carbon content which will allow calculation of the minimum sample thickness to produce a relatively reliable date with maximum temporal resolution.

5.3 CONSTRUCTION OF A DEPTH-AGE PROFILE

A series of reliable radiocarbon dates can be used to estimate the sedimentation rate and deposition time of lake sediments. It is generally believed that the majority of lake sediments are derived from terrestrial sources (section 4.2.1) and that sediment supply is determined mainly by erosion rates within the drainage basin (Mackereth, 1966). Factors which influence erosion rates at a site include topography, geology, climate and vegetation. The integration of sedimentation rates, loss-on-ignition data, and palynology can therefore provide information on soil stability and changes in hydrological or climatic conditions. Accurate radiocarbon dates and sedimentation rates are also fundamental to the construction of pollen accumulation diagrams (Berglund and Ralska-Jasiewiczowa, 1986) and alleviate the inherent problem of sedimentation rate variability in concentration diagrams (Davis et al., 1973).

To calculate sedimentation rates, radiocarbon dates are plotted against the corresponding sample level in a depth-age diagram. A linear graph may be constructed with the mean age and mean depth connected by a straight line, the gradient of which is taken to equal the sedimentation rate between the two points. This assumes a high degree of accuracy for each date and also assumes a constant sedimentation rate between samples and changes that occur at stratigraphic boundaries may go undetected. At each radiocarbon date there is an abrupt change in accumulation rates which is an artifact of the method rather than a true reflection of the sedimentological regime.

This method is generally recommended for studies with few accurate dates and where the stratigraphy indicates that a relatively constant sedimentation rate may be assumed. However, with many available dates, a curve can be fitted through the points, either mathematically, graphically or by eye. The curve takes into account the standard deviation on dates and sample thickness. The gradient at any one point on the curve is equivalent to the sedimentation rate and there are no sudden sedimentation rate changes at points of inflection.

The relatively long cores and few radiocarbon dates (especially in the top five metres of core) from Llyn Hendref and Llyn Cororion, meant that the former method is acceptable for the construction of depth-age graphs. The dates have relatively small errors and at Llyn Cororion there are no sudden stratigraphic changes to suggest that Postglacial sedimentation rates were inconsistent. Llyn Hendref is more complex, with evidence for changing sedimentation processes and patterns after 6000 BP, (section 7.1). A depth-age diagram is presented but lithological changes (possible evidence for a change in depositional regime) have been marked on the graph to indicate points of potential change that may have remained undetected.

All estimated or interpolated dates (eg. dates used for some zone boundaries) are taken directly from the depth-age diagrams. The estimated time scale may be imprecise but is likely to be more accurate than dates extrapolated from other sites and those based on the assumption of synchronous vegetational events (Craig, 1978).

5.4 RADIOCARBON DATING OF CORE MATERIAL

5.4.1 METHODS

One aim of this project was to study temporal and spatial variations in vegetational history; therefore it was decided that significant vegetational events (eg. introduction or expansion of a taxon) should be dated rather than zone boundaries (cf. Botterill, 1988). The zone boundaries in this project exist only for descriptive purposes and unless the boundary coincides with a dated level, zone boundary ages have been interpolated. The major lithostratigraphic change from inorganic to organic sedimentation was also dated.

After consideration of other dates available in North Wales, and important biostratigraphic events identified in this project, a total of eleven samples were taken from the Llyn Cororion core and ten from Llyn Hendref. Tables 5.2 and 5.3 shows the related biostratigraphic horizons. All samples for 14C dating were taken from counted levels and no material was taken from the upper few centimetres of cores to avoid potential contamination by younger sediments. The high organic content of the samples meant that 2cm slices of sediment yielded enough carbon for dating. This reduced errors associated with large sample size or bulk sampling (cf. Ince, 1981).

The core surface was thoroughly cleaned to remove smeared material and the oxidised surface. A 2cm transverse slice was extracted (1cm from either side of the level to be dated) and checked for macrofossils or rootlets. Back-up samples of 1cm thickness from either side of the slice were also extracted although it was not found necessary to use these (Harkness pers. comm., 1988). Samples were placed in polythene bags and submitted with full site and sample descriptions to the NERC

Radiocarbon Laboratory, East Kilbride.

5.4.2 PROCESSING

All samples underwent the following pre-treatment (Harkness, pers. comm., 1988):

1. Digestion in 0.5 M. acid at 80°C for 24 hours to remove labile organic components which may have diffused within the sediment. This pre-treatment also removes carbonates.
2. Washing to remove acid.
3. Drying to a constant weight in a vacuum oven.

The dry weight of organic carbon recovered after pre-treatment is listed in table 5.1. The carbon content is expressed as a weight percent calculated from the volumetric measurement of CO_2 produced by high pressure combustion of the whole sample. The values can therefore be taken as representative of the acid washed detritus, and are accurate to within +/-0.1% (Harkness pers. comm., 1989). The results are based on the Libby half life of 5568 (5570) +/-30 years. The age estimates have not been calibrated and the radiocarbon dates are therefore expressed as years before present (yrs. BP).

5.5 RESULTS

5.5.1 POSSIBLE SOURCES OF ERROR

LLYN CORORION

The radiocarbon dates for Llyn Cororion are illustrated in table 5.2, with one standard deviation and S13C values. The S13C values for the samples range between -28.3o/oo and -31.6o/oo indicating that the samples are depleted in 13C and enriched in 14C. Lake sediments tend to have reduced 13C values due to productivity in the water column, diagenesis, and terrigenous input (Harkness, pers. comm., 1989), and the general range for lake sediments is -18o/oo to -35o/oo

Table 5.1 Organic carbon in pre-treated (acid washed) lake sediments

Depth in core (cm)	Wt. recovered (gm)	wt % carbon
Llyn Cororion		
47 to 49	2.53	37.7
151 to 153	1.75	47.1
375 to 377	2.99	50.3
559 to 561	2.38	47.0
701 to 703	3.35	44.7
779 to 781	3.86	37.6
803 to 805	4.76	43.7
833 to 835	5.19	26.8
875 to 877	6.89	34.1
891 to 893	4.72	32.8
947 to 949	7.85	22.8
Llyn Hendref		
55 to 57	4.90	22.0
550 to 552	3.92	32.9
552 to 554	3.39	38.9
597 to 599	2.23	41.3
607 to 609	3.00	36.9
659 to 661	3.87	31.0
679 to 681	3.68	29.4
697 to 699	4.50	28.5
711 to 713	3.57	20.6
719 to 721	8.73	8.4

Radiocarbon Results

Table 5.2 LLYN CORORION

Lab Ref.	Depth cm	Biostratigraphic event	Date (BP)	%$\delta^{13}C$
SRR 3467	047-049	Rise in Cannabaceae	780 ± 60	-30.3
SRR 3468	151-153	End of *Ulmus* decline	1585 ± 65	-31.3
SRR 3469	375-377	*Ulmus* decline	4985 ± 65	-31.6
SRR 3470	559-561	Empirical limit *Fraxinus*	6450 ± 65	-31.8
SRR 3471	701-703	Empirical limit *Alnus*	7745 ± 65	-31.5
SRR 3472	779-781	Rational limit *Pinus*	8425 ± 70	-29.6
SRR 3473	803-805	Rational limit *Quercus*	8660 ± 65	-29.6
SRR 3474	833-835	Empirical limit *Ulmus*	8845 ± 70	-30.5
SRR 3475	875-877	Rational limit *Corylus*	9215 ± 65	-29.8
SRR 3476	891-893	Empirical limit *Corylus*	9365 ± 70	-29.6
SRR 3477	947-949	Onset of organic Sedimentation.	9680 ± 65	-28.3

Table 5.3 LLYN HENDREF

Lab Ref.	Depth cm	Biostratigraphic event	Date (BP)	%$\delta^{13}C$
SRR 3540	055-057	Rise in Cannabaceae	3370±65	-29.2
SRR 3541	550-552	Above unconformity	4920±65	-30.0
SRR 3542	552-554	Below unconformity	5735±65	-29.2
SRR 3543	597-599	*Alnus* rise	7805±75	-30.3
SRR 3544	607-609	First continuous *Alnus*	7950±70	-30.6
SRR 3545	659-661	*Quercus* rise	8780±70	-30.0
SRR 3546	679-681	First continuous *Ulmus*	9425±75	-26.7
SRR 3547	697-699	*Corylus* rise	9420±75	-24.9
SRR 3548	711-713	First continuous *Corylus*	9890±90	-25.9
SRR 3549	719-721	Onset of organic sedimentation	10285±95	-24.7

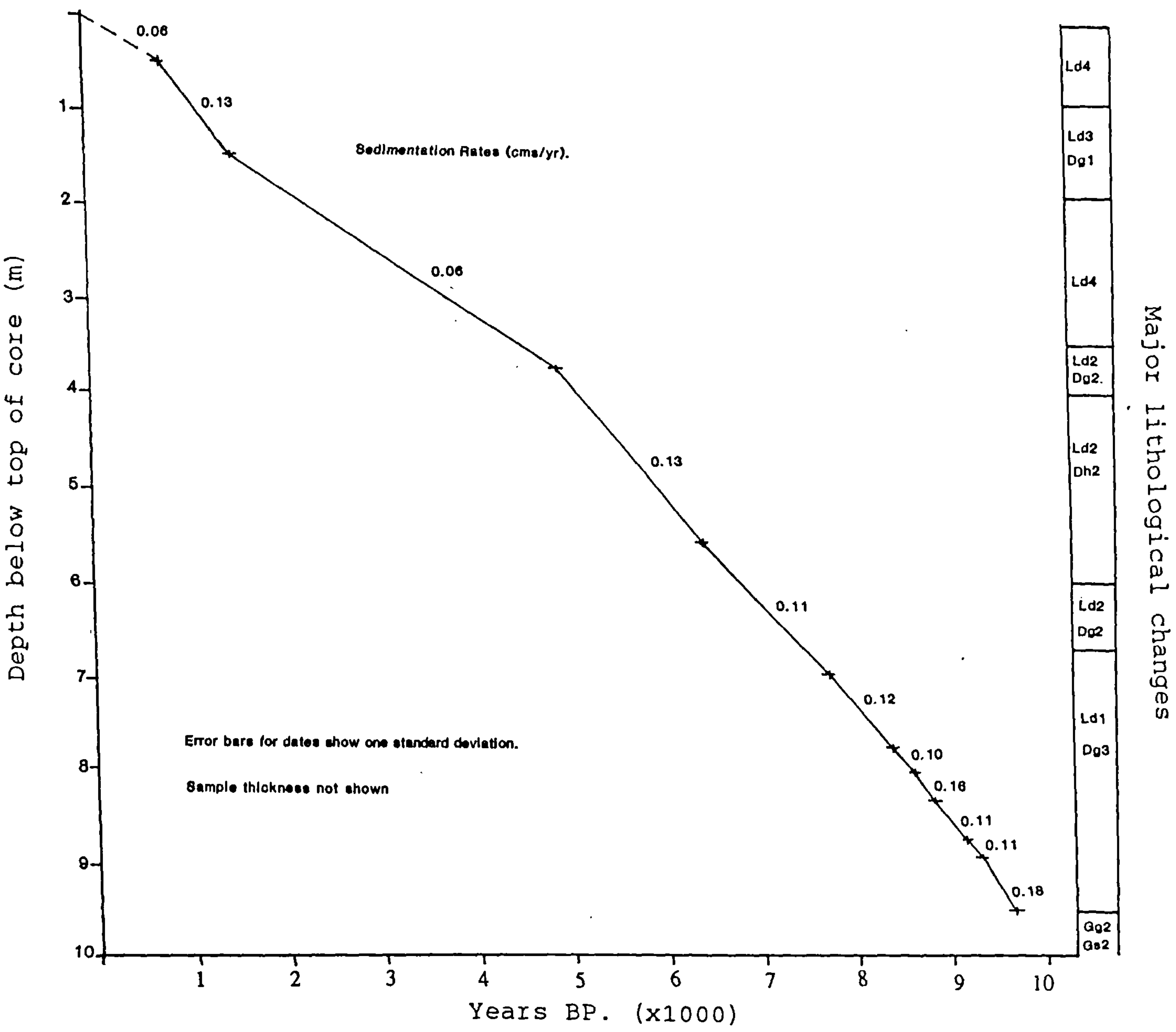


Figure 5.1 Llyn Cororion: Depth-Age Curve

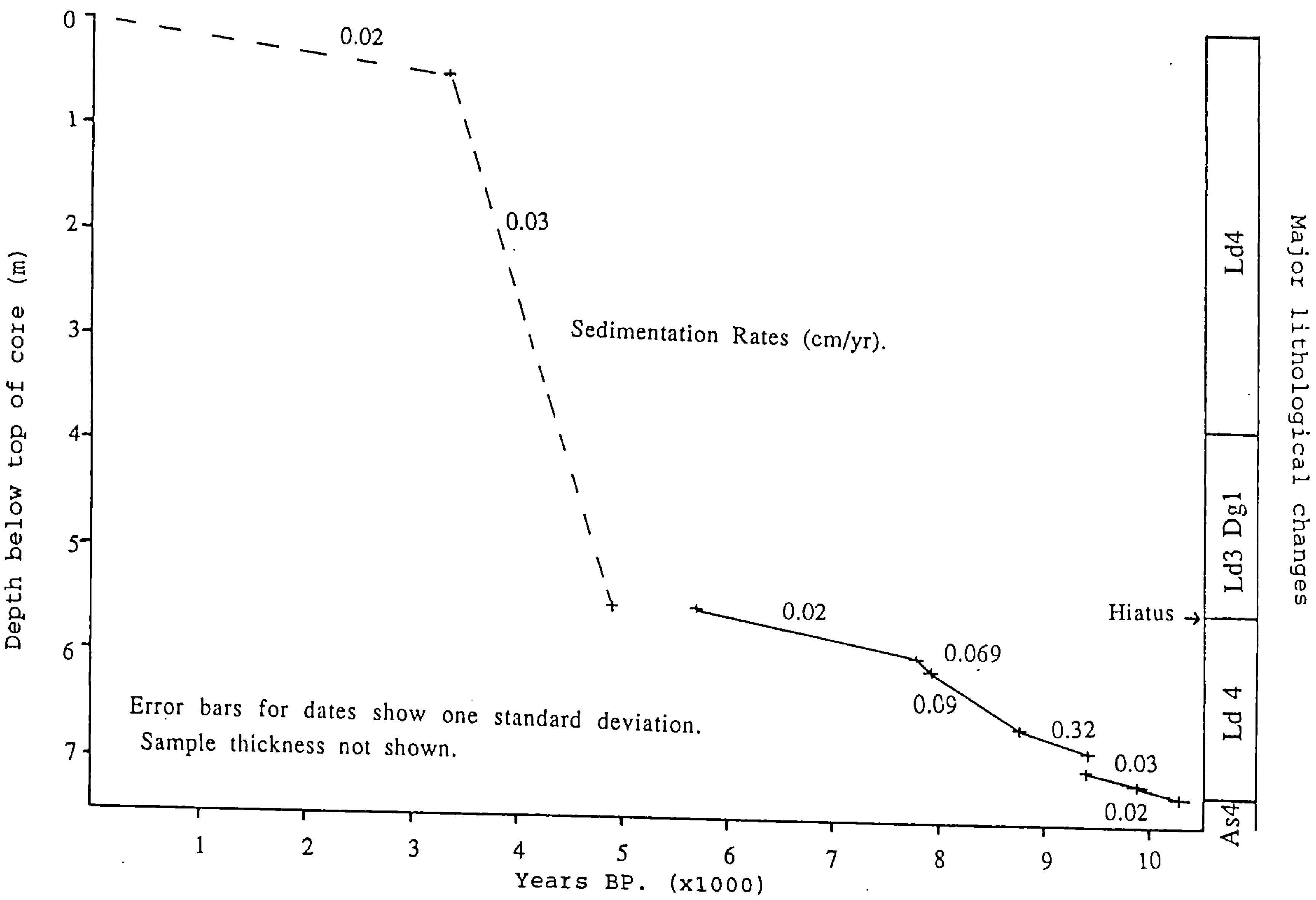


Figure 5.2 Llyn Hendref: Depth-Age Curve

Key for figure 5.3 and Table 5.4

SITE			m OD.	AUTHOR
1	Llyn Hendref	Lake/bog	52.0	Watkins, this project
2	Llyn Cororion	Lake	82.5	Watkins, this project
3	Nant Ffrancon	Valley Bog	198.0	Hibbert and Switsur, 1976
4	Melynllyn	Lake	632.0	Walker, 1978
5	Tre'r Gof	Mire		Botterill, 1988
6	Malltraeth	Estuary		Prince, 1988
7	Cors Gyfelog	Mire		Botterill, 1988
8	Gwernan	Lake	170.0	Lowe, 1981
9	Cors Dolfriog	Lake	80.0	Edwards, 1982
10	Llyn Llydaw	Lake	440.0	Ince, 1981
11	Llyn Goddionduon	Lake	224.0	Ince, 1981
12	Cwm Cywion	Mire	600.0	Ince, 1981
13	Moel y Gerddi	Valley mire	300.0	Chambers and Price, 1985
14	Clogwyngarreg	Mire	235.0	Ince, 1981
15	Clarach Bay	Coastal		Heyworth, Kidson and Wilks, 1985
16	The Dovey	Estuary		Prince, 1988
17	Tregaron	Bog	165.0	Hibbert and Switsur, 1976
18	Cefn Gwernffrwd	Basin Bog	395.0	Chambers, 1982
19	Coed Taff (c)	Basin Bog	355.0	Chambers, 1983
20	Traeth Mawr	Infilled ice hollow	330.0	Walker, 1980
21	Crose Mere	Lake	91.0	Beales, 1980
22	Llyn Mire	Bog	170.0	Moore, 1977
23	Cledlyn Pingos	Infilled	200.0	Handa and Moore, 1976
24	Cwm Idwal	Lake	375.0	Tipping, 1990
25	Llyn Clyd	Lake	746.0	Evans and Walker, 1977
26	Durham	Kettlehole	137.0	Bartley et. al., 1976

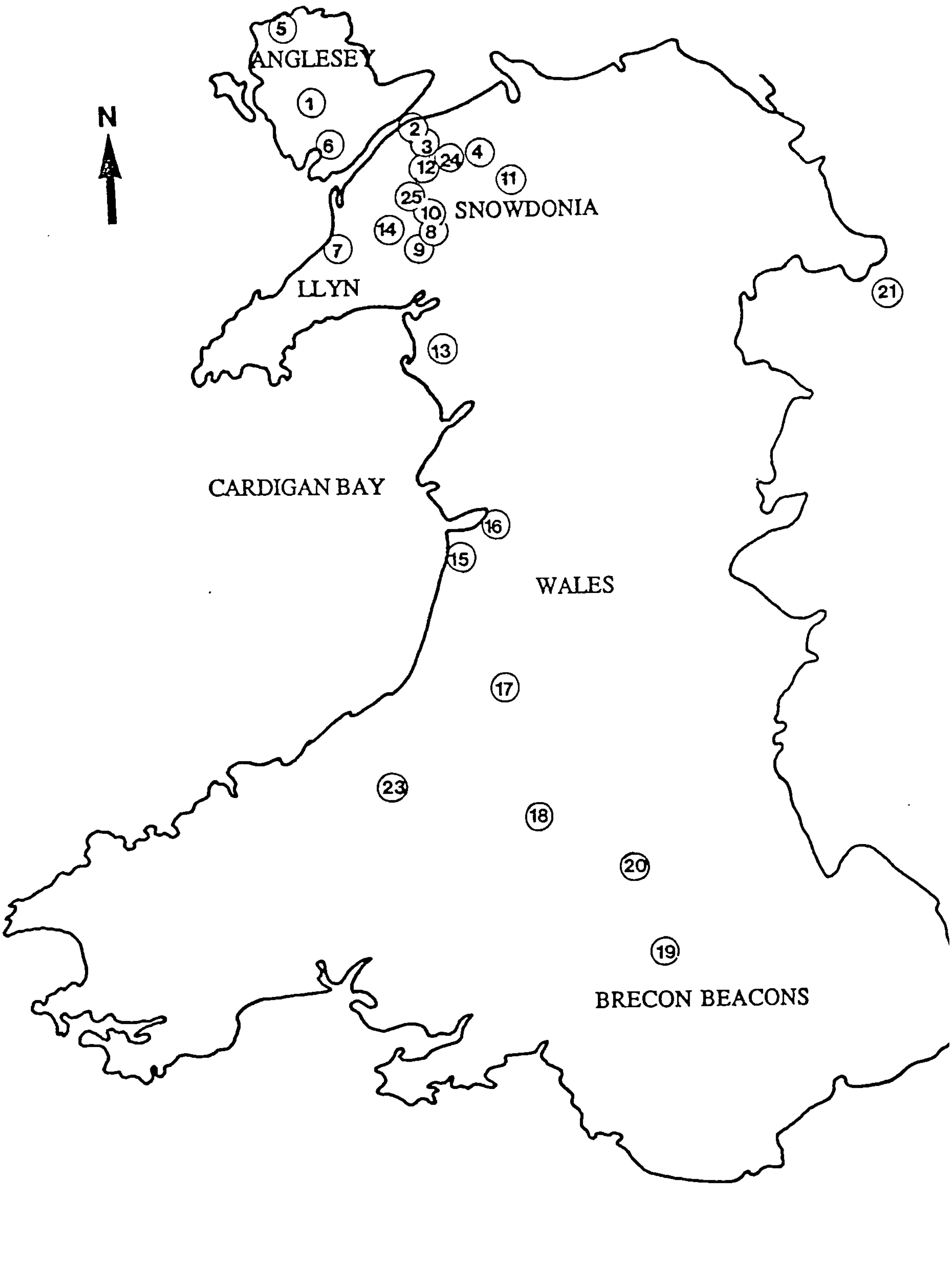


Figure 5.3 Map of Wales showing the location of sites discussed in the text.

Table 5.4 Comparison of Radiocarbon dates quoted in text

Site	Onset of Organics	EL *Corylus*	RL *Corylus*	EL *Ulmus*	EL *Alnus*
1 Llyn Hendref	10285 +/- 95	9890 +/- 90	9420 +/- 75	9425 +/- 75	7950 +/- 70
2 Llyn Cororion	9680 +/- 65	9365 +/- 70	9215 +/- 65	8845 +/- 70	7745 +/- 65
3 Nant Ffrancon	10080 +/- 220	9870 +/- 200	8930 +/- 170	8640 +/- 150	8450 +/- 150
4 Melynllyn	10257*	9428 *	8900*	8428*	7378 +/- 160
5 Tre'r Gof			8700*	7550	7500
6 Malltraeth		>9710			8300*
7 Cors Gyfelog			9300*	7250 +/- 60	8450*
8 Gwernan	10040 +/- 80	9070 +/- 70	9070 +/- 70		
9 Cors Dolfriog		8850 +/- 100	8850 +/- 100		
10 Llyn Llydaw	9930 +/- 120				
11 Goddionduon	9970 +/- 115				
12 Cwm Cywion	9905 +/- 290	9200*	8365 +/- 200	8900*	7000?
13 Moel y Gerddi			>8595	>8600	>8595*
14 Clogwyngarreg	10760 +/- 140	9900*	8700*	8700*	
15 Clarach Bay	10100*	9600			8900
16 The Dovey		>9610			
17 Tregaron	10200 +/- 220	9747 +/- 220	9300 +/- 190	9550 +/- 200	7130 +/- 180
18 Cefn Gwernffrwd	9665 +/- 120	9665 +/- 120	9070 +/- 120		7035*
19 Coed Taff (c)		9600*			6685 +/- 110
20 Traeth Mawr	9970 +/- 115	8100*	7700*	7000*	>7000
21 Crose Mere		9136 +/- 210	9136 +/- 210		

Site	RL *Alnus*	EL *Quercus*	RL *Quercus*	RL *Pinus*
1 Llyn Hendref	7805 +/- 75	9890*	8780 +/- 70	
2 Llyn Cororion	7745 +/- 65	9365 +/- 70	8660 +/- 60	8425 +/- 70
3 Nant Ffrancon	6880 +/- 100	9745 +/- 200	8120 +/- 120	8120 +/- 120
4 Melynllyn	7150*	9857*	8800*	
5 Tre'r Gof	7500*		8600*	8600*
6 Cors Gyfelog	7250 +/- 60	9300*		9000
8 Gwernan				
9 Cors Dolfriog	7590 +/- 90		8350 +/- 100	
12 Cwm Cywion	7000*	8900*	8365 +/- 200	8365 +/- 200
13 Moel y Gerddi	8456*	>8595		8595 +/- 95
14 Clogwyngarreg		8700*		
15 Clarach Bay	8900*			
17 Tregaron	6980 +/- 100	9300 +/- 190	9300 +/- 190	8285 +/- 150
18 Cefn Gwernffrwd	6815 +/- 85			
19 Coed Taff (c)	6645 +/- 85			
20 Traeth Mawr	>7000			

Site	EL *Fraxinus*	*Ulmus* Decline	Rise in Cannabaceae
1 Llyn Hendref			3370 +/- 65H
2 Llyn Cororion	6450 +/- 65	4985 +/- 65	780 +/- 60C
3 Nant Ffrancon	6880 +/- 110	5050 +/- 75	
4 Melynllyn	4755 +/- 90	>4755 +/- 90	
9 Cors Dolfriog		5060 +/- 60	
10 Tregaron	6530 +/- 110	5510 +/- 170	
13 Moel y Gerddi			6435 +/- 85H
21 Crose Mere			1610 +/- 75C
26 Durham			2004 +/- 60C

* Denotes estimated date
All dates are quoted in years BP
+ Possible error
Numbers refer to fig. 5.1 and key

EL Empirical limit
RL Rational limit
H Identified as *Humulus lupulus*.
C Identified as *Cannabis sativa*.

(Olsson, 1986b). The small deviations from the standard of -25o/oo, means that the quoted radiocarbon dates do not need correcting for isotopic fractionation, as any correction falls within the age range suggested by the statistical uncertainty.

The dates all form a consistent rational sequence with no inversions or evidence of unconformities. The site situation and pre-treatment suggests that it is unlikely that contamination would be introduced from older carbonates. There were no modern rootlets in the samples and contamination from humic acids is unlikely. The only possible source of error may be the introduction of 'older' organics into the basin during erosion of the soils around the lake, which is most likely to have occurred after 5000 BP. If this did occur, it cannot be detected from the radiocarbon dates. A depth-age curve for Llyn Cororion has been constructed (fig. 5.1).

LLYN HENDREF

The results for Llyn Hendref are shown in table 5.3. The 13C values fall between -24.7o/oo and -30.0o/oo, a wider range compared with Llyn Cororion), with samples SRR3547 and SRR3549 slightly enriched in S13C. The values fall within the accepted range for lake sediments (Olsson, 1986b) and the small range indicates that isotopic fractionation is not a major source of error. The radiocarbon dates have therefore not been adjusted.

An inversion occurs between SRR3547 (9420+/-75 BP) and SRR3546 (9425+/-75 BP). These two dates are 20cm apart and yet yield similar ages. Taking the statistical error of the upper date into account, it is possible that the dates are correct, but the possibility of contamination should be considered.

Hard water does not appear to have affected the core and there is no evidence of modern carbon or humic acid contamination. The upper date may be affected by the redeposition of older material. A consideration of the concentration diagram shows that at the empirical limit of Ulmus (SRR3546) the concentration values of all taxa simultaneously increase suggesting an influx of pollen grains and associated sediment.

This may be due to the inwash of older peat or soils or the re-suspension and redeposition of littoral sediments. The pollen record suggests the latter explanation (section 7.2), with peaks of submerged aquatic taxa (Potamogeton, Myriophyllum) and increased Pediastrum and corroded, crumpled and broken grains. The evidence for redeposition and sediment focusing (section 7.1) and the presence of an hiatus, means that caution must be exercised in the interpretation of these radiocarbon dates and pollen data.

It appears that in the late Postglacial the sedimentary regime of the lake basin became unstable and much of the sequence is disturbed. Although the majority of the dates appear to be reliable, a constant sedimentation rate between points cannot be assumed. Only dates believed to be correct are joined on the depth-age curve (fig. 5.2). Sedimentation rates were calculated to produce an influx diagram although the reliability of the results is questionable (section 3.5.2).

5.5.2 DISCUSSION OF RESULTS

In this section the terms 'empirical limit', the point at which the pollen curve first becomes continuous, and 'rational limit', the point at which the curve begins to rise to high values, are used, (Smith and Pilcher, 1973); however, it must be noted that the empirical limit is 'of limited comparative value' (Chambers and Elliot, 1989) as it is affected by the pollen sum chosen and the sampling interval.

It is difficult to estimate the accuracy with which radiocarbon dates from different sites can be compared, as errors can depend on sample thickness, diagram resolution, and sediment type. However, a number of authors have shown that dates from different depositional environments of various size and geomorphological situation, can exhibit great similarity. This is supported by dating of the rational limit for Corylus in mainland Scotland (Boyd and Dickson, 1986), and the *Ulmus* decline which is apparently synchronous over much of Britain (Hirons and Edwards, 1986).

Dates from different site types are therefore assumed to be comparable for particular biostratigraphic events. It is also assumed that dates quoted are accurate unless their author gave cause to doubt their reliability. Ranges of dates for particular biostratigraphic horizons are mentioned to put the results of this project into context, and differences and similarities with other sites are noted. The locations of sites discussed are shown in fig. 5.3 and dates discussed are shown in table 5.4. Where possible the results from Llyn Cororion and Llyn Hendref are presented together to prevent repetition of discussion and to facilitate ease of comparison.

ONSET OF ORGANIC SEDIMENTATION

SRR 3477	Llyn Cororion	9 680 +/- 65 years BP.
SRR 3549	Llyn Hendref	10 280 +/- 95 years BP.

Llyn Cororion: Even when the statistical error is taken into account this is a relatively late date compared with other sites in North Wales (eg. Llyn Hendref, Nant Ffrancon and Llyn Llydaw). The majority of sites in Wales have a Lateglacial/Flandrian boundary at around 10,000 BP, (Lowe, 1981).

The pollen data at the core base show that vegetation was established in this area before 9680 BP, and this is supported by higher altitude sites (eg. Clogwyngarreg; Ince, 1981) which record a transitional period of open grassland before the arrival of pioneering trees. The late date at Llyn Cororion could be explained in a number of ways:

1) Delayed ice decay: This has been identified as a possible problem in dating the earliest sediments in kettleholes (Tipping, 1987b), but the stratigraphy at Llyn Cororion suggests a lake had formed early during the Loch Lomond Stadial, before the onset of organic sedimentation. The basal

sediments are laminated and undisturbed (section 6.1) with no evidence of slide and slump structures normally associated with ice collapse. Llyn Cororion also lies well outside the limits for Loch Lomond stadial ice in North Wales (Gray, 1982). It is therefore thought unlikely that the late onset of organic sedimentation at Llyn Cororion is a result of delayed ice melting.

2) Sediment focusing: The lake basin would have originally been deep (minimum 15.5 m) and some sediment focusing may have taken place. It is possible that the position of the present deep is different to the early Postglacial deep, and that the core was taken to one side of this. The date of 9680+/-65 BP only represents the onset of sedimentation at one particular point, and may not be from the earliest sediments. This possibility highlights the problem of locating the greatest thickness of limnic sediments without a time consuming coring program.

3) Drainage: Organic materials may occur but not accumulate if underlying sediments are permeable and allow free drainage. At Llyn Cororion, the organic sequence is underlain by a coarsening-up sequence of sands and gravels (plate C). Thus, at the onset of organic sedimentation, the first fine-grained organics may have percolated downwards and accumulated in the interstices between the gravel. This would have continued until an impermeable horizon formed, upon which sediment could accumulate. The gravels were not subjected to loss-on-ignition, but during preparation for grain size analysis, relatively large quantities of unidentifiable organic material were removed in suspension, supporting this hypothesis. Macrofossils, at the base of the organics (eg. Salix leaves), would have contributed to this process by blocking pore spaces. This is thought to be the most likely explanation.

4) Contamination: Contamination by 'modern' plant material of the radiocarbon sample, which would produce an apparently young date, is not apparent and there is no obvious evidence of sediment disturbance or mixing.

5) Condensed sequence: Due to the thickness of the sample required for radiocarbon dating (2cm), it is possible that the date of 9680 BP is an average age of a condensed sequence (cf. Pennington, 1964). This is unlikely as the radiocarbon dates suggest that initial sedimentation rates were relatively high, producing good temporal and biostratigraphic resolution.

Llyn Hendref: The onset of organic sedimentation at Llyn Hendref has one of the earliest radiocarbon dates for North Wales (table 5.4), and compares favourably with an extrapolated date of 10257 BP at Melynllyn and a radiocarbon date of 10,200+/-200 BP recorded at Tregaron. The basal organics are underlain by laminated silts and sands, with no coarse fraction (as at Llyn Cororion), and in the upper 10cm these get progressively more organic (up to 15%). This suggests that the date of 10,280+/-95 BP is a minimum, and that organics were supplied in low quantities before this time but were diluted by minerogenic material. This date is taken as correct and contamination is not suspected.

FIRST CONTINUOUS CORYLUS (EMPIRICAL LIMIT)

SRR 3476	Llyn Cororion	9365 +/- 70 years BP.
SRR 3548	Llyn Hendref	9890 +/- 90 years BP.

The rapid expansion of _Corylus_ in West Wales during the early Postglacial was noted by Moore (1972a) and Deacon (1974), and is characteristic of many sites in the British Isles. Birks (1989) discusses the arrival of and transfer mechanisms for _Corylus_, and concludes that water transfer from the western fringes of Europe was the most likely dispersal method. This is supported by early dates from sites such as Tregaron (9747+/-220 BP) and Clarach (9600 BP). Relatively early dates have also been recorded at Nant Ffrancon (9870+/-200 BP) and the Dovey (>9610+/-50 BP). Smith and Pilcher (1973) record a range of empirical dates from 9789+/-200 BP (Red Moss) to 7735+/-155 BP (Bigholm Burn) with a main expansion at around 9,000 BP.

The date for Llyn Hendref compares favourably with Nant Ffrancon although has a smaller standard error. If correct, then it is one of the earliest recorded dates for Wales and supports the hypothesis that low lying locations were quickly colonised by hazel in the early Postglacial. This is also supported by a date from Malltraeth estuary (Anglesey) which showed first continuous records of Corylus before 9710+/-50 BP.

The Corylus empirical limit at Llyn Cororion is relatively young compared with most sites in North Wales (table 5.4), but there is no evidence to suggest contamination. Below the start of the continuous curve there are sporadic and isolated counts of Corylus, suggesting that although hazel was growing close to the lake, a critical threshold needed to be crossed before it could become established (section 6.3). If Bennett's (1983b) concept of isolated counts possibly indicating arrival is accepted, then Corylus may have been present, and the empirical limit may be an artifact of pollen recruitment and deposition, sampling interval and the pollen sum.

RISE IN CORYLUS (RATIONAL LIMIT)

SRR 3475	Llyn Cororion	9215 +/- 65 years BP.
SRR 3547	Llyn Hendref	9420 +/- 75 years BP.

Smith and Pilcher (1973) show that the rational limit of Corylus was around 9,000 BP but dates varied between 9430+/-150 BP (Roddons Port, Co. Down) and 7735+/-155 BP (Bigholm Burn, Dumfrieshire). Earlier dates tend to occur on the lowlands. The oldest date in Wales is at Tregaron (9300+/-190 BP) and the youngest at Cwm Cywion (just after 8365+/-200 BP). The age estimates from Llyn Hendref and Llyn Cororion are relatively old and have small standard errors when compared with other sites.

The Llyn Hendref date lies within the standard error of the Tregaron date, as does Llyn Cororion and is the oldest rational limit of Corylus in North and West Wales, although extrapolation of data at Cors Gyfelog, a mire site on the Llyn

Peninsula, gives a rational limit for Corylus of 9500 BP. Both dates are taken as correct and match with data from the isochrone map produced by Birks (1989). The relationship between SRR 3547 and SRR 3546 at Llyn Hendref has already been discussed.

FIRST CONTINUOUS ULMUS (EMPIRICAL LIMIT)

SRR 3474	Llyn Cororion	8845 +/- 70 years BP.
SRR 3546	Llyn Hendref	9425 +/- 75 years BP.

There are relatively few sites in Wales with a date for the empirical limit of Ulmus. The oldest is from Tregaron at 9550+/-200 BP, but the date from Llyn Cororion is consistent with Nant Ffrancon (8640+/-150 BP) and Moel-y-Gerddi (8600 BP). It is younger than the 7250+/-60 BP age estimate recorded at Cors Gyfelog. Smith and Pilcher (1973) suggest that the rational unit for Ulmus lies between 9490+/-160 BP and 7640+/-160 BP. The date for Llyn Cororion is acceptable and fits well with the isochrone maps of Birks (1989).

The date from Llyn Hendref is more problematic. The level sampled is 20cm above the rational limit for Corylus, yet the date is 5 years younger. Although the date falls within the acceptable range for the empirical limit for Ulmus, it is rejected as there is evidence of sediment redeposition and contamination. However, Ulmus was established at Llyn Hendref between 9420BP and 8780 BP (the rise of Quercus), suggesting the early immigration of Ulmus into Anglesey.

QUERCUS RISE (RATIONAL LIMIT)

SRR 3473	Llyn Cororion	8660 +/- 65 years BP.
SRR 3545	Llyn Hendref	8780 +/- 70 years BP.

This is a well dated biostratigraphic horizon in Wales and both dates fall within the range quoted by Smith and Pilcher (7640+/-160 BP to 9090+/-150 BP). The Llyn Cororion result is close to Nant Ffrancon (8450+/-150 BP) and the extrapolated date for Tre'r Gof (8600 BP). Younger dates have been recorded at Cors Dolfriog (8350+/-100 BP) and Cwm Cywion (8365+/-200

BP). The empirical limit for Quercus at Llyn Cororion is 9365+/-65 BP suggesting that it took 700 years for a rise in Quercus pollen values to be registered.

The rational limit for Quercus at Llyn Hendref is slightly younger than Llyn Cororion although the pollen diagram suggests that Quercus may have been present as early as 9890+/-90 BP. The rational limit of Quercus coincides with that of Corylus but prior to this there were isolated counts of Quercus. Dates from both sites are accepted as being representative of the true age estimate.

PINUS RISE (RATIONAL LIMIT)

SRR 3472 Llyn Cororion 8425+/-70 years BP.

The Pinus rise at Llyn Cororion is a rapid event, and could not be detected at Llyn Hendref. At the latter site, Pinus values rise gradually but never reach the large percentages (65%) registered at Llyn Cororion. Birks (1989) suggests that Pinus did not expand into Wales until between 8400 BP and 8100 BP and Llyn Cororion lies just within this range (taking 1SD into account).

The problems associated with interpretation of Pinus pollen records are discussed by Bennett (1984) and Huntley and Birks (1983). If >25% is taken as representing the local presence of Pinus, and >50% represents its local dominance, the date from Llyn Cororion may record the early presence of pine forest on the coastal lowlands. The isochrone map of Birks (1989) therefore needs modification. Llyn Cororion is unusual in that Pinus expansion and dominance occurs after the Quercus and Ulmus rise (cf. Bennett, 1984).

FIRST CONTINUOUS ALNUS (EMPIRICAL LIMIT)

SRR 3471	Llyn Cororion	7745 +/- 65 years BP.
SSR 3544	Llyn Hendref	7950 +/- 70 years BP.

Many papers have discussed the spread of Alnus and its modes of dispersal (Smith, 1984; Chambers and Price, 1985; Bush and

Hall, 1987; Chambers and Elliot, 1989). It is a well-dated horizon in Wales and discussion has concentrated on arrival time and establishment. The range of dates for the empirical limit as presented by Smith and Pilcher (1973) vary between 8120+/-135 BP and 5805+/-85 BP.

Dates from Llyn Cororion and Llyn Hendref are relatively young as most dates for Wales occur towards the older end of the spectrum, suggesting an early spread from a western refugia (Chambers and Price, 1985). It appears that by 8800 BP alder was locally abundant along the mid-Wales coast and at inland areas near Harlech, (Birks, 1989). The range of dates for the empirical limit of Alnus in North Wales is shown in table 5.4. An estimated date for the Llyn suggests an Alnus arrival around 8450 BP in north-west Wales and a date from Malltraeth suggests early (between 8450 BP and 8170 BP) establishment of alder in estuarine areas. An estimated date from Clarach of 8900 BP supports the theory of local but isolated stands of alder along the coast early in the Postglacial.

ALNUS RISE (RATIONAL LIMIT)

SRR 3471	Llyn Cororion	7745 +/- 65 years BP.
SSR 3543	Llyn Hendref	7805 +/- 75 years BP.

The rapid rise in Alnus pollen from low quantities to high values is a distinct feature in many British Postglacial diagrams (Chambers and Elliott, 1989). At Llyn Cororion this is especially marked with the coincidence of the empirical and rational limits; at the majority of British sites there is a time lag between the empirical and rational limits. Smith and Pilcher (1973) report rational limits of between 7610+/-150 BP and 5145+/-70 BP and the range of dates for Wales is given in table 5.4.

At some sites (eg. Nant Ffrancon), the difference between the empirical and rational limit is considerable, suggesting that the spread of Alnus was limited by environmental and ecological factors other than climate. Chambers and Price (1985) stated that there was a 'gross regional gradient in the timing and nature of the expansion of alder in Wales' based on evidence which suggested a later and protracted rise in the South.

The dates from Llyn Hendref and Llyn Cororion are both relatively old, but there is no evidence to suggest contamination. They support the hypothesis that an early alder rise took place on the low-lying coastal areas of Wales. They do not fit the isochrone map of Birks (1989), which suggests that in lowland Gwynedd dates of around 7000 BP would be more appropriate. Early rational limits for Alnus in the British Isles are discussed by Chambers and Elliott (1989).

A second Alnus rise has been identified at some sites in Wales, and has been dated at 6980 BP (Tregaron), 6680 BP (Nant Ffrancon) and 7000 BP (Clarach). An apparent second Alnus rise on the Llyn Hendref frequency diagram is an artifact of the percentage calculations.

FIRST CONTINUOUS FRAXINUS (EMPIRICAL LIMIT)

SRR 3470 Llyn Cororion 6450 +/- 65 years BP.

Only three reliable dates for this horizon are available in Wales and generally dates have to be extrapolated. The empirical limit of Fraxinus is often difficult to define as Fraxinus does not always form a continuous curve, and values are often low. Smith and Pilcher (1973) state that it is the most difficult limit to define and quote a range of dates from 3000 BP and 5000 BP, but many sites have sporadic earlier counts.

The dates recorded in Wales are generally older, eg. 6430+/-110 BP at Tregaron, 6880+/-110 BP at Nant Ffrancon, but there is a younger date at the high altitude site of Melynllyn (4755+/-90 BP). The date from Llyn Cororion is early compared with the isochrone map of Birks (1989) but compares well with the Tregaron site. The wide range of dates in Wales can be explained by edaphic and environmental controls, and there is no evidence to suggest that the Llyn Cororion date is not accurate.

<u>ONSET OF THE ULMUS DECLINE</u>

SRR 3469 Llyn Cororion 4985 +/- 65 years BP.
A reduction of <u>Ulmus</u> frequencies from 5% to 1.5%.

The <u>Ulmus</u> decline is 'the most extensively dated horizon in the British Postglacial' (Smith and Pilcher, 1973) and most results suggest that it is a synchronous horizon. There has been much debate over the cause of the elm decline and epidemic disease, clearing, selective gathering by Neolithic man, and climate have all been forwarded as possible factors (Oldfield and Stratham, 1963; Pilcher, 1969; Hirons and Edwards, 1986). The situation remains largely unresolved, with evidence at different sites supporting different hypotheses (Godwin, 1975).

Dates of 5050+/-75 BP and 5060+/-60 BP have been obtained for the <u>Ulmus</u> decline at Nant Ffrancon and Cors Dolfriog respectively, and within the limits of statistical error, they are consistent with the age estimate from Llyn Cororion. The apparently synchronous dates obtained from different site types (lakes, mires etc.), diagrams of different resolution, and samples of different thickness, suggest that despite these variations the radiocarbon dates are reliable.

<u>RISE IN CANNABACEAE (RATIONAL LIMIT)</u>

SRR 3467	Llyn Cororion	780 +/- 60	years BP.
SRR 3540	Llyn Hendref	3370 +/- 65	years BP.

Llyn Cororion and Llyn Hendref are the first sites in Wales to be specifically dated for this event. The occurrence of Cannabaceae is recorded at a number of sites in Wales but most records do not distinguish between <u>Cannabis</u> and <u>Humulus</u> and do not have a specific date for the Cannabaceae rise. Most diagrams have an estimated date, based on the extrapolation of data or on the appearance of other taxa (Godwin, 1967).

<u>Cannabis</u> is believed to have been imported by Anglo Saxons and

cultivated until 1594 (Bradshaw _et al._, 1981). A _Cannabis_ curve at Durham (which reaches frequencies of 19%, Bartley _et al._, 1976) has been dated at 2064+/-60 BP and this is one of the earliest dates for the British Isles. At Crose Mere, a _Cannabis_ rise is seen at 1610+/-75 BP with a maximum of 15% at approximately 1500 BP. The rise of _Cannabis_ is often associated with a phase of forest clearing, (Bradshaw _et al._, 1981; French and Moore, 1986). Early and discontinuous occurrences of Cannabaceae are usually assigned to native _Humulus lupulus_ (Godwin, 1975) as they pre-date the known date for the introduction of hemp into the British Isles. The earliest dates for Cannabaceae in Wales are recorded at Moel-y-Gerddi (Chambers and Price, 1988) and low, intermediate frequencies between 6435+/-85 BP and 5705+/-80 BP probably represent native _Humulus lupulus_.

Other diagrams suggest that the cultivation of hemp was more recent and historical documentation supports this. Lindlow Moss (Birks, 1965) was surrounded by _Cannabis_ cultivation in the 12th and 13th century, and in Tudor times. A similar situation is recorded at Hockham Mere (Sims, 1978) with a _Cannabis_ peak at 734+/-30 BP. At Llyn Cororion, the Cannabaceae pollen was positively assigned to _Cannabis sativa_, and the radiocarbon date of 780 BP suggests a calendar date of around 1170 AD.

Llyn Hendref yielded little Cannabaceae which were identified as _Humulus lupulus_. The date is problematic because it occurs within a disturbed sequence. Thus it may be that the level of first recorded Cannabaceae is redeposited. _Humulus lupulus_ may have been growing in damp marginal areas around Llyn Hendref, (section 7.3). It is unlikely that the dates from Llyn Cororion and Llyn Hendref represent comparable events. The Llyn Cororion record shows the introduction of an 'exotic' species for cultivation, whereas at Llyn Hendref the date is for the presence of a native taxa.

HIATUS/UNCONFORMITY

SRR 3541 Llyn Hendref Above hiatus 4920 +/-   years BP.

SRR 3542 Llyn Hendref Below hiatus 5735 +/- years BP.

After the construction of the pollen diagram, it became obvious that around 552cm there was some form of hiatus within the core. This was suggested by both the biostratigraphy and lithostratigraphy (section 3.5.2). Two samples were taken, one on either side of the hiatus, to date the break and verify the quantity of time missing; the results suggest an hiatus of 815 radiocarbon years. This may represent a phase of non-deposition, the loss of sediment through erosion or complete disturbance of the late Postglacial sequence (section 7.1).

5.6 SEDIMENTATION RATES

5.6.1 INTRODUCTION

Sedimentation rates are an important variable in palaeoecological studies as they control the temporal, and therefore biostratigraphic, resolution of a pollen diagram. Slow sedimentation rates result in low resolution and condensed sequences which are difficult to date and interpret. Variations in sedimentation patterns over time also impose limitations on the palaeoecological information which can be obtained from a single core (Dearing et al., 1981).

The particular problems of sediment focusing, resuspension and redeposition have been discussed by Davis (1968, 1973). Hilton et al., (1986) conclude that sediment focusing is one of the dominant distribution mechanisms of lakes, and irregular sedimentation within lakes results in errors when estimating dates. Sediment focusing is more likely to occur in steep sided basins such as kettle holes, or simple basins which conform to the theoretical frustrum or hyperboloid models of Lehman (1975).

Sedimentation therefore has a direct impact on the final pollen diagram, and the problems and limitations of calculating sediment accumulation rates should not be underestimated. The accuracy of sediment accumulation rates calculated from a depth-age curve depend on the reliability and density of radiocarbon dates and associated errors. Radiocarbon dates are average estimates for a thickness of sediment, and sediment rates have to be interpolated between points. Radiocarbon dates are also not equivalent to calendar years, and have a maximum deviation between approximately 2,000 and 6,000 BP (section 5.2.4). This results in an apparently faster accumulation rate for this time period compared with dates outside this range. Date calculations are usually based on dates from one core and may not be representative of the basin as a whole due to temporal and spatial variations in sedimentation. Dearing et al., (1981) found that Llyn Peris did not conform to Lehman models, and that the use of one core could over- or under-estimate influx values up to 4 times, depending on core location. Lehman (1975) reported that influx rates from ellipsoidal or sinusoid shaped basins would generally reflect conditions for the whole lake.

The final calculated sedimentation rate records the net yearly addition of material to the permanent record after deposition, compaction, and diagenesis, and may include material that has been redeposited or redistributed by sediment focusing. Pennington (1973) indicated that the input of seston was up to 2.5 times greater than the annual increment of material added to the consolidated record due to resuspension and redeposition processes. It therefore needs to be assumed that the addition of material to the permanent sediment is proportional to the annual material input, and is indicative of the general sedimentation regime within the lake.

The final quantity of material incorporated into the sediment depends mainly on three factors; 1) rate of supply; 2)internal lake processes and 3) diagenesis. If the latter two can be assumed to have been constant throughout lake history then fluctuations in calculated sedimentation rates can indicate changing rates of supply. The supply of material to a lake basin is dependent on the size and nature of the drainage basin, and factors such as topography, geology, hydrology, soil stability, vegetation cover, rates of erosion and lake level fluctuations. Topography and geology are relatively constant, so changes will tend to reflect variations in the other factors. They can be used to infer changes within the catchment, and, indirectly, climatic variations.

Pennington and Lishman (1984) studied Blelham Tarn in the Lake District and concluded that the dominant factor in controlling sediment supply to the lake in the last 5,000 years had been land use. The removal of trees exposed soils to precipitation and run off, and resulted in increased sediment supply. The sediment would have become increasingly inorganic as erosion rates increased.

Climate change with increased precipitation also causes increased soil erosion (Walker, 1978). It has been suggested that lowering of lake levels increases sedimentation rates with the transport of coarse inorganic material to deeper areas (Digerfeldt, 1986). The presence or absence of streams affects the input and sediment provenance. 'Closed' basins have lower sedimentation rates, with input dependent on slopewash and internal productivity. Allochthonous material accumulation rates tend to be greater than that of autochthonous detritus even if a lake has high productivity (Hakansson and Janssen, 1983).

Sedimentation rates alone provide limited palaeoecological data. Integration with pollen data, loss-on-ignition results, lithological changes, and chemical analysis help to elucidate the causes of changing accumulation rates. It is difficult to compare sedimentation rates between sites because of environmental variability. Studies of sedimentation rates are relatively rare but a recent paper on sediment accumulation rates (Webb and Webb, 1988), analysed the variation of accumulation rates with geographical location, human disturbance, climate, sediment type and age. They produced 'typical' rates for small lakes which contained uninterrupted sequences and constant accumulation rates; the typical range was between 0.016-0.257cm/yr with a mean rate of 0.06cm/yr. Lakes with low sedimentation rates, <0.01cm/yr, tended to have discontinuous sedimentary sequences, associated with rapid changes in depositional regime, and abrupt lithological changes and hiatuses associated with non-depositional or erosional events.

Modern day calculations (since 1963) for Blelham Tarn (Pennington and Lishman, 1984) range from 0.5cm/yr to 0.92cm/yr. These values are high when compared with sedimentation rates for the same lake throughout the Postglacial. Since 5723 BP, accumulation rates increased from 0.0125cm/yr until by 1,000 AD., rates were estimated to be 0.067cm/yr. Beales (1980) produced an depth-age curve for Crose Mere, and commented on the wide range of results obtained. Values of 0.2cm/yr were calculated for the early Postglacial with rates of 0.01cm/yr by the core top. Some variation was attributed to actual change in material supply, but many of the rates were indicative of post depositional redistribution, as postulated by Webb and Webb (1988).

Bennett (1983c) calculated sediment accumulation rates for Hockham Mere and compared values both temporally and spatially. Values for the deepest areas of the basin varied between 0.023cm/yr and 0.27cm/yr and towards the edge of the basin the range was 0.055cm/yr to 0.217cm/yr. The higher rates at the lake edge were due to inorganic material input with little sediment redistribution. Increased rates in the lake centre were due to the onset of sediment focusing.

There are few sedimentation rate studies in North Wales. Guppy and Happey-Wood (1978) estimated recent deposition rates in Llyn Peris and Llyn Padarn. In Llyn Padarn accumulation rates were estimated at 0.05cm/yr at 7073 BP increasing to 0.13cm/yr for the present day, the increase attributed to greater erosion within the catchment.

5.6.2 LLYN CORORION SEDIMENTATION RATES

Sedimentation rates at Llyn Cororion vary from 0.06cm/yr to 0.18cm/yr (fig. 5.1), most within the typical range forwarded by Webb and Webb (1988). The fastest sedimentation rates, 0.18cm/yr, occur at the core base (949-891cm) and correspond to a high minerogenic input, but it is difficult to ascertain if this is a true or apparent accumulation rate. The pollen diagram indicates a relatively open landscape at this time, and the high input may reflect the rapid deposition of material from easily eroded soils. Sediment focusing may also have been occurring. The present day morphometry of Llyn Cororion and depth of core extracted suggests that the basin originally had steep sides and therefore the potential for sediment focusing was high.

Sedimentation rates for the rest of the core are relatively steady, suggesting that if sediment focusing continued throughout the Postglacial, it was compensated for by increasing sediment input. Given the probable shape of the basin and the evidence that soils were stabilising (section 6.1), it is likely that sediment focusing only occurred in the early Postglacial.

The steady rates indicate stable conditions both within the catchment and in the lake basin. Between 891cm and 375cm the accumulation rate is around 0.11cm/yr, with a range between 0.10cm/yr to 0.13cm/yr, except for slightly increased values up to 0.16cm/yr, between 833cm and 803cm. This corresponds to the appearance of Ulmus, Quercus and Pinus and increased organic input, indicating maximum forest cover. Pediastrum and Botryococcus concentrations remain low, so there is no indication of increased lake productivity. Interestingly, there are also more indeterminable grains at this level, and maximum values for crumpled and corroded grains suggest the possibility of either redeposition or the input of eroded organic soils.

Between 375cm and 153cm the sedimentation rate is halved to

0.065cm/yr. This occurs during a period of increasing *Betula*, but declining *Tilia*, *Ulmus* and *Corylus*, and lowered values of *Alnus* and *Salix*. Herbs were generally increasing and maximum values of *Osmunda* and *Polypodium* are recorded but algal values are minimal. These data suggest the presence of a fringing macrophyte community around the lake edge which trapped sediment and reduced the quantity of material reaching the lake centre.

Between 153cm and 47cm sedimentation rates increase to 0.13cm/yr. This is associated with increasing inorganic input (30-45%), interpreted as enhanced soil erosion, and high *Pediastrum* values indicate that lake productivity increased. This phase is associated with maximum deforestation and high inorganic input (60%). The low sediment accumulation rate at the core top is an artifact of the calculations. The upper surface of the core was taken to represent 0 years BP but it is probably older than this as it represents the surface of the consolidated sediment and does not take account of the seston above.

The data from Llyn Cororion, show that after initial sediment focusing, the sedimentary regime remained stable throughout the Postglacial. All accumulation rates are within the accepted range for small lakes. The pollen influx diagram shows no synchronous variations and there is no evidence of major erosional events. The present day lake shape suggests that there was just one basin area for sediment accumulation and its small size implies a relatively simplistic sedimentary regime. The morphometry of Llyn Cororion and the surrounding topography help explain the stable conditions. A relatively constant water level (section 6.1) reduced potential for peripheral erosion and subdued catchment topography reduces the likelihood of highly variable stream inputs. Wind fetch at the site would be limited because for much of the Postglacial the lake was fringed by a protecting carr woodland. There has therefore been relatively constant and high sediment accumulation throughout the Postglacial producing excellent biostratigraphic resolution.

5.6.3 LLYN HENDREF SEDIMENTATION RATES

The Llyn Hendref results are highly variable (fig. 5.2), ranging from 0.02cm/yr to 0.32cm/yr, the majority falling within the range, 0.016-0.257cm/yr, recorded by Webb and Webb (1988). The wide range of values suggests that sediment was sometimes unevenly distributed over the lake bed and the site was subject to changes in sedimentary regime. Most sediment accumulation rates are low suggesting that the sedimentary regime was continually disturbed, (cf. Webb and Webb, 1988). Llyn Hendref poses problems, such as disturbed sequence and unreliable pollen data, similar to those described by Beales (1980) at Crose Mere where sedimentation rates varied between 0.01cm/yr and 0.2cm/yr.

Between 720cm and 698cm the sediment accumulation rate is relatively low, between 0.02 and 0.03cm/yr. This is associated with a sharp decrease in inorganic values, to between 65-55%, and increasing Betula, Corylus, Salix, Potamogeton and Pediastrum (5%) suggests increased internal productivity in a shallowing lake. There is no evidence that the sequence is disturbed, except for one possible period of resedimentation at 698cm, and therefore the accumulation rates are a true reflection of material input; the low values result from the close proximity of the coring site to what was the basin edge. It is likely that most sediment was directed to deeper areas, and a thin condensed sequence accumulated at the lake edges. Preferential sediment accumulation into deeper areas of lakes in the early Postglacial, has been recorded by Pennington (1974).

Between 698cm and 598cm the sedimentation rate increased to 0.065cm/yr and corresponds to decreases in inorganic content, the introduction of the main tree taxa and decreased Pediastrum values. The influx diagram indicates that this is a relatively stable period, with little evidence of redistribution or erosion. The value of 0.065cm/yr is similar to the mean sedimentation rates recorded in Llyn Padarn (Guppy and Happey-Wood, 1978) at 0.084cm/yr and the figure of 0.058cm/yr recorded at Ennerdale (Pennington, 1974).

The most likely explanation for the increased sedimentation rate at Llyn Hendref would be a changing sedimentary regime. The basin may have accumulated enough material to even out bottom relief present in the early Postglacial and sediment could now accumulate evenly over the whole basin instead of being directed to deeper areas. If this was the case, then the value of 0.065cm/yr would be representative of the whole basin. Another possibility is that the focus of differential sedimentation had shifted with preferential sedimentation at the core site.

An increased sediment accumulation rate associated with increased organics and Corylus dominated-woodland was noted by Bennett (1983c). He suggested that finer organic material, of a lower density, was redistributed in deeper areas, resulting in an apparently increased sedimentation rate. This may be the case at Llyn Hendref but there is no evidence of the simultaneous changes in pollen influx and raised indeterminable values, expected with sediment redistribution.

The period between 598cm and 553cm saw a return to a low sedimentation rate, 0.02cm/yr, and is associated with a decrease in the pollen accumulation rates for most taxa, and also minimum inorganic percentages. The latter suggests that some of the reduction is due to decreased erosion within the catchment, but the figure is too low to be solely due to this. Decreased pollen influx values are also unlikely to reflect decreased vegetation cover (section 7.3) and are thought to reflect decreased productivity and a change in sediment deposition patterns within the basin. The reversion to lower sedimentation rates suggests a switch of focus for preferential sedimentation to another part of the basin. It is also possible that there were sporadic, and short-lived periods of erosion although these are almost impossible to detect in the pollen diagram. Davis et al., (1984) suggested that low, intermittent sedimentation rates are characteristic of a relatively high energy environment, causing winnowing of organics.

At 552cm a hiatus is identified with approximately 815 radiocarbon years missing, (section 5.5.2). Given the apparent disturbance within the lake after 552cm some of the following statements are speculative, and are impossible to test without further radiocarbon dates. Between 551cm and 056cm the sedimentation rate is high (0.32cm/yr), outside the range predicted by Webb and Webb (1988).

The high sedimentation rate is associated with a stratigraphy of lake muds, remains of ligneous and herbaceous plants and increased minerogenics. There is also an increase in herb percentages. Minerogenic input is initially high at 60%, but declines to 38%, at 600cm, before rising to 65% by 56cm. Part of the higher sedimentation rate and initial increased inorganic content may be attributable to destabilisation of soils as a result of deforestation, (cf. Pennington and Lishman, 1984), possibly superimposed on larger effects of a hydrologically unstable lake system. The simultaneous increase of all pollen accumulation rates suggests that sediment focusing occurred and the increased inorganic deposition and indeterminable grains suggest it was a result of littoral sediment erosion. The core site was now a location of rapid deposition in contrast to the previous phase when deposition was minimal.

The top 50cm of core is characterised by low sedimentation rates (0.02cm/yr). This may be due to decreased lake productivity or reduced material input, error due to radiocarbon dating, error associated with the assumption that the core top represents 0 years BP, or sedimentary factors. The accumulation rate is likely to be a result of a combination of these factors. The sedimentation rate does not reflect the vegetational changes that were occurring within the catchment (section 7.3). Deforestation within the catchment had begun and the lake was surrounded by productive carr. These factors should theoretically increase the sediment input but this is not reflected in the sedimentation rate.

The deposition rates after 552cm had to be estimated over a long time period due to the shortage of dates in the part of the core and, given the apparent sediment disturbance, the calculated sedimentation rates are unreliable. A date at the top of the consolidated sediment, rather than assuming it represents 0 years BP, would help to provide a more reliable sedimentation rate. Two metres of seston above the core site were too liquid to sample and represent an unknown time span.

The results show that after an initial phase of relatively steady sedimentation rates in the early Postglacial, the sedimentary regime became unstable with periods of erosion and redeposition. The potential factors affecting sedimentation are:

1) Topography. In areas of high relief, sediment input is often highly variable, with peaks of sediment input (Sly, 1978) containing a coarser component. This is unlikely to be a major influence at Llyn Hendref.

2) Basin morphometry. This controls internal dynamics and hence sediment distribution. Temporal changes in shape and depth induce variations in sediment accumulation and water circulation. At Llyn Hendref morphometry changed due to infilling by bog (section 7.2) which would have affected lake levels and internal hydrology.

3) Local climate. The frequency and strength of winds influences the quantity of resuspended sediment. Long, narrow basins, aligned to the fetch direction receive a concentration of wave action at either end (Sly, 1978). Shallow lakes will have a greater proportion of their bed disturbed. Llyn Hendref would have been exposed to strong south-westerly winds which would have had an increasing effect as the lake shallowed.

4) Lake level changes. These alter the sedimentation limit, with littoral areas switching between being depositional and erosional. This is a strong possibility at Llyn Hendref.

The calculated sedimentation rates and radiocarbon dates have shown that the sedimentological history of Llyn Hendref has been relatively unstable. This is important as it suggests that pollen was deposited from resuspended material and does not therefore reflect true vegetational change. Below the hiatus the sedimentary sequence is believed to be virtually intact and the pollen record can be interpreted in terms of vegetational change. Above the hiatus, the uncertainty over the reliability of the sedimentation rates directly affects pollen concentration and pollen accumulation rate calculations making interpretation difficult. A number of processes were interacting both temporally and spatially. Without an extensive coring program to identify the original morphology of the lake, and more radiocarbon dates to increase the accuracy of the calculated sedimentation rates, it is impossible to be more specific about the processes that were operating in the lake as a whole.

CHAPTER 6

POSTGLACIAL HISTORY OF LLYN CORORION

LLYN CORORION: INTRODUCTION

There is little evidence to suggest major lake level fluctuations during the Postglacial and Llyn Cororion has changed little in historic times (section 2.3.3). Marshy ground around the lake therefore results from high water tables and periodic flooding rather than lake infilling.

Initially there was a regional pollen source area, but as the landscape became forested, the pollen source area was reduced with background pollen filtered out by increasing canopy, trunk area and local pollen input. The predicted pollen source area for the Postglacial is extra-local and local (appendix A4) with most pollen derived from within a few kilometres of the site. Pollen would also have been derived from carr woodland and aquatic vegetation around the lake edge. The lack of stream input makes the pollen source area relatively easy to define (cf. Llyn Hendref)

Llyn Cororion appears to fit the category of an 'ideal' lake basin for pollen analysis as described by Smith (1959); that is one' that is deep in relation to its surface area and is sheltered from the wind' as well as having no significant inflow and a small drainage area. Pollen zone characteristics are summarised in table 6.1.

6.1 LLYN CORORION : STRATIGRAPHY AND SEDIMENTOLOGY

Basal inorganics (1014-948cm)

Embleton (1964a) identified a series of 'major kettleholes' developed within outwash sands and gravels between Pentir and Tregarth (fig. 1.4b). Llyn Cororion was not specifically identified, but its dimensions, morphometry and location suggests it should be included within the series. The

Table 6.1 Llyn Cororion Local Pollen Assemblage Zones

Local Pollen Assemblage Zone		Depth (cm)	Age (yrs.BP)	Average Percentages %PS		
				Trees	Shrubs	Herbs
LC 8	Cannabaceae -Gramineae	048-000	780-?	21	5	65
LC 7b	Fraxinus-Betula	112-048	1250-780	45	10	43
LC 7a	Fraxinus-Betula -Quercus	324-112	4200-1250	67	21	9
LC 6	Tilia-Fraxinus -Quercus	460-324	5650-4200	68	26	2
LC 5	Alnus-Corylus -Quercus	702-460	7745-5650	86	12	2
LC 4	Pinus-Quercus	780-702	8425-7745	69	25	5
LC 3	Corylus-Quercus	860-780	9000-8425	36	51	6
LC 2	Betula-Salix	936-860	9600-9000	62	15	17
LC 1	Betula-Salix -Juniperus	948-936	9680-9600	28	32	36

Local Pollen Assemblage Zone		Sedimentation rate (cm/yr)	Average Conc. (gr/cm^3)	Average PAR. ($gr/cm^2/yr$)
LC 8	Cannabaceae			
	-Gramineae	0.06	$3.5x10^5$	$2.1x10^4$
LC 7b	Fraxinus-Betula			
LC 7a	Fraxinus-Betula	0.13	$1.8x10^5$	$2.4x10^4$
	-Quercus	0.12	$2.9x10^5$	$2.8x10^4$
LC 6	Tilia-Fraxinus			
	-Quercus	0.12	$1.3x10^5$	$1.4x10^4$
LC 5	Alnus-Corylus			
	-Quercus	0.12	$2.6x10^5$	$3.1x10^4$
LC 4	Pinus-Quercus			
LC 3	Corylus-Quercus	0.12	$8.5x10^5$	$9.8x10^4$
LC 2	Betula-Salix	0.12	$6.2x10^5$	$8.0x10^4$
LC 1	Betula-Salix	0.15	$2.0x10^5$	$2.9x10^4$
	-Juniperus	0.18	$2.2x10^5$	$4.1x10^4$

kettleholes suggest rapid ice wastage at the end of the Late Devensian leaving detached dead ice masses buried beneath outwash deposits. Without penetrating datable Windermere Interstadial sediments, the date of lake formation remains unknown; radiocarbon dating suggests a minimum of 9365 years BP.

The original basin shape is unknown but the present day morphometry suggests that the lake was symmetrical with steep sides, and at least 15m deep. The catchment area is relatively limited due to the subdued topography. Catchment deposits consist of outwash sands and gravels, (recorded at SH599691) overlying chaotic supraglacial boulder clay and lodgement till (Greenly, 1942). The stratigraphic sequence recovered, and the date obtained from the lowermost organics indicates that only the Postglacial and upper Loch Lomond Stadial sediments were recovered. Coring equipment was unable to penetrate the basal clays and there is no positive indication that they were the base of the sequence. Fifty-six centimetres of basal clays and gravels were recovered (excluding a gap between 954-962cm) but the maximum thickness of Loch Lomond Stadial deposits is unknown.

The main mineral source would have been from immediately around the lake edge, transported in by solifluction and slopewash. It is possible that clay minerals (kaolinite) and some pre-Quaternary spores were deposited by onshore winds (section 3.7.4). Llyn Cororion was outside the Loch Lomond Stadial ice limit but the climate here at that time would have been severe with periglacial activity and possibly the formation of perennial snow patches.

The laminated clay sequence suggests deposition in standing water, and the laminae dip (3°) indicates that the core was not taken in the depositional centre of the lake. The lowest clays are consolidated with variable lamination size (<0.5mm). Laminations are defined by grain size and colour and only became apparent when the core dried out. Paler layers are silt rich and the darker thinner laminae are composed of clay with a total organic content averaging 3%. The laminae suggest deposition in undisturbed water beneath the sediment entrainment limit of wind driven currents. Small deep lakes with limited surface area are unlikely to suffer bottom disturbance as a result of water circulation (Smith, 1959). There was also no disturbance from inflowing or outflowing streams and benthic fauna would have been limited by oxygen deficient water. The laminae appear to be 'couplets' as described by Saarnisto (1986); the fine dark clay and relatively organic layers are deposited during stagnant conditions in the winter, and in the summer light coloured sands and silts are deposited in more turbulent conditions (Smith, 1959).

There are 13 pairs of laminae in 1cm suggesting a deposition rate of approximately 0.8 mm/yr assuming annual deposition. The laminae decrease in thickness upwards, suggesting reduced material input or sediment focusing. Sediments may have initially been focused into the central part of the basin but as deeper areas filled, sediment was distributed over a larger area, resulting in thinner laminations and an apparently decreased sedimentation rate. This is supported by the declining laminae dip which reduces up-core.

X-ray diffraction results (section 4.4.4) indicate that the clays are predominantly chlorite, kaolinite, illite and vermiculite. This indicates erosion of local outwash and glacial materials but with a possible windblown component. Material was initially unconsolidated and susceptible to erosion by aeolian activity, and under periglacial conditions, slope creep would have been efficient. Chemical data suggest that the clay material was inherently deficient in sodium and calcium and may also have contained rock-flour. Potassium concentrations are relatively high, associated with allochthonous mineral input, and increase upwards perhaps reflecting decreased sedimentation rates or an increase in fine grained material (section 4.2.3).

Towards the top of the clay sequence there is a reduction in pre-Quaternary spores and indeterminable grains perhaps indicating reduced erosion and the onset of landscape stabilisation. A level (978cm) rich in organic material (4%) and containing moss fragments, is matched by a peak in Sphagnum spores in the pollen record. The coincidence of spores and macrofossil remains suggest moss colonies surviving on stony patches or in boggy pools. Organic fragments (>118 microns) are recorded in the pollen washings (fig. 3.3) but the loss-on-ignition results do not register a significant increase in organic sedimentation. Above the organic layer are 4cm of laminated clays overlain by 6cm of graded sand and gravel.

The sands are poorly sorted with a high proportion of clay and silt but crude, reverse grading can be identified by eye. Grain size analyses show that the sequence coarsens upwards with fine and medium sand at the base grading into coarse sand at the top. The gravel and coarse sand fractions were divided into lithological groups. The dominant rock types are quartzite, slate/schist (micaceous) and vein quartz with minor quantities of conglomerate, sandstone and igneous material of local derivation. All clasts were subangular to angular suggesting an immature deposit.

Without dating evidence, it is not possible to say if the gravels were deposited gradually or as one isolated but rapid event. It seems unlikely that climatic conditions deteriorated sufficiently at the end of the Loch Lomond Stadial to promote increased solifluction although it should be noted that Crabtree (1965) described increased erosion prior to the onset of organic sedimentation at Llewesig. Except for the crude grading there is little to denote a possible transport mechanism and the laminated clays suggest that disturbance within the lake was relatively rare. The sands and gravels were possibly deposited as slumps resulting from sediment defrosting.

LC1: (948-936cm)

The onset of organic sedimentation is indicated by a sharp boundary between graded gravels (organic content 3%) and overlying lake muds (organic content 48%). The boundary is dated at 9680+/-65 BP which, when compared with similar contacts at other sites is relatively late (section 5.5.2). This age estimate is a minimum and it is likely that soil stabilisation and organic accumulation began earlier but that the evidence was not preserved. The earliest Postglacial sediments probably dispersed through a permeable layer of gravel; organic fragments were observed during the gravel washing (section 5.5.2).

The organic content of the sediment gradually increases upwards reflecting the continual accumulation of organic soils under developing Betula and Salix scrub. Associated with this increased productivity is a rise in sodium and potassium concentrations. Assuming that lake morphometry has remained unchanged, the sedimentary regime would have been relatively simple with one well defined deep acting as a focus for sediment accumulation. Coarse material would have been deposited in limited littoral areas, with most fine material directed downslope. The dominant sediment distribution mechanisms would have been dispersal by plumes; there is no evidence of slumping. It is likely that preferential sediment accumulation occurred in the deepest areas although the stratigraphy of the basal clays (section 5.6.2) indicate that sediment focusing decreased upcore.

There is an estimated sedimentation rate of 0.18 cm/yr for zone LC1, the highest recorded for the Postglacial at this site. It is likely that this is in part attributable to sediment focusing, but could also reflect the continuation of relatively high erosion rates within the catchment. The landscape was still open (section 6.3) and the continued input of inorganic material >118 microns (fig. 3.3) supports the idea of persistent soil instability. The organic material is laminated, defined by both grain size and colour, (plate C) indicating cyclic deposition with little disturbance by waves or currents or burrowing fauna; the latter perhaps a reflection of the anoxic state of the bottom waters. Laminations in organic material have been described by Saarnisto (1986) who suggests that formation may be due to a combination of seasonal rhythmic changes in biogenic production, minerogenic matter, water chemistry and inflow. Occasional coarse organics observed in the core were probably derived from limited aquatic vegetation.

LC2 (936-860cm)

Zone LC2 is characterised by an apparently decreasing sedimentation rate and increasing organic content. Potassium concentrations reflect the decreasing mineral input and sodium values are relatively steady; sodium input from organic sources will have increased but this would be offset by decreased extractable sodium associated with mineral material. Calcium values remain steady despite increasing organic input and it is possible that calcium was related to the aquatic vegetation which shows little change in zone LC2.

The reduced sedimentation rate reflects a number of variables; soils were stabilised by rootlets and an increased canopy cover resulted in precipitation interception, reduced run-off and waterlogging. Low-lying areas around the lake were now colonised by carr vegetation and this, in association with developing macrophyte vegetation possibly acted as a sediment trap. It is also possible that the decreasing sediment rate was partly due to reduced sediment focusing as the lake gradually infilled. Laminations are more frequent in this zone and a decrease in thickness up core supports the latter hypothesis.

There is no evidence of sliding or slumping and laminations indicate that there was still relatively deep water with no bioturbation or disturbance by currents. The laminations are composed of alternating organic lake muds and paler 'clay rich' layers which only became apparent as the core dried out.

The laminations may represent annual laminations (cf. Saarnisto, 1986) and suggest permanently oxygen deficient bottom waters with no benthic organisms and no significant inflow.

The data suggest a stabilising landscape with increased terrestrial productivity and reduced soil erosion. Pediastrum values are low and so most organic material was probably terrestrial matter and debris derived from fringing reedswamp and aquatic vegetation. The sediments are predominantly fine grained organic lake muds suggesting a distal depositional environment with the majority of coarse allochthonous material deposited in littoral regions, although occasional coarse material was deposited in deeper areas, eg. a leaf rich layer occurs at 915cm (fig. 3.3).

Between 878-882cm there is an increase in the clay and silt content of the sediment and at 886cm a small pod of fine sand (quartz rich) was recorded. The latter coincides with an initial Corylus rise; an association between the introduction of a new taxon and increasing inorganic content was also noted at Llyn Hendref, (section 7.1). This phase of increased mineral input is also characterised by increased Artemisia and Dryopteris (both pollen and macrofossil remains) suggesting reduced tree cover and unstable soils. The establishment of a species in this relatively open landscape resulted in increased competition and apparently increased soil exposure. It is possible that the association is coincidental, with the sand band being attributable to a localised and isolated event (eg. storm action). It is unlikely to reflect redeposition as there is no evidence from the influx diagram or stratigraphy to suggest disturbance of littoral sediments or changes in lake level.

LC3 (860-780cm)

The stratigraphy remains relatively constant indicating continued deposition of fine organic lake mud with associated sodium (section 4.2.3). Allochthonous organic input apparently increases to 79%, reflecting well developed stable soils, and increased productivity within the catchment. Potassium concentrations decline reflecting decreased mineral deposition and increased soil leaching. Stable soils were now leached of soluble elements and subsequent erosion resulted in deposition of base-poor sediments.

The pollen washing results and the loss-on-ignition data show decreased mineral input although occasional high percentages occur (eg. 56% at 820 cm, 50% at 836cm). The first increase is accompanied by increasing Ulmus, and the second phase coincides with decreased Betula values and rising Corylus frequencies. These isolated mineral fluctuations are difficult to interpret; they may reflect variations in organic input and are therefore an artifact of the percentage method, or they may result from short lived variations in internal inorganic productivity or isolated erosion events. The lake was now protected from wind by woodland and the shoreline would have been less susceptible to erosion and redeposition, supporting the latter hypothesis.

There is no clear evidence for lake level fluctuations and sedimentation rates decline to 0.12cm/yr, a function of decreased erosion rates and reduced sediment focusing. Shallowing occurred, as a result of increased macrophyte vegetation, bringing the sediment-water interface above the sediment entrainment limit and increasing sediment disturbance. Saarnisto (1986) states that laminations are more common in water depths greater than 15m and Llyn Cororion would have been shallower than this at this time; the upper seston would now be disturbed by spring and autumn overturn.

LC4 (780-702cm)

Zone 4 is characterised by maximum vegetation cover (section 6.3) and stable deposition rates (0.12 cm/yr). The core stratigraphy remains constant (table 3.1) indicating continuity of sedimentary processes and deposition. The apparently constant sedimentation rate suggests that there is now an equilibrium between organic sediment production and deposition. Sediment focusing was no longer a dominant process and deposition is likely to have been from plumes of fine suspended sediment.

An isolated minimum (54%) in organic content is recorded between 748-732cm, coinciding with increased ligneous and herbaceous content. The pollen and spore record suggests that a slight amount of shallowing may have occurred during this phase (section 6.3), verified by occasional *Phragmites* remains within the sediment. This was also a period of increased *Alnus* frequencies, decreased *Pinus* values and increased charcoal records. Increased fire frequency may have resulted in increased slope wash and higher inorganic input into the lake. *Pediastrum* values suggest a rise in internal productivity and there is evidence for an associated spread of macrophyte vegetation. Associated with the change in stratigraphy is an increase in sodium and potassium and reduced calcium concentrations.

LC5 (702-460cm)

The stratigraphy indicates that there was continued deposition of organic lake muds with increased frequency of coarse organic debris. The loss-on-ignition results show that organic deposition reaches high values (83%), probably associated with stable mature soils and minimum erosion rates. Dense canopy cover would have increased precipitation interception, and soils would have been bound by understorey vegetation, reducing the efficiency of slope wash.

The majority of the organic material was derived from local terrestrial sources with steady erosion of accumulating litter, organic soils and coarser plant debris. The latter, especially leaf rich layers, appear to be responsible for increased potassium and sodium concentrations. Macrophyte vegetation fringing the lake is thought to have contributed significant quantities of sodium to the sediment (section 4.2.3). Increased coarse organic material is thought to indicate erosion of older carr substrate as water level fluctuated. Erosion of littoral sediments is indicated by occasional resedimentation, and increased macrofossil deposition reflects expanding vegetation around the lake edge. Algal material does not appear to have been a major source of organic sediment with Pediastrum values reaching a minimum indicating either decreased production, associated with reduced nutrient supply, or reduced preservation.

Inorganic material is thought to have been terrestrially derived, with the stony northern shore as one possible source. Fire occurrence also opened up the woodland exposing mineral substrates to erosion. Material deposited in the central area of the lake would be fine grained silts and clays with coarser sands accumulating nearer the lake edge. Some inorganic material may have been autochthonous in origin with an increase in internal inorganic precipitation (eg. biogenic silica) effectively 'diluting' the organic content.

Estimated sedimentation rates remain steady (0.12cm/yr) but this is an average for the whole zone; short term fluctuations are not identified, but may be responsible for variations in the chemical record. The structureless nature of the lake muds suggests either rapid sedimentation and/or bioturbation. The latter is more probable with a gradual infilling of sediment raising the zone of deposition to depths tolerated by burrowing benthos fauna. It is also possible that the lake bottom was now affected by annual overturn, vertical water circulation, and sediment mixing; there is no evidence of sediment focusing.

The pollen concentration diagram (enclosure 2) indicates that there were occasional phases of erosion and sediment redistribution which may explain fluctuations in the loss-on-ignition curve and chemical data. A sand rich layer at 588cm and a decrease in organic material at 512cm are associated with increased indeterminable grains. Both of these may represent littoral erosion with transport of mineral material to deeper areas. Sediment redistribution appears to have been an occasional event of limited duration, possibly related to small scale water fluctuations, or infrequent severe weather conditions.

LC6 (460-324cm)

Deposition within the lake continued un-interrupted with the accumulation of highly organic lake mud. Loss-on-ignition values show that organic content reaches a Postglacial maximum of 98% at 424cm and high values are maintained until 368cm when a slight decrease is registered. The majority of the organic material was again probably terrestrially derived with some contribution from aquatic vegetation. Algal values are low and inconsistent, and their contribution to the sediment record is likely to have been negligible (cf. Pennington and Lishman, 1984). Calcium and sodium concentrations are still linked to organic rather than mineral input.

The inorganic content increases from 368cm upwards coinciding with decreasing *Tilia* and the beginning of the *Ulmus* decline. Disturbance within the woodland is apparent (section 6.3) and local soils were exposed to erosion. Increased corroded, crumpled and broken grains suggest superficial erosion of topsoil resulting in increased mineral material reaching the lake. During these phases the organic content is likely to have remained relatively constant but appears to have been reduced, perhaps an artifact of the percentage method adopted.

The average sedimentation rate remained at 0.12cm/yr suggesting that the sedimentary regime remained stable, with little evidence of sediment redistribution or focusing. The absence of laminae indicates possible bioturbation and annual overturn. Unstructured humified lake muds dominate the sequence with bands of leaf and ligneous detritus, concentrated in 2cm segments (353-355cm, 400-402cm). *Salix* leaves and *Betula* wood suggest inwashing from the carr. Lake levels appear to be relatively static with only gradual infilling by macrophyte vegetation.

LC7a (324-112cm)

The stratigraphy indicates that coarse organic accumulation declined and fine organic material dominates the sediment. This sequence suggests a slight rise in water level (cf. Digerfeldt, 1986). From 200cm onwards sand is recorded frequently but the estimated sedimentation rate remains stable at 0.12 cm/yr. Sedimentation rates within the basin should theoretically have risen as erosion increased but the radiocarbon date resolution is not accurate enough to identify the point at which this may have occurred.

The pollen and loss-on-ignition data indicate that disturbance was now more frequent and widespread within the catchment (section 6.3), but the initial high organic content shows that sediment erosion was superficial despite increased fire frequency. Temporary deforestation occurred but soils were perhaps stabilised by fast growing pioneering species forming secondary woodland. Fragments of birch bark and wood identified between 175-154cm and at 170cm show that trees grew on the lake edge.

Occasional sand bands are recorded at 243cm and 268cm and a large rounded pebble (quartz) was recovered at 164cm. The sand bands do not appear to be associated with declining vegetation and increased indeterminable pollen, so they possibly represent local deposition after storm events or vegetational disturbance too small to be recorded in the pollen diagram. There is no evidence of slumping or disturbance and so the pebble may possibly have been a dropstone deposited after winter freezing.

Above 148cm (around 950BP) the inorganic content permanently increases, probably a result of deforestation and increased sediment transport. Increased mineral input was responsible for increasing potassium values but sodium and calcium concentrations are still low suggesting that the soils were leached with soluble elements removed in solution (section 4.2.3).

LC7b (112-048cm)

The loss-on-ignition results show that organic input was decreasing, probably associated with permanent forest disturbance. Mineral soils were exposed to increased run-off and unleached material was deposited within the lake basin. The nutrient supply temporarily increased, and eutrophication and internal productivity were high. The source of organic material would have been predominantly terrestrial (macrophyte vegetation was declining) although given the high algal production (55%) some may be autochthonous. The inorganic content is largely local material transported by increased run-off and the severity of erosion is indicated by the increased sedimentation rate (0.13cm/yr) and rising potassium concentrations. High potassium values indicate that leaching was minimal with raw soils now being transported to the basin. Slopewash would have been more effective as forest was cleared from the lake edge and decreasing fringing vegetation would have resulted in more material deposited in the lake centre.

LC8 (048-000cm)

Inorganic input was now at a maximum as unleached soils were eroded and deposited. Chemical analysis indicates an increase in relatively base (especially potassium) rich sediments, derived from unleached substrates exposed by severe erosion, although the chemical data suggest that some sodium and calcium, the more soluble elements, were lost in solution.

The estimated sedimentation rate is lower at 0.06 cm/yr but this is believed to be an underestimate (section 5.6.2). Deposition rates are, in fact, likely to have increased as a result of further deforestation and increased erosion. Macrophyte vegetation was now limited in extent, possibly increasing the efficiency with which sediment was transported to the centre of the basin.

The stratigraphy suggests there was no major sediment disturbance as a result of slumping or sliding, but again structureless muds indicate active benthic fauna and/or annual disturbance due to overturn and sediment mixing. Sediment was still deposited directly from suspension but some would have been deposited by re-distribution of littoral material.

6.2 LLYN CORORION : AQUATIC AND HELOPHYTIC VEGETATION

LCA (1009-948cm)

There is little evidence of aquatic vegetation and low *Pediastrum* values indicating limited internal productivity. One isolated *Myriophyllum spicatum* grain (a species characteristic of Loch Lomond Stadial sites) suggests that this species may have been present. The lack of aquatic vegetation could be due to a combination of factors including a severe climate, lack of suitable habitats and unstable substrates.

LC1 (948-936cm)

In the early Postglacial Llyn Cororion was an open area of deep water sedimenting organic material and yet still receiving a relatively high clastic input, producing a nutrient status able to support high levels of algal production. The algal remains are difficult to interpret as identification was not to species level, but high *Botryococcus* values suggest that competition was at a minimum (cf. Birks, 1970).

Deep water plant communities predominated with limited reedswamp development. Low percentages recorded for reedswamp taxa suggests that the community was sporadic and only just developing, although low percentages may also reflect the central location of the core. *Equisetum* dominated with occasional *Typha latifolia* in shallow waterlogged habitats. *Typha latifolia* is often associated with organic rich waters but is also able to colonise nutrient rich mineral soils

(Grime et al., 1988). Species diversity in the reedswamp appears to have been low although there may have been associated Sparganium species and possibly sedge communities in the drier areas.

The reedswamp is most likely to have dominated as a transition between the sparse willow scrub (section 6.3) and the open water on the south-west and south-east sides of the lake where gradients are shallow and liable to flooding. The northern bank is steeper and would only have accumulated a thin and unstable organic layer, with relatively good drainage. Communities of Pteridium and Calluna would thrive here and high fern frequencies suggest that Dryopteris may have colonised damp patches away from the lake edge.

There is little evidence of a well established floating-leaved community and it is probable that the water was too deep and the basin sides too steep for colonisation. Potamogeton is recorded and may reflect species such as Potamogeton natans in shallower areas, perhaps grading into deeper water species; Potamogeton is able to thrive as a submerged plant and hence is less limited by water depth than floating aquatic species.

Totally submerged deep water taxa dominate the record. Deep water species of Potamogeton may have formed mats close to the substrate in areas of stagnant water, but the pollen record is dominated by Myriophyllum alterniflorum. This possibly reflects the availability of inorganic substrates where Myriophyllum alterniflorum is likely to have thrived in relatively exposed areas. Myriophyllum spicatum also thrived although there is little to suggest that the water was calcareous. Myriophyllum spicatum is characteristic of eutrophic conditions, in contrast to Myriophyllum alterniflorum, and although it can tolerate a wide range of trophic states it is predominantly found in base poor pools (Clapham et al., 1987). The co-existence of the two species is a common feature of early Postglacial lakes and suggests that either there were localised areas of contrasting eutrophic status or that tolerance thresholds have changed over the last few thousand years.

The aquatic record for zone LC1 indicates the beginning of a typical hydroseral succession, as described by Walker, (1970), with submerged taxa dominating and limited development of fringing reedswamp and macrophyte communities.

LC2 (936-860cm)

Concentration calculations show an overall decline in aquatic taxa but within this there is an increase in shallow water species, suggesting two possibilities; the natural development of fringing macrophyte vegetation as part of the hydroseral succession or, lake shallowing resulting in expansion of semi-aquatic vegetation. The former is the most likely as there is no stratigraphic or sedimentological evidence for a decreased lake level.

Deep water communities were reduced with decreases in *Myriophyllum spicatum* and *Myriophyllum alterniflorum*. A reduction in *Myriophyllum alterniflorum* may reflect an intolerance to the increasing organic input. *Potamogeton* was still present but without species determination it is difficult to know if this is attributable to deeper water species. Steady percentages suggest that species diversity has remained relatively constant but it is possible that there was a distribution change with submerged *Potamogeton* species displaced towards the centre of the lake as macrophytes colonised the edges. This is supported by the recovery of a *Potamogeton* fruitstone (fig. 3.3).

There was now colonisation by a rooted floating-leaved community. Occasional occurrences of *Nuphar* and *Nymphaea* reflect the development of limited waterlily associations in shallow water. *Nuphar* is common in nutrient-rich water up to 4m in depth (Schauer, 1982) and would have been associated with taxa such as *Ranunculus* and *Potamogeton*. *Ranunculus* percentages are low but species such as *Ranunculus circinatus* are found in present day lily communities (Bulow-Olsen, 1978).

The macrophyte vegetation would have gradually graded into increasing areas of reedswamp composed predominantly of Equisetum and Sparganium. The reedswamp vegetation composition remained relatively steady since zone LC1 but probably increased in areal extent. Typha latifolia is no longer recorded and, although this does not necessarily indicate its absence, it suggests a decrease in distribution, a reflection of decreasing inorganic input and increased competition from taxa such as Cyperaceae, Equisetum, Mentha type and Sparganium. Sparganium was now colonising muddy substrates in standing water, possibly on the south and east edge of the lake associated with increased carr development. Isolated Sphagnum suggests that areas around the edge of the lake were dry enough for encroachment of moss species.

The aquatic vegetation in zone LC2 represents a natural hydroseral succession and it is not necessary to invoke water level changes to explain vegetation development. A macrophyte assemblage was now developing with the gradual displacement of deeper water communities and the spread of reedswamp assemblages.

LC3 (860-780cm)

The aquatic record indicates increasing hydroseral development with a decrease in deep water taxa as floating leaved macrophytes increased. Algal values are dominated by Pediastrum suggesting that nutrient levels were maintained, but declining Botryococcus indicates a possible increase in competition (cf. Birks, 1970).

Large areas of open water still existed with Chara and Nitella oospores indicating that calcium input was sufficiently high for these taxa to survive. This is supported by the chemical data which indicates increased calcium input during this period. Daphnia and Cristatella statoblast remains are associated with increased coarse organic material; Cristatella is often associated with floating leaved aquatic communities (Birks, 1970).

There is an apparent decrease in species diversity and the submerged aquatic vegetation. Myriophyllum spicatum is eliminated and there are only isolated records of Myriophyllum alterniflorum, possibly reflecting lake shallowing and increased input of organic material. Myriophyllum alterniflorum colonises predominantly inorganic substrates and these would now be scarce as organic sedimentation increased. It is also intolerant of acid conditions so disappearance may signify increasing acidification of the lake.

Potamogeton species in deeper water would have declined as water shallowed and the availability of inorganic substrates reduced. In contrast, there is a slight increase in taxa characteristics of fringing macrophyte communities. Nymphaea dominated, perhaps around the shallow shores to the south and east, interspersed with pondweed species (Potamogeton natans?) and grading into areas of reedswamp and carr vegetation. There was a limited community of water lilies in protected areas of the lake, away from wave action and perhaps interspersed with open water or Potamogeton and Ranunculus species. The limited floating leaved communities may reflect lake basin morphometry. Basin gradient probably prohibited the formation of semi-aquatic and submerged assemblages, leaving much of the shoreline exposed.

Equisetum dominated, probably rooting in highly organic soils in shallow water (Grime et al., 1988), associated with taxa such as Ranunculus and Sparganium although the latter appears to have been limited. Sedge communities may have become established in more open areas and an isolated occurrence of Sphagnum fragments in the pollen washings suggest that moss was invading lake edge communities.

Reedswamp development appears to have been restricted perhaps indicating the lack of water-logged sites. Carr vegetation was probably growing at the water edge and the steep basin sides enabled macrophyte aquatics to develop but with little room for a transitional reedswamp. Reedswamp and marsh may have grown in transitional areas between the northern shore and the carr vegetation to the east and the west, thriving on areas of accumulated organic material that were not yet colonised by shrubs.

The main feature of zone LC3 is the reduction in deep water aquatic communities and the limited development of a fringing waterlily community.

LC4 (780-702cm)

Zone 4 is characterised by low percentages of aquatic taxa, partly a reflection of increased regional and extra-local pollen, but also an indication of the lack of habitats suitable for extensive aquatic communities (cf. Llyn Hendref). *Pediastrum* dominates the algal record and *Botryococcus* is reduced but persisted in low quantities.

Deep water species were now almost absent with the elimination of *Myriophyllum alterniflorum* and *Potamogeton*. The absence of *Potamogeton* may reflect increasing eutrophication of the lake (Grime *et al.*, 1988) but this is difficult to verify in the absence of identification to species level . An isolated count of *Myriophyllum spicatum* suggests that the taxa continued to thrive at the site but with limited distribution.

The fringing aquatic vegetation appears to have been succeeded by reedswamp vegetation possibly resulting from a corresponding displacement of communities outwards. *Nuphar* is totally absent but *Nymphaea alba* percentages increase suggesting gradual lake shallowing and an increase in the organic content of the substrate. *Potamogeton* is absent suggesting that the waterlily community was a monoculture, although *Ranunculus* may have been present. *Daphnia* and *Cristatella* are still recorded but the absence of Characeae or *Nitella* may indicate declining calcium levels. The presence of *Sphagnum* and increased *Equisetum* suggest that, at least locally, lake waters were mildly acidic. Equisetum dominated the emergent aquatic vegetation but Sparganium became increasingly common indicating areas of muddy soils and standing water. Equisetum perhaps now colonised infilled areas previously occupied by shallow water aquatics.

Reedswamp is most likely to have colonised mildly acidic soils on the northern shore. An isolated occurrence of a Juncus (Juncus effusus?)/Carex seed suggests the presence of rushes or the development of sedge tussocks adjacent to the open water. Sphagnum values are slightly increased indicating the colonisation of wetter areas by bog mosses as a component of the acid fen flora.

LC5 (702-460cm)

The aquatic vegetation in zone LC5 verifies water level fluctuations, as suggested by the stratigraphy (section 6.1). Species forming the previously limited broad-leaved aquatic communities appear to have increased with an associated decrease in reedswamp vegetation. Given the morphometry of the basin and the associated vegetational changes it is likely that water levels were raised during this phase resulting in increased shallow water habitats, a drowning of reedswamp communities and displacement of carr vegetation.

Pediastrum values decline but Botryococcus now forms a near continuous curve. Pediastrum absence is often taken to reflect a diminution of eutrophy and increasing acidification (Chambers, 1983). It appears that at Llyn Cororion, although nutrient levels were high enough to support the aquatic community, they dropped below critical levels for algal production. Daphnia and Cristatella remains also decline suggesting that critical factors affecting algal production also had a direct impact on these two taxa. Characeae remains coincide with the maximum calcium concentrations indicating that the lake was still supplied by relatively base-rich ground water.

The reedswamp community had either been displaced, diminished in extent or was no longer effectively recorded within the pollen record. Equisetum persisted but Sparganium appears to have been eliminated. Typha latifolia is able to thrive in nutrient rich peaty water especially on mineral soils (Grime et al., 1988) and its occurrence here may indicate colonisation of the northern shore as lake levels rose. An isolated occurrence of Alisma indicates nutrient rich water; this plant is commonly found associated with reed and sedge communities (Schauer, 1982).

Nuphar and Nymphaea alba formed an increasing waterlily colony that would have probably been prominent on the eastern and southern sides of the lake. The co-existence of both taxa suggests an increase in gently shelving but submerged habits with Nymphaea alba colonising shallower water grading out into Nuphar patches.

Myriophyllum spicatum indicates that a depleted deep water plant community may still have survived offshore; its occurrence coincides with maximum calcium concentrations. Myriophyllum is often associated with base and nutrient rich waters (Seddon, 1972) and it may have co-existed with Potamogeton species such as Potamogeton perfoliatus.

The aquatic record and stratigraphy in zone LC5 supports the idea of an apparently higher lake level and the continued development of the hydroseral sequence. A combination of these two processes provided increased shallow but water-logged habitats.

LC6 (460-324cm)

Zone 6 is characterised by the continued expansion of shallow water communities and the apparent absence of any significant deep water taxa. The pollen washing record and stratigraphic evidence indicates that the carr vegetation extended to the lake edge which was fringed with a lily community. Again, the northern shore probably had limited aquatic vegetation with occasional stands of reedswamp. Organic sedimentation was high but there is evidence of disturbance and increasing mineral input into the lake which may explain higher *Pediastrum* percentages. *Botryococcus* still occurred, apparently unaffected by the increasing macrophyte vegetation.

Equisetum dominated the shallow water communities around the lake edge and *Sparganium* reappears. Increased *Potamogeton* records may be attributable to species associated with waterlogged sites and emergent aquatics. *Nymphaea* and *Nuphar* both have relatively high percentages indicating the continued growth of a floating mat community. *Nuphar* may have been more common away from wave action and was possibly interspersed with open water or associated with taxa such as *Ranunculus* and *Potamogeton*.

Increased *Potamogeton* percentages could indicate the spread of one particular species (eg. *P.pectinatus*) associated with water lily colonies, or it may reflect increasing species. *Daphnia* remains are consistent throughout but the disappearance of Characeae above 400cm may indicate the drying up of a base-rich water supply (cf. Botterill, 1988).

Deep water taxa are largely absent in this zone perhaps reflecting poor pollen production and the swamping effect of tree and shrub pollen. Some *Potamogeton* species may have survived as submerged aquatics but the general absence of submerged aquatics probably reflects gradual lake shallowing and the dominance of fringing macrophytes.

LC7a (324-112cm)

Fringing macrophyte vegetation continued to dominate with an apparent increase in reedswamp communities. These changes are associated with increased records of *Daphnia* and *Cristatella*, and above 200cm, *Juncus* and *Carex* remains are common. Characeae and *Nitella* are no longer recorded indicating calcium poor waters; this is also supported by the chemical data. An increase in the frequency of arthropod remains (fig.

3.3) perhaps suggests a more active and diverse fauna in and around the lake. Algal values are low and sporadic with decreased Pediastrum percentages although Botryococcus frequencies increase slightly.

Reedswamp appears to have spread with increasing values of Equisetum and Potamogeton, perhaps related to an increased nutrient supply. Values are highest above the point at which the first cereal grain is recorded and where mineral input permanently increases. The macrophyte vegetation probably colonised increasingly larger areas and reedswamp built out over accumulating organic debris. Sedges and Equisetum stood in perennial water with aerial shoots and leaves, and colonisation was encouraged by the trapping of mineral material in the fringing vegetation. Alisma was present, possibly associated with patches of sedge.

Floating leaved macrophytes were dominated by Nymphaea and sporadic Nuphar. The pollen and spore record suggests that perhaps a minor fluctuation in lake level occurred at around 25cm (800 BP). Up to this point reedswamp vegetation dominated indicating shallower water but above this there is a significant increase in Nymphaea coinciding with declining Equisetum and Potamogeton.

The stratigraphy and pollen washings indicate diminishing deposition of coarse organic detritus and this, together with the aquatic record, suggests a slight lake level rise resulting in increased waterlily communities, with reedswamp able to survive in isolated localities. The probable rise in water level coincides with the point at which progressive deforestation begins, and erosion of organic soils is indicated by increases in indeterminable grains.

LC7b (112-048cm)

Taxa diversity remained the same in this zone but the pattern of dominance changed. The zone is characterised by large percentages (55%) of Pediastrum and increased Botryococcus.

Deforestation continued and effective erosion resulted in increased mineral input, and hence nutrient replenishment, within the lake. The data suggest that eutrophication was high resulting in increased internal productivity; Polygonum is often indicative of eutrophication and is present at Llyn Cororion at this time. Reedswamp persisted with increased Sparganium perhaps forming monocultural colonies which thrived as mineral input increased. Juncus seeds indicate that rushes were now common around the lake edge, associated with increased sedge communities and Alisma. Equisetum declined but Mentha was now present and may have included the species M.aquatica, common in reedbeds and communities of large sedges. Macrophytes persisted but concentration curves show a reduced community and a gradual shallowing after the raised water levels of zone LC7a. Nymphaea dominated but Nuphar was also present. Decreasing Potamogeton may have been a response to increased eutrophication.

LC8 (048-000cm)

The general characteristics of zone LC8 are of a continued decrease in taxa diversity and a decline in the areal extent of macrophyte vegetation. Open water persisted but the lake area was probably reduced by the growth of fringing aquatics and reedswamp. Increased Cristatella remains indicate the importance of the macrophyte vegetation, and Juncus and Carex seeds signify the presence of reedswamp. Algal concentrations decline with negligible records of Botryococcus and sporadic frequencies of Pediastrum. This is associated with maximum mineral input into the lake and theoretically a high nutrient availability; it therefore appears that some other factor (disturbance, silting or competition) was limiting internal productivity during this time.

The stratigraphy suggests that water levels were relatively stable and the decrease in coarse organics (eg. Betula remains, Dryopteris sporangia) may be a reflection of a recedence of carr vegetation and not of deepening water. There is no evidence of a thriving deep water community although some species of Potamogeton and Sparganium may have colonised areas beyond the semi-submerged vegetation.

Nymphaea dominated the floating leaved community and Nuphar values are low, the latter perhaps grading into or interspersed with reedswamp. Equisetum and Sparganium values are reduced, indicating either decreased representation in the pollen record or a real reduction in extent. Reedswamp was probably now restricted to more inorganic localities towards the western and northern shorelines where competition was minimal.

Ranunculus may have occupied areas of fluctuating water levels and Juncus appear to have become more important, probably associated with boggy areas between the carr and lake. Increased Cyperaceae values may in part be attributable to sedge tussocks in areas of perennial water (eg. Carex paniculata). Sphagnum may have occupied damp pools within the fen (eg. Sphagnum palustre) or formed part of the aquatic vegetation (eg. Sphagnum subsecundum). Increased Potamogeton percentages may reflect the presence of pondweed in wet areas and pools on the carr floor.

6.3 LLYN CORORION : VEGETATION HISTORY

LCA (1009-963cm)

Pollen counts from the basal minerogenics are presented in table 3.6a. Pollen sums and concentrations are low and there is evidence that much pollen is reworked. Basal gravels were not sampled but the clays beneath contained relatively well preserved pollen and eight samples were taken between 963 cm and 1009 cm. It is not possible to estimate their age range as sedimentation rates are impossible to calculate in the absence of radiocarbon dating (section 6.1). A comparison with Llyn Hendref suggests that zone LCA is equivalent with the upper portion of LHA.

There is a high background component of regional pollen input and the high percentages of indeterminable grains, predominantly crumpled and broken, are indicative of reworked and secondary pollen derived from the catchment (cf. Walker, 1982b). Deteriorated pollen frequencies reduce towards the clay/gravel transition reflecting increased concentrations of local pollen.

The presence of pre-Quaternary spores indicates either aeolian activity and/or derivation from local till (section 3.7.4), with maximum percentages coinciding with high indeterminable input. The organic content of the clays is low (<5%) and it is possible that this is derived or is indicative of initial vegetation colonisation around the lake. Low pollen concentrations suggest that if there was a vegetation cover, it was sparse and ineffective at stabilising the soils.

Pinus percentages are high (74% at 970 cm), over-emphasised by its effective dispersal, the open landscape and the lack of local pollen input. Concentrations are low and can be attributed to a long-distance windblown component. The interplay between Betula and Pinus values illustrates how the pollen source area fluctuates depending on local input. Alnus, Quercus and Corylus were also windblown components; the relatively high percentages are misleading and concentrations indicate that the landscape was largely unvegetated.

Betula, Salix and Juniperus are all recorded, the latter two only in the uppermost sample. Some Betula pollen may have been windblown, but it is possible dwarf shrubs survived the Loch Lomond Stadial at Llyn Cororion. The presence of Betula nana macrofossils recorded in the early Postglacial sediments (fig. 3.3) indicate that this species did occur, and was likely to have been present at the site during the Loch Lomond Stadial. It is also possible that Salix herbacea survived as occasional stands with Juniperus scrub in more sheltered locations.

The herbaceous record is similar to that identified at Llyn Hendref (section 7.3) and abundance is over-estimated by the inherent problems of percentage diagrams. Concentration results indicate low pollen input and the assemblage is indicative of tundra vegetation; a sparse and transient cover of pioneering herbs characterised by shade and competition intolerant taxa (eg. Caryophyllaceae Chenopodiaceae, Rumex acetosa and Artemisia). Rumex acetosa is an early coloniser of raw substrates, thriving in the absence of competition, and Artemisia survives on frost disturbed mineral soils or in well drained rocky substrates (Grime et al., 1988). Gramineae and Cyperaceae pollen values are relatively high but have a wide range of ecological tolerances which limits interpretation. Isolated Solidago type, Trifolium and Cruciferae suggests occasional patches of grassland with Rumex species and Pteridium.

Fern counts are initially high but decrease towards the zone top and Lycopodium spores (undifferentiated) could possibly represent Lycopodium selago. Absolute herb values are low indicating an essentially bare landscape with occasional patches of early pioneering elements. Other taxa present included Rosaceae undiff., Leguminosae and Filipendula but without greater taxonomic definition it is difficult to indicate potential habitats. The herbaceous assemblage is similar to that described from Glanllynnau (Simpkins 1974) and also to the communities described by Tipping (1988) in western Scotland. The basal pollen records at the latter site were dominated by pollen types interpreted as being derived from long distance transport and deposited in Loch Lomond age sediments.

An equivalent zone to zone LHB at Llyn Hendref, showing an expanding vegetational community and a gradual increase in the organic content, is not represented at Llyn Cororion. The transition between the Loch Lomond Stadial sediments and the Postglacial is abrupt at Llyn Cororion, possibly because the pollen record of the transitional vegetational phase has been 'lost' into the permeable gravel. The early Postglacial sequence at Llyn Cororion indicates that the landscape was already vegetated at the onset of organic sedimentation, with

Betula, Juniperus and Salix established. The transition between the relatively bare landscape and the pioneering vegetation was probably similar to that recorded at Llyn Hendref with increasing patches of scrub Betula and Juniperus around the site and Salix colonising wetter sites.

LC1 (948-936cm)

Zone 1 is a period of increasing organic sedimentation and undisturbed deposition within the lake. Open areas and thinly covered mineral soils were subject to erosion and high solifluction rates, as indicated by the loss-on-ignition results. The zone is characterised by a short-lived Juniperus expansion followed by a Betula peak.

The nature of the Juniperus rise at Llyn Cororion is not recorded, but as Juniperus appears to have been present in the Loch Lomond Stadial, it is likely that it responded to the rising temperatures in the early Postglacial, resulting in local population expansion. Previously stunted individuals, suppressed by a more severe climate, were now able to flower freely and as the substrate gradually stabilised, Juniperus was able to thrive on the base rich skeletal soils encouraged by the absence of competition.

The presence of Juniperus nana has not been verified but it is possible it survived through the Loch Lomond Stadial on stony ground or north facing slopes (cf. Walker, 1982b). In the early Postglacial it was probably quickly succeeded by Juniperus communis which was able to tolerate a wide range of soil conditions (Tipping, 1987) but avoided wetter areas. High concentrations suggest it was a major component of the vegetation. Juniperus tends to be under-represented in pollen diagrams and the values recorded at Llyn Cororion, up to 36%, indicate local Juniperus thickets and the spread of tall flowering Juniperus throughout the catchment. Growth was perhaps encouraged by relatively good drainage, the sheltered locality, stabilising soils and the slow expansion of Betula.

The *Juniperus* frequencies recorded at Llyn Cororion are uncharacteristic for a lowland site (cf. Glanllynnau, Simpkins, 1974; Tre'r Gof, Botterill, 1988; Llyn Hendref, this study) and are more reminiscent of higher altitude sites in Snowdonia (eg. Seddon, 1962, Crabtree, 1971). A comparable site is Llyn Llydaw (Ince, 1981) which has a rapid *Juniperus* rise to 40%. High values are generally interpreted as a response to a climatic amelioration (Birks, 1973) but Ince (1981) concluded that edaphic and migrational factors were as important in influencing *Juniperus* establishment. The *Juniperus* success at Llyn Cororion was a local phenomena and supports Walker's (1982b) contention that *Juniperus* distribution in the early Postglacial was not altitudinally controlled and that other influences, such as aspect, exposure and ground wetness, were more important.

Juniperus was therefore a dominant component of the early Postglacial vegetation at Llyn Cororion but the high herb percentages (average 36%) and continual mineral input indicate that much of the landscape was still open. Associated with the *Juniperus* scrub may have been a rich field layer of taxa characteristic of thin soils and heathland. *Salix* frequencies increase but the concentration diagram suggests that it only thrived after the *Juniperus* decline. *Salix herbacea* probably survived the Loch Lomond stadial at Llyn Cororion; macrofossils have been identified at Nant Ffrancon (Burrows, 1974) where it initially co-existed with the *Juniperus* scrub until succeeded by tree willow.

The *Salix* rise is not recorded at the site but it appears that expansion was rapid, colonising areas adjacent to the site resulting in increased local pollen input and *Salix* over-representation in the pollen diagram. *Salix* has fast growing seedlings (Grime *et al.*, 1988) which here were apparently uninhibited by edaphic conditions. Seedlings may also have colonised small patches of moist soil on the plateaux interspersed with *Juniperus* scrub. The regional role of *Salix* is obscure but it is unlikely that it formed a dominant component of the regional vegetation. Values of up to 16% and

Salix leaves in the sediment (fig. 3.3) suggest it dominated in the immediate vicinity of the lake. Mature trees would have been restricted to lakeside habitats colonising wet soils at the water edge, and avoiding perennial water and dry gravelly soils.

A high diversity of ferns were able to root in the increasingly organic substratum. Pteridophytes were common with increased values of *Filicales* and the occurrence of fern sporangia indicate abundant *Dryopteris*. Cyperaceae and Gramineae thrived and sedge tussocks and *Sphagnum* may have grown in the wetter areas gradually grading into marginal reedswamp. Tall herb communities persisted in open, drier localities; *Filipendula* (6.4%) was abundant, thriving on damp marshy ground, associated with taxa such as *Ranunculus* (*repens*?) and Rubiaceae (*Galium*?).

The *Betula* increase in zone LC1 is recorded in both the percentage (from 14% to 64%) and concentration diagrams and reflects the establishment of birch populations around the site. *Betula* is likely to have persisted through the Loch Lomond Stadial-Postglacial transition, and the presence of *Betula nana* is confirmed by macrofossil remains. Scrub birch was probably quickly suppressed by tree birch, but still persisted in marginal habitats such as exposed sites on hillsides or on thin stony soils.

Betula is a pioneering species with shade intolerant seedlings, a low warmth requirement and an ability to reach maturity quickly (Grime *et al*., 1988). At Llyn Cororion the rise in *Betula* appears to have been slower than that of *Juniperus*; it may have required a certain level of soil maturity (organic content) or stability (Birks, 1989), and was therefore initially limited by pedogenic factors. The delay may also have been due to migrational factors. *Betula* is over-represented in pollen diagrams due to both high productivity and efficient dispersal, and the open landscape and presence of local *Betula* increases this further. Theoretically values of >25% have to be obtained before local dominance can be suggested and only at 50% can a birch dominated landscape on a regional scale be inferred (Huntley and Birks, 1983).

Initial values of 14% indicate that Betula was restricted to local stands in a landscape dominated by Juniperus. Once edaphic conditions passed a critical threshold, Betula was able to expand, uninhibited by climate or competition; the Juniperus scrub was open and offered little resistance to the incoming Betula population.

Betula became a dominant part of the vegetation, expanding from isolated populations and gradually increasing in regional importance. The Juniperus scrub was seriously affected, suppressed to a poorly flowering understorey shrub or to isolated stands in marginal habitats.The spread of Betula was extensive but canopy density is likely to have been thin with no areas of closed woodland. The landscape was still open with a pollen source area dominated by extra-local and local sources. Low values of Quercus, Ulmus, Corylus and Pinus are all believed to be 'exotic' to this site with percentages too low to indicate their local presence.

A slight recovery in Juniperus percentages (3%), associated with a Betula decrease, demonstrates that Juniperus persisted locally, flowering more frequently when there was a reduction in canopy density. The success of Betula in outcompeting Juniperus (cf. Tre'r Gof, Botterill, 1988) at this site may have been partially due to fire. Charcoal is associated with the Juniperus decline, suggesting infrequent fires within the catchment which may have cleared Juniperus scrub, allowing further Betula colonisation. Juniperus was unable to regenerate under the increased shading and gradually disappeared from local sites.

Salix concentration values indicate that initially Betula had little influence on the carr vegetation. Their habitats may have been mutually exclusive, but it is also possible that Betula (pubescens?) was able to invade the drier areas of the carr without adversely affecting the Salix community. Betula may have been more successful on the better drained soils to the west and north of the lake whilst Salix remained dominant in wetter areas.

Herb percentages (36%) and loss-on-ignition results (mineral input 30%) indicate that there were still large areas of raw soils, bare drift and stony habitats. Slope processes and ground disturbance were still active although erosion efficiency was decreasing as soils stabilised. Soil inwashing persisted with deposition of corroded and degraded grains. Isolated grains of Ilex may be derived from till material as it is unusual for it to be recorded so early in the Postglacial. Many of the taxa recorded in the Loch Lomond Stadial persist, implying continuing substrate instability and disturbance (Artemisia, Rubiaceae) and also the persistence of open sites (Thalictrum, Lycopodium).

Artemisia, indicative of solifluction process and intolerant of competition, was probably associated with Achillea type, typical of rocky ground and well drained slightly acidic soils in open environments (Grime et al., 1988). Rumex undiff. indicates the increasing organic content of the soils, forming patches of tall herbs in unshaded sites (Grime et al., 1988), possibly associated with species such as Plantago lanceolata. Plantago lanceolata is indicative of disturbed and open grassland and is shade tolerant.

Within the birch woodland a thin layer of litter would have been gradually accumulating providing a substrate for Pteridophytes and Bryophytes. In damper areas Dryopteris and Filicales thrived, although these may also have been within the carr vegetation, and in drier areas Calluna vulgaris and Ericales grew on gravelly or sandy soils. The latter two are poorly represented in pollen diagrams (Birks, 1973) but the extremely low percentages suggest a sparse and low diversity understorey.

Epilobium type, Plantago undiff., Cruciferae and Compositae Liguliflorae could have been associated with either the

Juniperus/Betula scrub or the Salix carr. Taxa indicative of fresh unstable soils (eg. Artemisia) exist alongside those associated with an increasing humus content within the soil (eg. Filicales, Filipendula) indicating a wide diversity of habitats and the co-existence of taxa with contrasting ecological affinities.

Many of the herbs (eg. Trifolium, Gramineae, Achillea type) have increased percentages at 944 cm which is associated with high charcoal frequencies, suggesting fire disturbance. Mineral soils appear not to have been disturbed but opportunistic herbaceous taxa were quick to colonise areas previously inhabited by Juniperus. It is interesting to note that there is an increase in Corylus at this stratigraphic horizon, but the values are too low to ascertain its presence within the basin. The increased values may be a reflection of the opening up of the canopy and enhanced representation of the regional pollen component.

LC2 (936-860cm)

The loss-on-ignition results and sedimentological data indicate that raw mineral soils were no longer exposed and there was a contraction of open habitats, with the percentage diagram indicating increased vegetation cover (trees and shrubs average 77%). The concentration and influx data indicate that despite an increase in tree taxa canopy cover was still relatively open. Zone LC2 is characterised by the continuing expansion of Betula and the introduction of Corylus.

Betula percentages continue to rise rapidly with a maximum of 81% at approximately 9350 BP but the concentration diagram indicates that the rise is an artifact, with the large changes induced by varying frequencies of other taxa; maximum Betula concentrations are reached at the zone top. Betula nana was still present, as indicated by the macrofossil record, and Betula pendula and Betula pubescens may have both occurred occupying different ecological niches.

Betula woodland appears to have spread through the catchment encouraged by the open scrub which offered no resistance to colonisation. Percentage values are high enough to indicate that birch dominated both locally and regionally. Betula woodland would have extended over the coastal plateau and up into sheltered hillside localities, but Betula fruits verify the invasion of local habitats by tree birch and many minor fluctuations in the percentage record may reflect differences in the pollen productivity of local populations. Birch would have been effective at increasing soil stability, and mull humus continued to accumulate on the sandy soils within the catchment. The open Betula woodland dominated the area for the next 600 years, only disturbed by occasional forest fires.

Associated with the Betula spread was the continued reduction in Juniperus values. Initially Juniperus was reduced to an understorey shrub (percentages are <1%) and displaced to marginal habitats perhaps surviving on thin soils on higher ground to the east. The stony shore to the north may have provided a suitable habitat. Juniperus was finally eliminated from the catchment by increased canopy cover and competition associated with the expansion of Corylus.

Corylus records initial low values (1.5%) but then rises rapidly to 29% over 150 years. The empirical limit has been dated at 9365+/-70 BP with a rational limit at 9215 BP. Corylus is over-represented in pollen diagrams, although pollen representation does depend on woodland structure, and so the initial low values could represent a windblown component or possibly small localised populations (cf. Bennett, 1983b) with the rapid increase in frequencies reflecting expansion. At Llyn Cororion, Corylus expanded unrestrained by climate or edaphic conditions and quickly colonised fertile mull humus soils. The Betula woodland was open and Corylus was able to flourish under the light shade with little competition, and perhaps replaced small areas of Salix and eliminated the sparse Juniperus population.

It is interesting to note that high charcoal frequencies are associated with the _Corylus_ rise at Llyn Cororion. The role of Mesolithic man in enhancing hazel growth has been questioned (Smith, 1970), but at Llyn Cororion there is no archaeological evidence to suggest Mesolithic man colonised this area. Fire frequency was increased between 9600 BP and 9100 BP with an associated increase in sand input into the lake, suggesting soil disturbance. The cause of the disturbance is not known but is appears to have favoured the expansion of _Corylus_ and possibly also _Sorbus aucuparia_ and _Viburnum_.

The presence of _Sorbus aucuparia_ and _Viburnum_ indicate that the forest was relatively open, or that gaps, perhaps created by fire, were relatively common. _Sorbus aucuparia_ has a low pollen representation, so it is difficult to ascertain its importance, but it is indifferent to soil types and is light demanding (Clapham _et al._, 1987) and often associated with _Betula_ on north facing slopes (Grime _et al._, 1988). _Viburnum_ appears to have been associated with _Corylus_ and probably occurred on the damp soils within the woodland.

Quercus values increase in zone LC2 to produce a continuous curve, but percentages remain below 1% except for an isolated count of 6% at 912 cm. Generally the values are too low to indicate a local population but the isolated high suggests that occasional trees may have existed within the pollen source area but were prevented from expanding by the rapid spread of _Corylus_. _Ulmus_ and _Alnus_ frequencies are low and suggest a windblown component.

A reduction in herb frequencies reflects a restriction in open spaces, but a diverse community still existed either as an understorey component, or in open habitats associated with woodland margins or fire disturbance. The woodland probably had occasional _Juniperus_ scrub, until its elimination by _Corylus_, and possibly _Salix_ bushes forming a shrub layer with a ground layer of Bryophytes and Pteridophytes. _Pteridium_ is recorded but there are decreases in Filicales and _Dryopteris_.

Ericales and _Calluna_ frequencies decline reflecting the increased canopy cover and ineffective pollen dispersal in closed forests. Increased _Potentilla_ suggests an increase of undisturbed habitats and shading (Grime _et al._, 1988) although herbs of disturbed ground still persist. _Artemisia_, Caryophyllaceae, Cruciferae and Chenopodiaceae were present but with reduced concentrations and shade intolerant taxa were also decreased (Rubiaceae, _Thalictrum_). Reduced _Plantago_ undiff. and _Rumex_ undiff. indicate a decrease in the extent of open grassy areas.

The carr vegetation remained relatively constant with a slight adjustment between _Betula_, _Corylus_ and _Salix_. An initial decrease in _Salix_ frequencies associated with the _Betula_ percentages may not be due to a decrease in vegetation representation, as Birks (1973) notes that the representation of _Salix_ decreases when it co-exists with _Betula_ in a carr community. Willow thickets persisted in wetter areas, and the presence of _Betula_ macrofossils indicate that birch thrived up to the lake edge, perhaps on the northern shoreline. The understorey would have been dominated by Cyperaceae, _Ranunculus_ and tall herb communities of _Filipendula_ and _Succisa pratensis_. The latter species is characteristic of unshaded, moist soils with a minimum of exposed mineral material (Grime _et al._, 1988). _Ribes_ and _Geum_ are also recorded.

LC3 (860-780)

The stratigraphy and loss-on-ignition data indicate continued organic deposition but reduced sedimentation rates and mineral input. This suggests increased productivity within the catchment, with contraction of open habitats and an increasingly stabilised landscape. Soils matured under a predominantly birch forest with the development of fertile brown earth soils over much of the plateau area. Thinner soils would have been more common on higher ground and around the lake edge. The soil now provided an ideal substrate for the invasion of temperate deciduous tree taxa and zone LC3 is characterised by the expansion of Corylus, Quercus and Ulmus.

Average shrub frequencies increase (from 15% to 51%) reflecting the dominance of Corylus within this zone. With the progressive immigration and expansion of a number of tree types there was now increasing competition for resources and space which began to influence species distribution. Tree cover was now extensive and low herb percentages (6%) suggest relatively dense woodland throughout the catchment. Some herbs persisted as understorey taxa or in occasional gaps on the woodland margin.

Corylus was the first shade tolerant shrub to expand and attain dominance. The site was sheltered with relatively unleached soils and the open birch woodland (described in zone LC2) offered little resistance to the expansion of hazel. Corylus has shade tolerant seedlings (Grime et al., 1988) which were able to flourish under the thin birch canopy, compete successfully and quickly become the dominant taxa on rich sandy soils. From the charcoal record it appears that the dominance of Corylus was not associated with high fire frequency (cf. Smith, 1970) and was therefore not a fire climax feature. During the Corylus maximum there are minimum charcoal counts suggesting that if fire facilitated establishment, it was not necessary for continued expansion. Maximum percentages of 73% indicate that Corylus woodland prevailed both regionally and locally for the next 500 years.

The initial Corylus invasion resulted in a decrease in Betula percentages and concentrations but then values of the latter recover to 30% as the two taxa existed in semi-equilibrium. Betula was therefore initially suppressed (15%) by the Corylus invasion, as its shade intolerant seedlings were unable to compete with the rapidly increasing canopy. Corylus was able to compete for the rich fertile sites on the coastal plain and Betula was restricted to marginal habitats with thin poorer soils. Birch macrofossils (fruit and leaf fragments) found within the sediment indicate the presence of Betula within the carr vegetation, growing up to the lake edge, co-existing with

Salix.

Zone LC3 is also characteristic by the expansion and establishment of Ulmus and Quercus. Quercus was possibly present at isolated localities before the Corylus expansion (see zone LC2), and the percentage diagram suggests a gradual and smooth rise from 8660+/-65 BP throughout zone LC3 with a time lag of 740 years between the empirical and rational limits. Concentration values suggest a more rapid rise.

Quercus is over-represented in pollen diagrams (Bradshaw, 1981a) producing twice as much pollen as Ulmus; only values of over 10% can be taken as indicative of regional significance (Huntley and Birks, 1983). At Llyn Cororion, small local populations existed from 8660+/-65 BP and then an increase in pollen frequencies to 8% suggests limited expansion but not enough for Quercus to become regionally significant.

Quercus appears to have become locally established as a minor component of the vegetation but expansion throughout the catchment was delayed. This could have been due to a number of factors including competition from Corylus and Ulmus, slow growth rate, the length of time to reach maturity (first seeds are produced after 40 years; Grime et al., 1988) and shade intolerant seedlings. These made it difficult for Quercus to compete with the rapidly spreading Corylus woodland, which allowed little space for invasion and shaded out Quercus seedlings.

It was not possible to separate Quercus into species palynologically and it is possible that both Quercus petraea and Quercus robur were present. Rackham (1980) states that Quercus petraea is the most common oak species in ancient woodland. Quercus petraea favours well drained slightly acidic soils and may have competed successfully with Corylus which shows an immediate concentration decline as Quercus expands. Corylus percentages remain at 40%, so it was still important in the canopy and co-existed with occasional patches of oak woodland. Betula also appears to have declined, perhaps as a result of Quercus competition on the edges of the carr.

The Ulmus empirical limit is later (8845+/-70 BP) than that of Quercus (approximately 9000 BP), but expansion appears to have been faster with the difference between the empirical limit and maximum percentages estimated at around 250 years. Occasional counts below the empirical limit are taken as indicating a windblown component and the Ulmus rise coincides with the rapid Corylus expansion. Corylus was already established, and it appears to have offered little resistance to the subsequent establishment of Ulmus.

Ulmus seedlings are shade tolerant, able to thrive under a canopy and are successful at colonising sites with clay-rich soils (Huntley and Birks, 1983). Ulmus is under-represented due to poor dispersal. Low percentages are therefore significant with 2% indicating local Ulmus and percentages over 10% suggesting it was a significant component of the vegetation (Huntley and Birks, 1983); 6% is the maximum value recorded at Llyn Cororion.

Ulmus was initially established as a local population but it expanded and increased in importance within the woodland. It was probably never a dominant canopy species and the evidence suggests it occupied an exclusive niche rather than being dispersed throughout the woodland. The concentration data shows that once Ulmus was established it occupied a restricted niche with little interaction with other taxa; it was not affected by new incoming taxa but neither did it expand further.

Shrubs within the catchment include Viburnum (associated with the Corylus rise), Sorbus aucuparia and Hedera helix (increasing as Quercus percentages rise). Hedera helix tends to flower only in unshaded habitats and isolated occurrences in zone LC2 suggest perhaps that it was a component of the woodland but that flowering was suppressed by the shade. An increase in oak may have opened up gaps within the forest or cast a lighter shade, encouraging Hedera helix to flourish.

The increase in Quercus appears to have encouraged a diverse understorey with the spread of Solidago type, Rubus and Calluna vulgaris. Gramineae values are steady and Lonicera was more common probably occurring either as a free flowering woody climber in more open areas or as a prostrate non flowering shrub under woodlands away from bare soils and disturbance. Taxa indicative of disturbed soils are reduced with only isolated counts of Artemisia, Chenopodiaceae, Caryophyllaceae and Plantago.

Salix concentrations are only slightly reduced by the Corylus expansion and values then remain steady suggesting little interaction between the two taxa. Corylus may have formed isolated patches within the carr, perhaps occupying drier richer soils, but Salix thickets continued to dominate the carr vegetation colonising an exclusive niche which other tree taxa were unable to invade. The carr understorey consisted of taxa such as Filipendula, Caltha type, Ranunculus undiff., Rubiaceae, Urtica and Melampyrum.

LC4 (780-702cm)

There is an overall increase in tree and shrub percentages (trees average at 70%) indicating maximum tree cover for the Postglacial. The spore and herb frequencies are low, between 1% and 6%, reflecting a restriction of open habitats, and there is evidence that fire may have had an important impact on vegetation. Concentration and influx values are at a maximum, a reflection of the dense forest cover and the dominance of Pinus, a high pollen producer.

Quercus percentages reach maximum values (28%) indicating that except for a short period around 8000 BP, it was now an important component of the local and regional vegetation. Quercus petraea is a shade tolerant species (Grime et al., 1988) and it is possible that local populations replaced Betula around the edges of the carr and then, once established, it was able to compete successfully for the more fertile sites along the coastal plateau. These trees can grow to 30m in height, and although the shade they cast is not heavy, it appears to have been enough to prevent the successful regeneration of Betula. Both species of oak may have been present with Quercus robur outcompeting Corylus on the sandy moist soils of the plateau, and Quercus petraea competing with Betula on the carr margins.

Ulmus values fluctuate between 2% and 6% but concentrations are relatively steady. Elm continued to be locally dominant with its status unaffected by the Quercus and Pinus expansions suggesting that it formed almost pure Ulmus woodland. This distribution may have been controlled edaphically, with Ulmus occupying deeper fertile soils and Quercus restricted to poorer damper sites. Once established Ulmus does not appear to have expanded further, suggesting that perhaps it was limited by competition or local soil conditions. There is a slight reduction in Ulmus concentrations associated with the rise in Quercus values but interaction between the two appears to have been minimal with Ulmus continuing to thrive in an exclusive niche.

The major event in this zone is the introduction, establishment and dominance of Pinus. Percentage values for Pinus are difficult to interpret as the pollen is produced in large quantities and is effectively dispersed over wide areas (Godwin, 1975) resulting in over-representation in pollen diagrams (Bradshaw, 1981a). Bennett (1984) pointed out the difficulties in interpreting low Pinus frequencies which could be attributable to a long-distance component or to small, local populations. In the absence of macrofossil evidence, low percentages tend to indicate the absence or scarcity of Pinus trees (Bennett, 1984) and Bradshaw and Browne (1987) illustrate that counts of 20% may occur with no Pinus within the pollen source area. Huntley and Birks (1983) suggest that values >25% can be taken to indicate the local presence of Pinus with frequencies of greater than 50% needed before local dominance can be assumed.

At Llyn Cororion, *Pinus* pollen percentages show a rapid rise after 8425BP from 5% to 50% within 400 years. Values then drop to 13% at around 7900 BP suggesting a drastic decrease in distribution, but it becomes dominant again with frequencies of 65%. The concentration data records the same pattern and illustrates the rapid and apparently uninhibited expansion of *Pinus* from a small isolated population to a taxon that dominated the local vegetation.

Due to migrational differences, both *Quercus* and *Ulmus* had already arrived at the site and established before *Pinus* was present. The situation at Llyn Cororion is similar to that described for Lonsdale (Lake District) where *Pinus* peaks after *Quercus* and *Ulmus* (Oldfield, 1960). Despite the presence of well established mixed deciduous woodland, *Pinus* appears to have had little trouble colonising the local area. It is difficult to envisage *Pinus* invading the temperate woodland without initial disturbance as its seedlings are light demanding (Carlisle and Brown, 1968) but the high percentages indicate that it was more than just an occasional tree colonising gaps.

It is interesting to note that during the rapid *Pinus* increase there was a high incidence of fire within the catchment. At 772cm (around 8350 BP) *Pinus* frequencies rise from 1% to 33% with an associated charcoal increase and significant reductions in *Betula*, *Ulmus*, *Quercus* and *Corylus* pollen. There are increased records for *Calluna vulgaris*, *Hedera helix*, Gramineae and *Pediastrum*. After this phase of burning it appears that *Quercus* and *Corylus* were unable to recover but that *Betula* was able to regenerate as secondary woodland along with *Fraxinus*. *Fraxinus* has increased frequencies at the zone base which coincides with an increase in the fire frequency.

Other factors may have been instrumental in the establishment of *Pinus*. It is possible that in some marginal habitats, susceptible to flushing and leaching, an acidic substrate had developed upon which _Quercus_ and _Corylus_ were unable to compete. _Corylus_ is essentially a base demanding taxon and increasing acidity would have reduced its ability to compete as a canopy species. Increases in _Calluna vulgaris_, which now has a continuous curve and _Pteridium_ and _Sphagnum_ indicate that in some areas soils were becoming increasingly acidic.

Pinus establishment may also have been encouraged on the thinner soils to the north or on areas created by the progressive expansion of reedswamp and mire. The slight _Betula_ increase associated with _Pinus_ may indicate that the habitat supporting _Pinus_ was also capable of colonisation by _Betula_. A fall in lake levels is often used to explain the expansion of _Pinus_ into an area (Oldfield, 1965), with _Pinus_ occupying areas of dried fen and carr. At Llyn Cororion there is no stratigraphic evidence or indication from aquatic taxa that there were significant water level changes other than minor adjustments associated with the developing hydrosere. A gradual shallowing of the lake is suggested by the aquatic record, with a decrease in the deeper water species and an increase in the reedswamp and fen vegetation. It is therefore possible there was progressive drying out of the carr which was then colonised by first _Betula_ and then _Pinus_.

There are a number of possible explanations for the success of _Pinus_ at this site. These are all interlinked; the coincidence of fire, rapid vegetational change and possible interference by man make it difficult to establish the dominant influence. The occurrence of fire alters the hydrology and drainage on a local scale and indirectly influences soil development. Fire created gaps which may have encouraged _Pinus_ establishment. A combination of factors including fire, disturbance, natural soil regression and changing water levels may have opened up a number of habitats that were previously unavailable or were now not suitable for colonisation by other tree taxa.

The Postglacial *Pinus* peak (65%) was reached at 7800 BP with a corresponding low in *Quercus* and *Corylus*. *Pinus* was locally dominant, and a comparison with other lowland sites in north and west Wales (eg. Gwarllyn, Moore, 1973; Cors Gyfelog Botterill , 1988) shows that high pine frequencies are a local feature and that it never formed part of the regional vegetation. For much of the region *Pinus* was absent, unable to compete with the thick mixed oak woodland. Moore (1972b) suggests that the local differentiation of *Pinus* frequencies was perhaps controlled by edaphic variation rather than climatic factors.

Pinus appears to have been susceptible to fire damage with its importance reduced at around 7900 BP. Associated with this is increased charcoal abundance including coarse charcoal fragments in the pollen washings, and *Quercus*, *Ulmus* and *Betula* increases. *Corylus* declines, but fen vegetation increases with a rise in *Salix*, *Filipendula*, *Osmunda* and *Sphagnum*, and herbs such as *Solidago* type and Compositae Tubuliflorae suggest forest clearing. Increased carr vegetation may have been related to increased waterlogging, possibly a direct result of burning of predominantly *Pinus* woodland resulting in reduced canopy cover. This phase of forest disturbance appears to have been short-lived and *Corylus* and *Pinus* recover and re-invade their previous habitats.

Betula and *Corylus* declined in importance and now only occurred as occasional canopy species or formed part of the understorey shrub layer in the oak woodland. *Betula pendula* would have been more common on the hillside to the east of the lake and *Betula pubescens* would have thrived in damper areas around the lake; the local presence of *Betula* is suggested by macrofossil remains. The percentages, initially 30% then decreasing to 15%, suggest that it was reduced from a locally dominant taxa to sporadic occurrences.

Corylus concentrations show a steady decline as *Pinus* rises, and frequencies fall from 30% to 18% indicating that the status of *Corylus* changed as a result of *Pinus* immigration; it was now no longer the dominant taxa within the woodland and was reduced to a scrub forming species in marginal areas with pollen production and dispersal inhibited by the closed forest. Associated with the *Corylus* decline is a reduction in *Viburnum*, suggesting that they occupied similar habitats although the relationship between the two taxa is not known.

Corylus does not show a direct relationship with charcoal frequencies and whilst at some levels (eg. 772cm, 756cm) it appears that *Corylus* was damaged and its distribution reduced by fire, at other times it was apparently enhanced by the increased fire frequency. The relationship between fire and the status of *Corylus* within the catchment is therefore not direct and other factors were influencing the behaviour of hazel.

The presence of *Fraxinus* and *Sorbus aucuparia* may be indicative of windthrow gaps or growth on forest margins. Increasing *Fraxinus* coincides with the *Quercus* rise and may reflect a thinner canopy and increased light associated with the spread of the oak forest. *Fraxinus* seedlings are sensitive to shade (Grime *et al.*, 1988) but once saplings have penetrated the field-layer, mature trees are able to persist in more shaded sites although it tends to remain a shrub in less favourable habitats. Moore (1978) noted that *Fraxinus* pollen is rare in pre-*Ulmus* decline sediments but records have been noted from Cors Goch (Seddon, 1958) and also Llyn Mire (Moore, 1978).

The possible presence of *Alnus* at this site during this phase has to be considered. Low counts (<1%) are recorded from 8200 years onwards with a slight increase in values corresponding with the *Pinus* minimum noted at 720cm. It is interesting to note that low sporadic counts of *Alnus* begin at a phase of increased fire frequency after an apparent lull in fire activity. Huntley and Birks (1983) suggest that values of 2% can be used to indicate local but sparse populations, but recent work has suggested that it is possible that negligible percentages and repeated sporadic counts could be significant. Chambers and Elliott (1989) suggest that for Alnus in Wales, low percentages, previously attributed to long distance transport, possibly indicate sparse local populations. The sporadic counts at Llyn Cororion are dated at around 7760 BP and at this time alder was established at other lowland sites; Alnus was recorded from 7805 BP onwards at Llyn Hendref and sites such as this could have provided a regional pollen source.

The catchment was therefore dominated by carr vegetation around the lake edge, a drier transitional zone occupied by Pinus and Betula and then over a wider area, Quercus and distinct pockets of Ulmus dominated. Within the carr Salix dominated the wetter areas with occasional Betula (pubescens?). Fraxinus may have occurred as a scattered component but would have required shallow, well drained soil for its establishment (Grime et al., 1988), and so would have avoided waterlogged sites.

The carr understorey appears to have flourished and many taxa may have expanded as a result of gradual lake shallowing. Cyperaceae and Gramineae were predominant and Filipendula formed tall herb communities in association with species of Ranunculus. The Filicales record and the presence of Polypodium and Dryopteris indicates abundant ferns. Increases in Sphagnum towards the zone top indicate patches of acidic bog, and drier areas of the mire may have supported Calluna vulgaris and Ericales undiff. although it is possible that these two taxa also occurred as a field layer under the pine woodland.

The herbaceous pollen record is difficult to interpret because burning opened up the woodland providing habitats other than the understorey. The areas associated with the Pinus woodland is likely to have had relatively acid soils and, with a thick litter accumulation, the field layer is likely to have been restricted. Calluna vulgaris, Ericales undiff. and Pteridium may have formed a sparse cover with associated sedges and grasses in the more open areas. The mixed Quercus woodland would have supported a more diverse flora with understorey Betula and Corylus associated with Hedera helix and occasional Sorbus aucuparia. Hedera helix is characteristic of moist fertile sites and often occurs with Quercus although pollen production is inhibited by shading. It is also a species characteristic of secondary woodland (Rackham, 1980), and it appears from the pollen diagram that its occurrence was associated with fire suggesting that burning encouraged its growth and enhanced its flowering potential. Simmons and Tooley (1981) suggest that high concentrations of ivy arise from its use as fodder for winter feeding by Mesolithic man but there is no definite evidence that this was the case at Llyn Cororion.

It is difficult to verify the presence of Mesolithic man at Llyn Cororion as there is no archaeological evidence indicating his presence. Fire occurrence within the pollen source area may be indicative of anthropogenic activity although it may not have been intentionally managed. Many of the herbs recorded in this zone are often taken to indicate arable farming, such as Artemisia, Chenopodiaceae, Ranunculus, Compositae; alternatively these could also be opportunistic weeds that took advantage of gaps in the canopy produced by natural forest fires. It is difficult to identify successional phases and the occurrence of charcoal at almost every level complicates interpretation.

The temporal resolution of the pollen diagram is not sufficiently great to distinguish individual events but the high charcoal frequencies suggest that fire was related to human activity. This may have included deliberate forest burning, slash and burn, or domestic fires (cf. Bennett et al., 1990b). A sudden increase in charcoal is recorded at around 8400 BP possibly attributable to exploitation of the site; climate change and subsequent natural forest fires would produce a more gradual change in the charcoal record. Similar charcoal results have been recorded from Moel-y-Gerddi and again it is not possible to definitely state that fire was caused by Mesolithic man, although the charcoal frequencies have been taken to indicate human influence (Chambers and Price, 1985). Evidence of Mesolithic activity in west Wales suggests that the population was generally restricted to coastal locations, and Moore and Chater (1969b) suggest that there is little evidence to suggest that they interfered substantially with the vegetation. It is not possible to identify the charcoal source area, or to deduce fire frequency, but the presence of coarse charcoal in the pollen washings (fig. 3.3) would suggest that there was intense burning in the immediate vicinity of the lake basin.

Fires appear to have been non-selective; all vegetation types were disturbed, except for the carr vegetation, with tree taxa able to recover relatively quickly. Fire intensity appears to have varied with high intensity fires burning off resistant taxa such as <u>Corylus</u> (hazel is only destroyed by intense ground fire but is then able to sprout again quickly; Simmons and Tooley, 1981), exposing the soil to erosion. This occurs for example at 772cm (around 8350 BP) with a sharp decline in <u>Corylus</u> values and reductions in <u>Quercus</u>, <u>Ulmus</u> and <u>Betula</u> percentages. There is also an increase in indeterminable grains, especially corroded and broken grains, suggesting the influx of eroded substrate. Herbs associated with this level include <u>Solidago</u> type, Compositae Tubuliflorae, Cruciferae and <u>Plantago</u> undiff. Other herbs associated with high charcoal counts include <u>Urtica</u>, <u>Cirsium</u>, <u>Artemisia</u> and <u>Calluna</u>.

<u>Melampyrum</u> is often associated with charcoal records (Godwin, 1975) but at Llyn Cororion there does not appear to be a direct relationship between the two. <u>Melampyrum</u> reaches frequencies of 11% indicating that it was a major component of the herbaceous community. <u>Melampyrum</u> is often associated with woodland margins but <u>Melampyrum sylvaticum</u> is also common in conifer woods (Schauer, 1982). The coincidence of the high <u>Melampyrum</u> percentage and the <u>Pinus</u> peak at Llyn Cororion suggests that this association may have been occurring.

Zone LC4 is therefore characterised by some major changes within the catchment. Mixed deciduous woodland covered most of the area with distinct pockets of Ulmus and Pinus locally. Distribution is now controlled by interaction and competition between the species and also, increasingly, by fire. The cause of the fires remains speculative but it is possible that Mesolithic man was responsible for limited temporary clearings which caused little permanent change to the woodland structure. The role of fire in the promotion of Pinus is not clear but there appears to have been hydrological and pedogenic changes within the basin that allowed Pinus to establish. The closed forest composition varied depending on edaphic conditions and Ulmus was still able to maintain an ecologically separate niche in which other tree taxa were unable to compete. The herbaceous community generally declined as a result of reduced flowering under an increased canopy cover and poor pollen dispersal, but after burning a phase of increased species diversity and distribution occurred.

LC5 (702-460cm)

Tree percentages reach a maximum (86%) but shrub values are reduced, with frequencies averaging 12%, a direct result of the Corylus decrease. These values indicate that the catchment was still heavily forested, and average herb percentages (2%) show that open spaces were limited perhaps only available after fire disturbance. Average pollen concentration and influx values decline but this is unlikely to represent an actual decrease in tree cover; it is more likely to be a function of well-represented taxa (eg. Pinus and Corylus) being replaced by taxa which do not have well dispersed pollen (eg. Alnus and Tilia). Reduced concentrations may also reflect periodic clearing that was occurring within the catchment. The understorey vegetation is not well represented due to poor pollen dispersal and 'swamping' by the tree taxa.

Zone LC5 has a distinct charcoal record and abundance variations suggest that it was produced locally and not derived from regional sources (cf. Bennett et al., 1990b). Charcoal counts show that fire was frequent between 7400 BP and 6250 BP; from 6250 BP until the top of the zone (5600 BP) the absence of charcoal suggests that burning was negligible. The zone can be divided into two phases; the fir t is characterised by changing habitats and the introduction of new taxa, and the second phase is stable with few vegetation changes and little evidence of fire after 550 cm.

An Alnus rise and subsequent Pinus decline dominate the record. The concentration diagram indicates that the two events are linked, but the relationship between the two taxa is complicated by the occurrence of fire. The associated Pinus decline and Alnus rise has been observed at a number of sites and is usually explained as a direct result of hydrological and/or climatic change (West, 1970) producing an increase in the precipitation:evaporation ratio, raised water-tables and waterlogging in low-lying sites (Moore, 1972a). Pinus seedlings are unable to tolerate waterlogging (Grime et al., 1988) and Alnus was able to successfully colonise wet areas that were usually associated with coasts and mesotrophic mires. Birks (1989) points out that decreasing water levels would have a similar effect in increasing the number of habitats available for Alnus. At some sites (eg. Moel-y-Gerddi) the Alnus rise is associated with charcoal and increased herbaceous taxa suggesting that disturbance resulted in decreased precipitation interception and increased effective run-off. This resulted in waterlogging and improved nutrient flushing allowing Alnus colonisation.

At Llyn Cororion the empirical and rational limits of Alnus coincide (7745+/-65 BP) indicating that it was able to expand rapidly, unrestricted by edaphic or climatic conditions. The data do not conclusively identify which potential influencing factor was instrumental in the rapid rise of Alnus; it appears to result from the coincidence of a number of events.

The stratigraphy and aquatic record suggest that lake levels increased and the influx data suggest that there were minor fluctuations in water levels, but their extent or cause remains unknown. These do not necessarily have to be attributable to major climatic changes and it is possible that with disturbance within the catchment, local run-off increased resulting in a rise in lake levels; when the artificial drainage channel becomes blocked at the present day the lake floods for some considerable distance to the south and east.

There is evidence of temporary fire disturbance prior to, and at the time of, the Alnus invasion and the Pinus decline. The charcoal records are accompanied by increases in crumpled and broken grains, Sorbus aucuparia, Pteridium and also herb taxa such as Plantago undiff., Calluna vulgaris and Gramineae. Charcoal occurs in two discrete phases within zone LC5 suggesting that it is not controlled by changing climatic parameters which would be expected to be more random. It appears therefore that at least some fires were a direct result of human activity within the catchment. The charcoal record does not continue through to the Alnus maximum suggesting that once Alnus was established it was not maintained by the fire regime. Smith (1984) concludes that at Newferry, (Co. Antrim), human activity accelerated changes within the catchment that encouraged Alnus growth. Tree clearance possibly increased run-off and produced extensive waterlogging within the carr providing an ideal habitat for Alnus colonisation. If man was responsible for clearing areas of Pinus, which were then colonised by Alnus, then it is perhaps surprising that less fertile sites immediately around the lake were chosen. It is possible that Pinus was relatively easy to burn or was selectively felled for timber.

In the absence of archaeological data to support the presence of Mesolithic man at the site and without a more detailed charcoal record, it is difficult to be more precise. It appears that at around 7700 BP conditions were no longer suitable for Pinus to thrive and Alnus, which had been in the region since around 8000 BP, was able to take the opportunity and colonise the resultant gaps. The sporadic occurrence of Alnus before 7750 BP suggests that there may have been an isolated population in the area that was unable to compete with the relatively dense woodland. Alnus therefore replaced the Pinus population but this is unlikely to have been by direct competition as Alnus seedlings are shade intolerant (Grime et al., 1988); it was necessary to have disturbance within the catchment before Alnus was able to expand as an opportunistic taxa.

The pollen record is taken as indicating the presence of Alnus glutinosa which is the species native to the British Isles (Godwin, 1975) but it was noted during counting that many of the grains were four pored. These were counted separately and the results show that four pored grains were dominant up to 5700 BP and then five pored grains increase in importance. Godwin (1975) suggests that four pored grains are associated with hybridity.

Alnus values rise from 5% to 17% within an estimated 50 years indicating that there was no resistance to invasion. This suggests that as Pinus declined, Alnus moved in immediately to take over. Alnus has seedlings that are restricted to waterlogged sites and are susceptible to drought and cold periods in early spring (McVean, 1956). Salix is more tolerant of acidic, less fertile sites and is able to thrive under light shade and so the taxa appear to have been able to co-exist within the carr. Alnus seedlings are also more tolerant to waterlogging than Betula pubescens and again it appears that there was little competition between the two species, with Betula occupying the drier areas away from the lake edge. The influx data suggests that there was some initial interaction between Quercus and Alnus and although Alnus is most common in waterlogged habitats it can also occur on moist sites within plateau woodlands (Rackham, 1980); this may have been the case at Llyn Cororion with alder forming a minor constituent of the oak woodland. Alnus possibly invaded the mixed oak woodland and colonised isolated moist sites but Ulmus and Quercus remained the dominant genera over much of the catchment.

Betula and Corylus show some initial decrease in concentrations but this is temporary as the carr vegetation readjusted to Alnus immigration. Corylus was probably replaced on the carr edge or flowering may have been reduced by shading. Betula percentages of 25% indicate that it was still locally dominant within the carr, verified by macrofossil finds, but it may have also occurred as an understorey shrub within the mixed woodland. Salix concentrations are also steady but low (between 1-3%), suggesting that Salix was no longer dominant within the carr, a role now occupied by Alnus. The associated understorey was composed of Filipendula, Rumex, Succisa pratensis, Cyperaceae, Dryopteris, Caltha type and Ribes. Caltha type is typical of wet woods and marshy habitats and Ribes is a common constituent of alder carr (Schauer, 1982).

Alnus therefore expanded from sparse local populations to form a dominant, but not overwhelming, species around the lakeside, (cf. Huntley and Birks, 1983). The local nature of the taxon and the variability of possible habitats means that it is difficult to apply correction factors to gain an idea of its true representation (Lowe, 1982). Its local occurrence at Llyn Cororion means that many minor frequency fluctuations could be due to variations in pollen production and dispersal within the local community.

The Pinus decline is rapid (down to 17% by 7700 BP) although concentration data suggest that values stabilised before a second decline at 7050 BP. The pollen frequencies suggest that Pinus quickly disappeared from the local vegetation; probably now restricted to isolated trees, surviving on stony ground or occurring as small stands on the thinner and poorer soils on steeper slopes to the east. The concentration data indicate that it continued to survive in marginal areas on the fringes of the pollen source area until 7050 BP when a second gradual reduction in populations resulted in its extinction. The second major decline was associated with increased charcoal levels and it appears that the burning was selective, perhaps due to anthropogenic activity.

The mixed deciduous woodland appears to have changed little throughout this time and was still dominated by Quercus. Percentages (between 20% and 30%) indicate that Quercus was the predominant canopy tree within the pollen source area whilst Ulmus frequencies (between 4% to 6%) indicate that the latter did not cover large areas. Again it appears that the two tree types were exclusive with a predominantly Quercus wood and exclusive patches of Ulmus trees. The shrub layer within the forest consisted of Corylus, Betula and occasional Fraxinus with a field layer of Pteridium, Gramineae and assorted ferns.

Corylus was initially reduced by the Alnus invasion but pollen frequencies (between 20% to 33%) suggest that it became a more prominent taxa within the woodland although it is unlikely that it re-invaded the oak woodland as a canopy species. Corylus possibly formed a shrub layer associated with Betula. The coincidence of increased Corylus associated with the second decline in Pinus suggests that Corylus took over habitats previously occupied by Pinus. This may have been in a transitional zone between the carr and the woodland; an area too dry for the establishment of Alnus and too poor for the spread of Ulmus and Quercus. The increased importance of Corylus could be associated with fire occurrence although a direct relationship is not easy to establish.

At around 6000 BP there is the first record of Tilia. The counts are sporadic (<0.35%) but because Tilia is under-represented in pollen diagrams, (Andersen, 1970) this suggests that Tilia was marginal to the pollen source area. It is interesting to note that the occurrence of Tilia within the pollen record is associated with a decrease in the Corylus record suggesting the interaction between the two taxa even at low frequencies.

LC6 (460-324cm)

Zone LC6 is characterised by maximum organic deposition (98%) but with declining values as clearings within the pollen source area expand. There is an increased mineral input coinciding with the Ulmus decline and reduced Tilia values. Pollen influx is reduced (average $1.4 \times 10^4 gr/cm^2/yr$), resulting from a combination of factors including low pollen producing trees (Tilia) replacing over-represented taxa (eg. Corylus). Temporary clearings also reduced the overall pollen input and errors in estimating the sedimentation rate could cause an artificial decrease in values. Tree and shrub values average at 94% suggesting dense forest cover but variations between 45%-98% indicate that at times there were considerable variations in canopy cover.

Forest history is now more difficult to interpret; anthropogenic influence increased, there is increasing evidence of fire and the possibility of climatic changes cannot be dismissed. The main features of the zone are the introduction and expansion of Tilia, a continuous curve for Fraxinus and a subsequent decline in both the Tilia and Ulmus frequencies. It is envisaged that there was relatively dense woodland cover but that canopy density and age structure varied depending on local events within the area. Mature Quercus-Tilia forest occurred over much of the catchment interspersed with secondary woodland, sporadic open grasslands, heath and burnt clearings.

PRE-ULMUS DECLINE

The Quercus-Betula woodland continued to dominate but fluctuations in the pollen record indicate sporadic clearance and burning. Ulmus was still significant within the local vegetation and initial frequencies of 4% indicate that it still colonised an undisturbed niche until a rapid decline in percentages from 4% to 1% is recorded at 4985+/-65 BP. This supports the idea that the Ulmus decline in North Wales was a synchronous event and compares favourably with dates of 5060+/-60 BP recorded from Cors Dolfriog, (Edwards, 1980), and 4890+/-70 BP at Nant Ffrancon, (Hibbert and Switsur, 1976).

Tilia is recorded as sporadic counts from 6400 BP onwards, indicating that it was within the region and possibly pr sent at the site (cf. Bennett, 1983b) before the rational limit dated at 5650 BP. Godwin (1975) suggests that low pollen records recorded in North Wales are attributable to long distance transport but the early, low percentages at Llyn Cororion could be 'a natural consequence of exponential population increase', (Bennett, 1983b) and indicate a local but expanding colony. Values gradually rise to a peak of 3% coinciding with the beginning of the Ulmus decline, as recorded in the percentage diagram. Expansion in North Wales appears to have been relatively slow, possibly because Tilia was reaching its climatic limit; this in association with competition from established woodland, limited the Tilia spread.

At Llyn Cororion Tilia appears to have co-existed with Quercus and may have replaced both Ulmus and Corylus. It appears from the concentration diagram that Tilia was in direct competition with Ulmus and Corylus although the record is complicated by the formation of temporary clearings and regeneration. The interaction between Ulmus and Tilia is not apparent in the percentage diagram but is clearly illustrated in the concentration results. Until 5600 BP, Ulmus occupied an exclusive ecological niche but Tilia appears to have been able to compete and replace it on areas of deep fertile mull humus soils.

During the Tilia invasion and establishment there was continued disturbance within the forest as indicated by the herb record and charcoal results. Between 5650 BP and 5500 BP there was an increase in fire frequency but the cause is unknown. Burning was random, evidently affecting all tree taxa within the basin and perhaps encouraging the expansion of Tilia at the expense of Ulmus.

The Tilia rise to 4% at Llyn Cororion indicates that there was a significant, if restricted, Tilia population on the coastal plain at around 5000 BP. Tilia is often found in association with Quercus and Ulmus but is rare as a forest dominant (Huntley and Birks, 1973). The occurrence of Tilia as a significant component of the forest is unusual in North Wales (cf. Botterill, 1988) and the population at Llyn Cororion appears to be a local phenomena. The success of Tilia at Llyn Cororion may be due to the relatively sheltered location of the site and also the availability of deep rich, well drained soils on the coastal plain. Pigott and Huntley (1978) note that in the Lake District 'the finest trees occupy deep soils on almost level ground in hollows filled by glacial drift' which is essentially analogous to the situation at Llyn Cororion. The local pollen source area of this small site would also ensure that Tilia was relatively well represented in the sediment.

The Corylus concentration record indicates a reduction as Tilia expands but with recovering values as both Tilia and Ulmus decline. This suggests that Tilia replaced Corylus perhaps in the marginal areas of the carr (cf. Godwin, 1975) with a reduction in Corylus flowering potential reflecting increased shade; Tilia casts relatively dense shade (Fairhurst and Soothill, 1989). When Tilia then declined, Corylus increased again suggesting that hazel was suppressed rather than displaced, with its status changing in response to competition, fire regime, varying canopy density and disturbance.

The empirical limit of Fraxinus (assumed to be Fraxinus excelsior; Godwin, 1975), has been dated at 6450+/-65 BP with frequencies of between 0.5%-1% suggesting that Fraxinus was locally dominant but not a major component of the vegetation. Fraxinus tends to be associated with moderately disturbed habitats and as its seedlings are shade intolerant; this infers an increase in open areas and carr which encouraged its expansion. Open areas are also suggested by the sporadic

Sorbus aucuparia counts which coincide with Corylus peaks suggesting recolonisation of open ground.

Fraxinus would initially have formed part of the pioneering phase of secondary woodland favouring areas of moist but well drained soils. It is likely that it also occurred in the drier areas of the carr associated with Betula. Fraxinus regeneration is favoured by disturbance (Grime et al., 1988) and, although concentrations suggest a relatively stable population, it is possible that the distribution of the local population changed depending on the frequency and distribution of clearings.

Betula probably existed as an understorey shrub within the oak woodland and was abundant only after fire occurrence. The importance of Betula in the carr vegetation appears to have increased with macrofossil remains recorded more frequently after 5150 BP. These are associated with slight increases in the Salix concentrations and rising Alnus values perhaps indicating an expansion of the carr community.

An expansion of the lakeside vegetation is suggested by increased frequencies of Filipendula, Cyperaceae, Gramineae and Osmunda, thought to be associated with continued lake shallowing. Alnus was locally dominant in the water-logged habitats around the lake edge but there also appears to be a direct relationship between Quercus and Alnus percentages suggesting that perhaps Alnus also grew on the coastal plain replacing Quercus on a small scale.

It is envisaged that alder-willow-birch carr thrived around the lake edge, perhaps with the exception of the northern shore, and was relatively unaffected by other vegetational changes occurring within the catchment. The carr had a rich field and ground layer consisting of Polypodium, Dryopteris, Osmunda and Filicales undiff., Cyperaceae, Filipendula, Caltha, Hydrocotyle and Ranunculus. Occasional records of Sphagnum suggest the existence of boggy pools, and drier areas may have been colonised by Pteridium, Calluna vulgaris and sedge tussocks.

It appears that up to approximately 5500 BP the forest was still relatively dense with Quercus-Betula woodland over much of the catchment associated with local populations of Tilia on more fertile soils and occasional Alnus on damper sites. Ulmus was already declining but mixed Tilia-Ulmus stands persisted. Betula and Corylus occurred as understorey shrubs and occasionally as canopy trees with the former becoming increasingly important in the carr vegetation, perhaps reflecting lake shallowing.

In pre-Ulmus decline deposits (as indicated by the percentage diagram) there is evidence of disturbance with occasional and sporadic charcoal records and herbs indicating anthropogenic activity, although again natural fires (climatically induced) and possible interference caused by herbivores (cf. Moore, 1978) cannot be dismissed as being responsible for creating clearings. Herbs commonly taken as indicative of pastoral activity, (eg. Plantago lanceolata, Rumex Pteridium and Urtica), are recorded, and periods of clearing affected all tree taxa, but with no evidence of selective felling. The sporadic nature of the charcoal record suggests that areas of land were cleared, used for grazing and then abandoned possibly when the population moved on. Clearings were temporary and limited in area, but increases in the potassium concentration of the lake sediment, associated with the charcoal records, signify soil disturbance with increased erosion and exposure of partially leached soils.

Clearance then followed by periods of re-colonisation, first by pioneering taxa (Corylus, Betula, Fraxinus, Sorbus aucuparia and Ilex) which were subsequently succeeded by Ulmus, Quercus and Tilia. The presence of Hedera helix, which is uncommon on grazed land, and increased Ilex values, which is resistant to grazing, indicates possible relaxation of grazing pressure. Regeneration phases were then followed by periods of relatively stable forest although small fluctuations in the records of Ulmus and Quercus and the continued presence of Fraxinus indicate that open spaces persisted.

It appears that before the Ulmus decline there was anthropogenic activity but that it was temporary, sporadic and limited in extent. It is possible that the disturbances were the result of an early pioneering phase of Neolithic people although the possibility of Mesolithic interference cannot be excluded. Early Neolithic colonists entered Wales both from the east and west, and initially colonised exposed coastal areas and woodlands of birch and oak (Linnard, 1979), whilst contemporary Mesolithic populations exploited upland localities.

THE ULMUS DECLINE AND TILIA DECLINE

The Ulmus decline, a reduction in percentages from 4% to 1%, is estimated to have occurred over 70 years although subsequent fluctuations in the record suggest that in some areas it was able to regain local prominence. Values of 1% at 4200 BP indicate that it was probably no longer local but persisted elsewhere on the coastal plain. The concentration diagram suggests a different scenario with a gradual decline in Ulmus beginning at 5500 BP, coinciding with the Tilia rise. This coincidence is not observed in the frequency diagram.

A number of theories have been suggested to explain what appears to be a synchronous Ulmus decline over the British Isles (Simmons and Tooley, 1981; Perry and Moore, 1987) including climate, competition, soil deterioration, selective collection of Ulmus leaves for fodder, selective felling and also disease. Some hypotheses are untestable, and it is likely that a combination of factors was responsible, although recently an anthropogenic cause has been favoured. Birks (1986) suggests that only specific pathogen attack would produce a rapid decrease in pollen percentages at approximately the same time and that the death of large areas of woodland would create clearings readily available for exploitation by man.

At Llyn Cororion the situation is complex with the coincidence of fire occurrence and anthropogenic activity, and also the differing dates for the decline suggested by the concentration data and the percentage diagram. The percentage diagram suggests that both Tilia and Ulmus began to decline together; the concentration data indicate an earlier Ulmus decline associated with the Tilia rise.

There is evidence for temporary clearings within the forest before the Ulmus decline, suggesting that man was active in the area making it difficult to distinguish between anthropogenic causes and natural competition. Although limited clearing and pastoral activity was occurring around Llyn Cororion there is little to suggest that the Ulmus decline was a direct result of this activity. The concentration data suggest that the Ulmus decline was a direct result of the Tilia rise; Tilia was able to compete successfully with Ulmus on rich soils that the latter had occupied for the previous 3000 years. It is not known if the demise of Ulmus and successful colonisation of Tilia was enhanced by disease or Neolithic activity, both of which would have reduced the ability of Ulmus to compete and regenerate. Charcoal is not present at the level of the actual Ulmus decline but there are high counts in subsequent samples suggesting that burning may have affected the woodland structure, discouraging Ulmus regeneration and encouraging Tilia colonisation.

Tilia appears to be absent from the local vegetation by 4200 BP with a decline over approximately 550 years. The Tilia decline is a recognisable feature in many British pollen diagrams and is usually attributed to anthropogenic activity (Turner, 1962). At Llyn Cororion it appears that there was some selection process as other tree taxa remained stable whilst Tilia continued to decline, even throughout periods of forest regeneration.

The Tilia decline at Llyn Cororion is associated with charcoal counts, but the frequency and abundance of charcoal counted is less than that recorded throughout the Tilia maximum, suggesting that although fire occurrence may have affected the ability of Tilia to regenerate it was not the primary cause of its decline. Also associated with the decline are taxa such as Plantago lanceolata, Pteridium and Rosaceae, but as these also occurred throughout the Tilia expansion, there is no substantial evidence to suggest that there was increased clearing activity which adversely affected Tilia. It is possible that although clearing intensity did not alter, there was a shift in the areas cleared, with rich soils favoured by Tilia now required for improved pasture.

Tilia may therefore have been selectively felled to clear areas of fertile soil or it may have been favoured as fodder for animals (Simmons and Tooley, 1981). At this site a number of potential influences on the Tilia decline present themselves and it is not possible to isolate the major factors. It may be that there was a coincidence of factors including soil retrogression, a slight climatic shift and continued disturbance and grazing. It is probable that at Llyn Cororion (altitude 82m), Tilia was near to its climatic limit and it would only have taken a small shift in climatic conditions and/or soil deterioration for regeneration to be prevented. As Tilia disappeared, the resultant gaps were then colonised by invading Fraxinus and Corylus.

POST-ULMUS DECLINE

Coinciding with the continual decline in both Ulmus and Tilia is an increase in the charcoal content of the sediment suggesting that fire frequency had increased in the local area possibly encouraging the final decline of both taxa. Increased fire activity and charcoal erosion occurred between 5100 BP to 4200 BP. It appears that there were two types of fire regime; the first type affected all primary tree taxa within the basin with a coincident increase in Corylus, Ilex, Hedera helix, Sorbus and Fraxinus. These levels were also characterised by Plantago lanceolata, Rumex, Pteridium and Compositae Liguliflorae. Fire was indiscriminate with no selective burning and there was subsequent re-colonisation by pioneering shrubs and light demanding taxa. Plantago lanceolata is generally absent from closed woodland and is most frequent in vegetational assemblages associated with reduced soil fertility and moderate disturbance (Grime et al., 1988). The second type of fire regime affected all trees and shrubs including Sorbus and Fraxinus suggesting that patches of secondary woodland were re-burnt before total regeneration could occur.

Climatically induced fires may have occurred within the area but the frequency of charcoal within the sediment suggests anthropogenic activity, although there is no evidence to suggest that fire was used exclusively for clearing. Charred seeds from Moel-y-Gerddi suggest that fire was actually used to initially clear ground (Kelly, 1988) but it is also possible that a 'slash and burn' method of clearing was adopted with the burning of felled woodland in the spring before the planting of seeds (Linnard, 1979).

There is no clear or regular pattern of clearing and subsequent regeneration, suggesting that perhaps more than one area was cleared at any one time and that some areas were cleared more than once. The pollen record is a composite of a number of different stages within the clearance-regeneration cycle. Possible clearance phases identified indicate that clearing was relatively rapid (50 years) followed by a phase of open ground (maintained by fire and perhaps grazing) and regeneration over the next 150 years. The evidence suggests that there were small populations of Neolithic people leading a semi-nomadic lifestyle based on pastoral farming. There is no evidence of cereal growing and it is likely that the people relied on cattle, sheep and pigs (Simmons and Tooley, 1981).

Neolithic pottery has been recovered approximately 500m to the north-west of Llyn Cororion (fig. 2.4, Kelly pers. comm., 1988) indicating that there was some local activity. Towards the top of the zone (4700 BP to 4200 BP) it appears that the site may have been abandoned, with a distinct break in the charcoal records and a reduction in herbaceous taxa including the absence of Plantago lanceolata, Rumex and Pteridium. An increase in the organic content (average 80%) of the lake sediments suggests that soils were maintained for a period with a decrease in erosion rates and reduction in fire frequency. The woodland appears to have stabilised although the pollen data suggest that many taxa were unable to recover fully.

Ulmus values are low enough to suggest that it now only occurred sporadically, and Tilia appears to have also been irreversibly affected by disturbance although low sporadic counts suggest that it was still an isolated taxon within the region, perhaps surviving in the shelter of the Ogwen valley. Quercus still dominated, but not as extensively as before. It may be that soils were degraded by grazing and increased erosion resulted in limited tree regeneration. This would explain the lower Tilia and Ulmus frequencies as these two taxa require relatively rich soils compared with Quercus which has a wider tolerance range of edaphic conditions. It is also possible that grazing by cattle within the relatively open areas prevented regeneration of Ulmus (Godwin, 1975). Corylus and Sorbus values increase suggesting that areas around the lake were dominated by patches of secondary woodland interspersed with Quercus and Betula woodland.

Zone LC6 is therefore characterised by a general and overall decline in the dominant tree taxa within the lake basin, and a corresponding increase in Betula, Corylus and light demanding species such as Sorbus and Fraxinus. The herb record fluctuates depending on the frequency of openings. The occurrence of charcoal at the point of the Tilia decline suggests that fire was an important factor in the decline of lime within the basin but the Ulmus decline is more difficult to interpret due to the conflicting evidence provided by the percentage and concentration data. In the case of Ulmus it appears that competition from Tilia was the major influencing factor, but anthropogenic activity and disease cannot be dismissed as having an effect. Neolithic clearings within the forest were at first sporadic, temporary and probably limited in extent, but the pollen record then indicates that following the *Tilia* decline clearings were more extensive perhaps a result of population increases in the late Neolithic.

The pollen diagram is the result of a number of short temporary clearance episodes but the temporal resolution of the diagram is not sufficiently detailed to consistently discern individual events. The clearings may have been the result of one population colonising the area and progressively clearing different areas around the lake with each abandoned patch regenerating as a new patch was cleared. It is also possible that the effects were caused by a number of successive communities moving in and out of the area. After 4700 BP it appears that the site was abandoned or that site use was limited allowing forest recovery although it never regained its former density.

LC7a (324-112cm)

Zone LC7a spans a number of archaeological phases, each characterised by a complex sequence of vegetational changes making generalisations difficult. The estimated sedimentation rate stays steady (0.12cm/yr) but this is an average figure and it is likely to have changed with increased deposition rates associated with clearance and fire occurrence. Occasional evidence of resedimentation suggests that lake levels may have fluctuated slightly, and variations in the mineral input (eg. a sand band at 164cm) indicates that fire intensity and the effects of clearance were diverse in terms of substrate damage.

Tree and shrub pollen frequencies (88%) signify that for much of the time the basin was still heavily forested, although a herb percentage of 9% indicates that there were phases of open ground and increased weed colonisation. It is possible that the high tree totals are due to an increase in secondary scrub-land and give a misleading impression of the woodland cover. Average concentration values are increased which is difficult to interpret in view of the fact that this is a phase of gradual deforestation. It is possibly due to enhanced pollen transport in a more open forest and an increase in the abundance of high pollen producers (eg. Betula and Corylus).

Soils remained stable for much of the time with disturbance and fire occurrence having little effect on the substrate until the beginning of progressive forest decline at around 2800 BP. Organic substrate erosion is indicated by the rise in corroded and crumpled grains. At this point there is then an associated increase in the inorganic input into the lake with a corresponding increase in the potassium concentrations of the sediment, indicating exposure and transport of raw unleached soils. At the zone base, fire occurrence appears to have been reduced, with no charcoal recorded between 4600 and 3450 BP, but thereafter fire increased in frequency with charcoal recorded at every level.

Zone LC7a can be broadly divided into four archaeological phases corresponding to the Neolithic-early Bronze Age transition, the late Bronze Age, the Iron Age/Romano-British period and the Dark Ages. The approximate dates for these periods have been taken from Megaw and Simpson (1979), but it is understood that the phases are not exclusive and the boundaries are transitional.

NEOLITHIC-BRONZE AGE TRANSITION

During this period there was little change in the vegetation from that recorded at the top of zone LC6, which supports the idea that the Beaker and Bronze age cultures were incorporated by existing populations (Moore and Chater, 1969b). Regeneration continued after the early Neolithic clearances and it is possible that the site was abandoned for a period, around 3650 BP, stimulating forest regeneration. Herbaceous percentages remain low (2.2%) and shrub and tree frequencies (93%) suggest that the area was still dominated by Quercus woodland. Betula values rise as the extent of secondary woodland increased, and maximum percentages of 41% suggest that for a short time it became dominant in the woodland. Its importance in the carr woodland appears to have decreased with a reduction of macrofossil evidence although this could also signify changes in sedimentation.

Immediately following the Betula maximum there is a peak of Quercus (30%) forming part of the successional phase within the woodland, and suggesting that at this time disturbance was limited enough to allow full regeneration. The high percentages indicate that the lowlands were still dominated by Quercus woodland associated with Betula, and occasional Corylus and Ulmus. Ulmus does not recover from its demise in the Neolithic but continued low values infer that Ulmus perhaps survived on the coastal plain on the margins of the pollen source area. Disturbance by fire appears to have resulted in the elimination of Ulmus from the immediate locality of the basin by 3200 BP.

Tilia increased slightly but low pollen values coinciding with peaks in Quercus and decreases in Corylus, suggest that during regeneration there were limited areas recolonised by a sparse population of lime trees. The increase was short-lived and Tilia declined again as fire frequency increased and disturbance re-occurred.

Decreased Corylus values coincide with increased frequencies of other tree taxa showing that before the major phase of regeneration, Corylus and Betula dominated implying that pioneering species were able to re-colonise cleared areas before they were succeeded by longer living species. Initially hazel was locally dominant but then percentages progressively decline as the forest closed and Corylus was succeeded by Quercus and occasionally Tilia and Ulmus. Corylus was apparently not encouraged by isolated fire incidence and was restricted to an understorey shrub and a minor component in the carr vegetation.

The idea that the forest was going through a period of substantial regeneration with a decrease in anthropogenic activity is supported by the associated decrease in shade-intolerant taxa such as _Fraxinus_, _Sorbus aucuparia_ and _Hedera helix_. _Fraxinus_ values are reduced, except for short lived fluctuations associated with fire occurrence, and during the phase of maximum forest cover the herb values and diversity are reduced although the occurrence of _Calluna_ and _Pteridium_ suggests that heathland persisted in some areas. Loss-on-ignition data show that organic input into the lake was still high (average 83%) suggesting little soil disturbance. Chemical analysis of the lake sediments indicate a phase of relatively stable but low potassium concentrations suggesting that disturbance of top soils was slight and that raw mineral soils were not exposed.

Fire activity was limited in this phase but appears to have been selective, affecting _Ulmus_ and _Betula_ but leaving areas of _Quercus_ woodland untouched. There is an associated increase in herbs but no corresponding increase in mineral input suggesting that fires were of limited extent and intensity and did not affect the overall process of recolonisation. Associated with the charcoal levels are an increase in _Calluna_, Cruciferae, _Sorbus_ and _Pteridium_ signifying that small patches of the woodland were burnt followed by a phase of grassland development and subsequent heathland. There are no indications of arable land-use, and it is not possible to say if fires were natural or man induced. If there was anthropogenic activity it was probably a limited population practising a predominantly pastoral economy perhaps leading a nomadic lifestyle.

The extent of the carr appears to have been reduced during this phase with a decline in _Alnus_ and _Salix_ values and a corresponding decrease in Cyperaceae and _Filipendula_. _Osmunda_ frequencies increase and although the pollen record for _Dryopteris_ is sparse the pollen washing results suggest that it was abundant in the local vegetation. It is possible that these vegetational changes represent subtle fluctuations in the lake level unrecorded in the stratigraphy and which did not favour taxa that required wet sites.

During the early Bronze age there was an abandonment of the site, with the expansion of shade intolerant species resulting in the formation of secondary woodland and scrub. A phase of regeneration then lasted until around 3650 BP with only periodic and limited fire disturbance which resulted in the temporary spread of grassland and heath. The cause of fire cannot be established and there is no evidence of settled agriculture and systematic clearing. If anthropogenic activity did take place then the vegetational record suggests that it was limited in extent. At the end of the early Bronze age there was therefore Quercus dominated woodland associated with Betula and Corylus, and possibly Alnus, but low frequencies of Tilia and Ulmus show that these latter taxa were failing to regenerate.

LATE BRONZE AGE

During the late Bronze Age phase, from approximately 3200 BP, there were significant and definite changes in the vegetation attributable to anthropogenic activity. Taxa diversity increased and the herbaceous record indicates a gradual opening up of the forest canopy. The most significant changes were the first record of cereal grains, frequent fire occurrence and the beginning of a gradual rise in Gramineae values.

Overall frequencies of tree taxa decline but there is little evidence of selective burning or felling. Quercus dominated the woodland with Betula as an occasional canopy species but probably more significant in the understorey and within the carr. Ulmus and Tilia were now absent in the local vegetation. Corylus values decline except for an isolated high associated with abundant charcoal (224 cm) suggesting that on this occasion fire encouraged its growth. Hedera helix forms a continuous curve (it is often characteristic of secondary woodland; Rackham, 1980) but Ilex aquifolium is now absent, perhaps a reflection of the demise of suitable habitats as clearing increased.

The carr vegetation appears to have recovered with increased Alnus values and slight rises in Salix, Fraxinus, and Cyperaceae concentrations. Increased Sphagnum values indicate the invasion of drier parts of the mire by moss species, and there are the first records of Cannabaceae, probably attributable to Humulus lupulus. Humulus is a native species common in damp areas of carr vegetation and oak woodland (Wilson, 1975), but it is possible it was associated with clearance and arable cultivation which increased the number of habitats at the transition between woodland and clearings. Ferns in the carr vegetation are represented by Osmunda, Dryopteris and Polypodium.

The first positively identified cereal grain is recorded at 2900 BP and is associated with burning suggesting that fire was deliberately used to clear woodland for agriculture. The occurrence of cereals is associated with a rapid rise in Gramineae, Cyperaceae, Plantago lanceolata, Rumex undiff. and Rosaceae. Many of the Rosaceae grains resembled Potentilla which is a herb associated with areas that are under high grazing pressure (Moore and Chater, 1969b). There appears to have been at least two distinct phases of clearance but it is difficult to say if these represent single isolated events or amalgamations of a number of clearance phases.

The first phase suggests that clearing was limited with tree taxa relatively unaffected but with a sharp decline in Corylus. It may have been that Corylus had taken over the areas previously occupied by Tilia and Ulmus and were selectively burnt as they now occupied the most fertile soils. The associated herb record was limited with an association of Gramineae and Pteridium, Plantago lanceolata and Melampyrum. Arable farming appears to have been restricted, and much of the area was probably colonised by weeds characteristic of grasslands. The loss-on-ignition data suggest that soil disturbance increased with periodic erosion and deposition of inorganic material. After temporary clearing there followed invasion of secondary woodland with a rise in Corylus and the occurrence of Calluna, suggesting that clearings were colonised by heath taxa. The presence of Polygonum persicaria and Chenopodiaceae suggest that clearings did not fully close and may have been maintained by grazing.

Within approximately 130 years the area was cleared again and the association of cereals and charcoal suggests that fire was again used as a method for clearance or for destroying felled wood. The second phase of clearance was more extensive with all tree taxa affected, including those characteristic of the secondary woodland, perhaps indicating that clearings were larger in extent. Betula values increased as it invaded clearing edges forming birch scrub and there are associated rises in Gramineae, Plantago lanceolata, Cruciferae and Polygonum persicaria.

This combination of herbs suggests that there was a mixed economy, and the extent of the clearings and frequency of cereal grains infers that arable agriculture was now expanding. From limited archaeological finds it is known that Bronze Age man frequented the area. A Bronze Age cooking place (site 815, fig. 2.4) is located to the north of the lake and a large Bronze Age cairn and food vessels have been discovered around Llyn Gwynt, approximately 500m to the north-west of Llyn Cororion. (Kelly pers. comm., 1988).

IRON AGE

In the transition to the Iron Age the mode of farming appears to have remained much the same but with a further increase in herb diversity as more habitats became available. Quercus woodland was now interspersed with clearings occupied by arable crops, grassland and patches of secondary woodland. Charcoal is now recorded at every level indicating increased fire activity and, although clearings were still temporary and limited, an increase in Sorbus aucuparia and Pteridium suggests that many areas remained open after they had been abandoned. The high fire frequency meant that the dominant tree taxa were unable to recover, and with progressive leaching and soil deterioration, grasslands and heath were stimulated. An increase in mineral input into the lake, now averaging 32%, indicates that for the first time soil was sufficiently disturbed to result in increased erosion and deposition of leached soils.

There appears to have been a slight delay (approximately 200 years) between the known arrival of Iron Age people in southern Britain and the beginning of major deforestation at western and northern sites. This may have been due to the time required for the 'diffusion of new technology' northwards, and the time of major clearance in the Iron Age appears to be associated with improved technology and a more settled lifestyle (Hicks, 1971). This appears to have been the case at Llyn Cororion with a continuation of temporary clearings until 2250 BP when there was another important change in the vegetation with the beginning of a progressive decline in the woodland with little evidence of regeneration. All tree taxa declined rapidly between 2250 BP and 2000 BP suggesting that there was an extensive clearance phase around this time which was then maintained but not extended. <u>Quercus</u> values decline to between 16%-25% indicating that, although the woodland was diminishing, <u>Quercus</u> remained the dominant taxa.

Fluctuations in the tree taxa curves suggest that there may have been sporadic and short-lived patches of regeneration with <u>Betula</u> and <u>Corylus</u> colonising disturbed ground. <u>Quercus</u> was occasionally able to recolonise areas but generally disturbance was too extensive and permanent to allow full regeneration. There appears to have been a mosaic of oak woodland of differing age, depending on if it was original woodland or secondary woodland, interspersed with <u>Betula-Corylus</u> scrub, secondary woodland, heath, grassland (possibly used for grazing) and clearings utilised for the growth of crops.

Increasing Gramineae, <u>Pteridium</u> and <u>Calluna</u> values indicate the spread of heathland, and there is increasing evidence of disturbance including Artemisia, Caryophyllaceae and Leguminosae. Hedera helix frequencies are sporadic, perhaps because it was cleared or was unable to tolerate the increasing disturbance. The carr vegetation appears to have been relatively unaffected by the clearance, with stable Alnus and Salix values and records of Filipendula, Caltha type, Urtica and Cyperaceae indicating a diverse understorey.

Cereals are now consistently present suggesting that arable farming occurred in the locality, although pastoral farming appears to have remained dominant. Gramineae values are consistently high, with increased Plantago lanceolata and Pteridium values suggesting that livestock husbandry was an important part of agricultural life.

Evidence of Iron Age activity around Llyn Cororion includes a possible Iron Age fort (site ref. 53, fig. 2.4) and possible occupation of ground approximately 300m to the south-west of the lake (site ref. 27, fig. 2.4). There are no dates from this site but it is thought that occupation may have extended back to the late Iron Age with re-occupation in Roman times (Kelly pers. comm., 1988). The increased activity in this area suggests that populations were increasing and permanent dwelling sites were now established. At Llandegai (2Km to the north) there is substantial evidence of Iron Age round houses that were constructed from timber on the former site of a Neolithic henge monument (Kelly, 1988). There is also evidence of iron smelting in the area (Kelly pers. comm., 1988) and the timber required for this and building construction would partly explain the acceleration in deforestation.

ROMANO-BRITISH/DARK AGES

The transition between the Iron Age and the arrival of Roman people in North Wales did not signify a change in farming practices, but there does appear to have been a change in the balance between pastoral and arable farming. The pattern of clearing that had characterised much of the Iron Age intensified and the continuous presence of cereals and decline in grassland taxa indicates that crop production now assumed increasing importance. A major decline in tree taxa, lasting about 160 years, is recorded from around 1700 BP with an associated increase in herbaceous taxa. *Corylus* and *Quercus* appear to have been affected which may reflect the organised and systematic destruction of the oak woodlands by the Romans (Linnard, 1979) as there was increasing demand for building materials and fuel. *Betula* persisted as scrub and the macrofossil record suggests that it remained important in the carr vegetation. The carr vegetation appears to have increased in extent with higher values of *Salix* and increasing *Alnus*.

Hedera helix now has a continuous curve and herbs include Caryophyllaceae, *Polygonum persicaria*, *Lonicera* and *Plantago lanceolata*. Gramineae values increase and cereals are consistently recorded along with *Calluna vulgaris*, Chenopodiaceae, *Sorbus aucuparia*, *Rumex* and *Pteridium*. Compositae Liguliflorae, *Melampyrum*, *Solidago* type, Compositae Tubuliflorae and Leguminosae are also common. It appears that there was now systematic clearing of increasingly larger areas with maximum human interference between 1700 BP and 1400 BP.

Increased activity and soil disturbance is also reflected in the loss-on-ignition and chemical data. The organic content of the lake sediments declines with a corresponding increase in coarse detritus (leaves, twigs, wood). Increasing potassium concentrations suggest deeper disturbance of soils and the occasional incursion of sand and pebbles reflects increased erosion. There is a large increase in indeterminable grain input indicating topsoil erosion.

It is possible that Iron Age pastoralists continued their way of life but with increased areas of cultivation (Hicks, 1971) resulting from the necessity to produce grain to feed soldiers stationed at forts, such as those established at Caernarfon. Stone huts, 300m to the south-west of the lake were probably occupied during this phase, forming semi-permanent dwellings surrounded by cleared agricultural land and scattered remains of the oak forest. A large complex of Romano-British huts has also been identified approximately 500m to the south-east, located on a ridge above the lake.

From 1500 BP until approximately 1250 BP there appears to have been a decline in arable activity. This coincides with the withdrawal of the Romans and a return to tribal warfare in north and west Wales which resulted in less intensive agricultural activity (Moore, 1968). Tree frequencies continued to decline and fire was still a frequent occurrence within the catchment, allowing an expansion of herb taxa (now 20%). Cereals were reduced but there was an associated increase in Calluna vulgaris, Chenopodiaceae, Cruciferae and Rumex undiff. suggesting that areas may have been given over to pasture or colonised by weeds. An isolated cereal grain and the occurrence of Melampyrum, Compositae Liguliflorae, Solidago type and Compositae Tubuliflorae suggests that arable farming continued but on a restricted scale.

During this phase it appears that the carr vegetation recovered further; Salix now formed an important component of the vegetation suggesting that water levels were insufficient to enable re-colonisation by Alnus. An understorey of Humulus lupulus, Filipendula, Osmunda, Cirsium (palustre?) and Cyperaceae was able to flourish.

LC7b (112-048cm)

Zone LC7b is estimated as spanning the period 1250-780 BP, (700AD to 1170 AD) and is characterised by a rapid expansion of herbs (average 43%) and an associated decline in trees (36% average) and shrubs (10% average). Quercus percentages are now continually reduced and the vegetation is dominated by Alnus and Betula. The charcoal record suggests that fire was a common occurrence, and the presence of coarse charcoal in the pollen washings suggests that fires were more intense, on a larger scale, and closer to the lake than on previous occasions. It is also possible that charcoal transport was improved as erosion increased and slopewash became more significant. Tree cover was reduced resulting in increased erosion of top soils and deposition of derived grains. Estimated average sedimentation rates were increased (0.13 cm/yr) with rapid erosion and disturbance of deeper soils that were relatively unleached and contained high sodium concentrations. Maximum soil disturbance culminated at around 1050 BP.

The high diversity of herbaceous taxa and Gramineae increases infer large areas of cleared land used for agricultural purposes. The herb record suggests that there was mixed economy with both pastoral and arable farming. Cereal grains are recorded and other taxa indicative of arable activities include Artemisia, Chenopodiaceae, Cruciferae, Caryophyllaceae and Campanula. Areas of pasture were also extensive, characterised by herbs such as Plantago lanceolata, Rumex, Ranunculus and Potentilla. Areas of open pasture and Corylus scrub would have expanded and contracted depending on grazing intensity and fire occurrence.

Numerous other herbs occur, including Melampyrum, Polygonum persicaria, Umbelliferae, Calluna, Rumex, Ericales, Gramineae, Pteridium and Urtica, indicative of grasslands and heath. There are now low and sporadic counts of Cannabaceae suggesting that the cultivation of Cannabis sativa was taking place in the locality, but as yet there is no evidence of retting within the lake (cf. Bradshaw et al., 1981).

Associated with the obvious increase of agricultural activity was a corresponding decrease in the extent of woodland within the catchment. Quercus woodland appears to have undergone a drastic and progressive decline with little opportunity for regeneration. From occupying significant areas of woodland, Quercus was now reduced to a local occurrence suggesting that clearance was now permanently destructive. Betula and Fraxinus were able to colonise the disturbed ground on the edges of pasture and occasionally invade open areas to form scrubland. Increasing pressure on the land is also indicated by a decline in Corylus and Hedera helix and occurrences of Ilex aquifolium.

Betula was still a component of the carr vegetation although a reduction in macrofossil deposition could indicate limited distribution. Alnus concentrations indicate that it also decreased in importance. Salix concentrations are reduced and it is possible that areas of carr were now being cleared with increasing pressure on the land. An indication that the carr was gradually opening up is the increased diversity of herbs associated with damp organic soils, including Urtica, Geum, Filipendula, Cannabaceae (of which some grains may be Humulus lupulus), Succisa pratensis, Cirsium, Vicia/Lathyrus and also Dryopteris.

This was therefore a period of both arable and pastoral farming, although the slight decline in cereal frequencies suggests that more land was used for grazing than previously. This may reflect increased leaching and erosion making the soils less productive. There was now widespread clearance and forest destruction as timber for building and fuel became less easy to obtain. There was no evidence of woodland regeneration and carr woodland was now apparently undergoing clearance as resources became increasingly scarce.

LC8 (048-000cm)

It is estimated that zone LC8 spans the phase from 1170 AD to approximately 1600 AD, the latter date estimated by assuming a sedimentation rate of 0.12cm/yr. The transitional seston at the top of the core was not collected and evidence of at least one phase of resedimentation suggests that sedimentation rates were probably higher; 1600 AD is therefore a maximum date for the core surface but without radiocarbon dates this is difficult to verify.

Zone LC8 is characterised by high Cannabaceae concentrations. Low values are recorded from 950 BP onwards with a rapid expansion at 780 BP (50% at 1170 AD) and except for an isolated low at 16cm, around 1450 AD, frequencies remain high into the 16th century (and possibly later). These are the highest percentages of positively identified Cannabis sativa that have been dated within Wales and are reminiscent of those recorded in eastern England by Bradshaw et al., (1981). At most British sites (eg. Seamere; Sims, 1978) a continuous Cannabaceae curve begins with the arrival of the Anglo-Saxons (approximately 800-1000 AD) and positive identification of Cannabis sativa at Hockham Mere (Godwin, 1967), shows that cultivation reached a maximum during this phase with associated records of Linum, Chenopodiaceae and Cruciferae. At Crose Mere (Shropshire) Cannabaceae concentrations reach $4.5x10^6 gr/cm^3$ with a rational limit dated at 1610+/-75 BP and a subsequent decline after 1055+/-72 BP (Beales, 1980). Cannabis values up to 10% are recorded at Llyn Mire (Moore, 1978) and are believed to be associated with Roman activity with further cultivation in Tudor times.

The fibre in Cannabis is thought to have been used in rope making (Bradshaw et al., 1981), sailcloth and canvas production. The seeds were used for oil, and it was also known for its medicinal and herbal properties (New Scientist, 7th July, 1988). The process of hemp retting in pits on lake edges to obtain the residual fibre resulted in the deposition of large quantities of pollen and in the decomposition of the plant. This process explains the high concentrations ($4.2x10^4 gr/cm^3$, 57%) of Cannabis pollen from the 18th century, recorded at Thompson Common (Bradshaw et al., 1981).

At Llyn Cororion, Cannabis concentrations of $8.3x10^4 gr/cm^3$ suggest there were fields of hemp around the lake and, as the results are comparable with those at Thompson Common, hemp retting was probably taking place. Associated with the Cannabis pollen is a rich herbaceous flora, including cereals, Gramineae, Umbelliferae, Artemisia, Solidago type, Compositae Tubuliflorae, Ranunculus undiff. and Campanula indicating the continuation of both pastoral and arable farming.

The Cannabis rise may explain the decreased carr woodland, as damp areas were cleared for hemp cultivation (cf. Beales, 1980) and improved access to retting areas. The temporary Cannabis decrease suggests that there was a short period of inactivity around 1450 AD, coinciding with a temporary phase of tree regeneration, but thereafter cultivation continued. Llyn Cororion was therefore an important site for the cultivation and retting of hemp from the 12th century onwards. The lack of natural lakes on the coastal plain may have made Llyn Cororion a significant site, but without further study it is difficult to say if Cannabis cultivation was a purely local phenomena or a widespread practice.

Decreased carr vegetation reflects clearing intensity and the increased use of the damp areas around the lake. Alnus carr would have been reduced to isolated stands in waterlogged areas too wet for agricultural use or for other shrub taxa to colonise. Salix and Betula still thrived but the increased herb record suggests a thinner canopy. There was a relatively diverse field and ground flora including Hydrocotyle, Potentilla, Filipendula, Succisa pratensis, Urtica, Cirsium and Dryopteris. Macrofossils of Dryopteris and Betula decline suggesting that these taxa may have had a limited distribution, but the presence of Caryophyllaceae seeds indicates the local presence of the latter. Myrica gale may have been present in damp scrubby habitats possibly associated with fern taxa (eg. Polypodium, Dryopteris), moss communities and sedge.

The zone is also characterised by final and complete woodland clearance except for isolated stands, and an expansion in arable agriculture. There is a rapid expansion of herbaceous frequencies and tree values are reduced (21%), indicating that the landscape was now essentially treeless. The inorganic input into the lake was at a maximum, and coarse mineral material in the pollen washings reflect clearance intensity and soil disturbance; the relatively high percentages of broken and corroded grains and increased Filicales undiff. indicates soil reworking.

Fire was now a frequent occurrence and increased charcoal particle size, abundance and frequency imply that fires were more extensive and common. Increased charcoal also reflects improved sediment transport as vegetation cover was reduced and there was less 'trapping' of material within the carr. Associated with the charcoal records is increased input of coarse organic detritus and leaf fragments suggesting increased erosion efficiency and frequency. The lake continued to shallow with evidence that there may have been phases of resedimentation and sediment focusing with the possibility that these were caused by local disturbance.

The period from 1170 AD onwards represents the period of Monastic establishment within Wales. Associated with this was extensive deforestation, increased arable farming and the introduction of large scale sheep farming (Ball, 1963). The charcoal record suggests clearings were managed using fire, and the increased grazing resulted in the permanent destruction of the remaining woodland. The landscape was dominated by open grasslands, pasture, areas of crop cultivation and Betula-Corylus scrubland.

The concentration diagram indicates that the last phase of clearing occurred around 1480 AD. Quercus no longer formed a dominant part of the vegetation and forested areas were now negligible. Decreasing Quercus percentages could reflect the demand for building material and fuel and the use of oak bark for tanning (cf. Linnard, 1979). Hedera helix was reduced, unable to colonise areas of continual disturbance and persistent grazing, and Ilex aquifolium occurs sporadically indicating a decline in soils with a high humus content (Fairhurst and Soothill, 1989). Low values of Sorbus aucuparia and Fraxinus indicate that these taxa were reduced to isolated stands, perhaps on the margins of the carr, with little opportunity for secondary woodland to become established. It is also likely that with a shortage of other woody taxa, *Fraxinus* was now felled for use as fuel and charcoal production.

Fluctuations in *Corylus* and *Betula* reflect the occasional formation of scrub although a proportion of the Coryloid record may be attributable to *Myrica gale* which would have thrived in the damp areas around the lakeside. The progressive decline in *Corylus* values may indicate the increasing importance of hazel wood for construction as other timber became rare or perhaps regeneration was prevented by grazing pressure. At approximately 1450 AD there was a slight rise in *Quercus*, *Ulmus*, *Corylus* and *Betula* values associated with decreased herb values, including a decrease in Cannabaceae concentrations, which could indicate a slight increase in the woodland cover and a temporary pause in farming, but tree values were still low and this does not represent a major regeneration phase.

The landscape around Llyn Cororion was therefore characterised by *Betula*-*Corylus* scrub and isolated *Quercus* stands, interspersed with arable and pastoral farming. After final deforestation the vegetation around the site changed very little and only the distribution or proportion of arable and pastoral farming must have varied. An increase in taxa associated with pastoral activity suggests that around 1400 AD animal husbandry became more important and there was less arable activity within the locality perhaps reflecting a reduction in population (cf. Moore, 1968).

CHAPTER 7

LLYN HENDREF POSTGLACIAL HISTORY

LLYN HENDREF: INTRODUCTION

Llyn Hendref and Cors Bodwrog (fig. 2.5) lie in a SW-NE trending, geologically defined depression which was accentuated by Late Devensian ice. It is essentially a glacial erosion feature coincident with the Penmynydd schist zone and now infilled with Lateglacial and Holocene lacustrine and terrestrial deposits. Similar depressions are recorded at Llyn-yr-Wyth-Eidion (personal observation) and Cors Goch (Seddon, 1958).

From photographic evidence it is known that the area of Llyn Hendref was reduced by drainage work (fig. 2.6) in the 1960s although without a detailed coring program in Cors Bodwrog, its original extent, in the early Postglacial is difficult to estimate. The lake probably extended, towards the north-east and north-west, with isolated highs possibly forming small islands. The slopes to the north were relatively subdued with a gently shelving shoreline ideal for marsh formation. Deeper basins probably existed in the south-west, the area occupied by open water today, with steeper rocky shores to either side. Streams would have entered the system at various points around the basin, most frequently in the north.

The pollen source area would have been affected by a series of complex and interacting factors which changed through time as the lake hydrology varied and as vegetation developed. The relatively open landscape, large open lake and stream input resulted in a predominantly regional pollen source area but pollen was also derived from eroded soils and from plants colonising the lake edge and stream banks. The probability that the core was taken from a site that was close to the original lake edge also accounts for a high local pollen input. The possible pollen source area throughout the Postglacial has been represented on figure A4.1 and a summary

Table 7.1 Llyn Hendref Local Pollen Assemblage Zones

Local Pollen Assemblage Zone	Depth (cm)	Age (yrs.BP)	Average Percentages %PS		
			Trees	Shrubs	Herbs
LH 7 Cannabaceae -*Alnus*	56-0	3800-?	41	16	32
LH 6 *Alnus-Corylus*	432-056	4600-3800	45	21	20
LH 5 Gramineae -Cyperaceae -*Alnus-Corylus*	552-432	4920-4600	36	18	40
LH 4 *Alnus-Pinus* -*Quercus*	596-552	7850-5735	57	37	3
LH 3 *Corylus-Ulmus* -*Quercus*	692-596	9420-7850	34	56	9
LH 2 *Betula-Salix*	712-692	9890-9420	60	14	23
LH 1 *Betula-Juniperus*	720-712	10285-9890	37	11	27

Local Pollen Assemblage Zone	Sedimentation Rate (cm/yr)	Average Conc. (gr/cm^3)	Average PAR. (gr/cm^2/yr)
LH 7 Cannabaceae -*Alnus*	0.02	2.8×10^5	4.6×10^3
LH 6 *Alnus-Corylus*	0.32	2.6×10^5	8.4×10^4
LH 5 Gramineae -Cyperaceae -*Alnus-Corylus*	0.32	4.32×10^5	1.4×10^5
LH 4 *Alnus-Pinus* -*Quercus*	0.02	2.7×10^5	6.0×10^3
LH 3 *Corylus-Ulmus* -*Quercus*	0.06	3.9×10^5	1.1×10^4
LH 2 *Betula-Salix*	0.03	2.9×10^5	8.8×10^3
LH 1 *Betula-Juniperus*	0.02	5.3×10^4	1.0×10^3

of local pollen assemblage zones is given in table 7.1.

7.1 LLYN HENDREF : STRATIGRAPHY AND SEDIMENTOLOGY

Basal Inorganics (1006-720cm)

The core stratigraphy indicates that a Postglacial and late Loch Lomond Stadial sequence were sampled. It is possible that Windermere Interstadial sediments were not deposited (but this is unlikely). Windermere Interstadial deposits recovered from Cors Goch (fig. 1.6) indicate that Anglesey supported scrub vegetation with a diverse herbaceous flora during the short climatic amelioration. Interstadial pollen-rich organics have also been recovered from sites at higher altitudes (eg. Clog-wyngarreg; Ince, 1981). There is nothing to suggest that Anglesey could not have supported taxa such as *Salix herbacea*, *Betula nana* and *Juniperus* throughout the Loch Lomond Stadial. Failure to recover sediments of this age could be due to inability of the coring equipment to penetrate coarse minero-genics associated with Loch Lomond Stadial deposition. This is also possibly the case at other lowland sites (eg. Tre'r Gof; Botterill, 1988) that have failed to produce a complete Late Devensian sequence.

The basal sequence (1006-720cm) at Llyn Hendref indicates a severe climate with sparse vegetation. Cwm glaciers formed in higher areas of Snowdonia (section 1.3.4) and in the lowlands there was increased erosion and renewed solifluction. At Llyn Hendref a total of 286cm of basal inorganics (plate D1) were recovered; this is a minimum length and it is not known if the base of the sequence was sampled. Assuming that the basal gravels represent the onset of the climatic deterioration around 11 000 BP (a date of 11 300+/-300 BP has been obtained from Glanllynnau, Simpkins (1974) and a date of 11 160+/-90 BP at Llyn Gwernan, Lowe (1981), has been obtained for the same horizon), then a minimum average sedimentation rate for this period can be calculated. The resultant value of 2.6 cm/yr is high, (Craig, 1978) implying a severe climate and processes such as freeze-thaw action, solifluction and mass movement before minerogenic deposition in standing water.

The basal 'gravels' at Llyn Hendref can be divided into two units, both inclined at 30° and coarsening upwards from medium/fine sand to gravel (plate D1). The mineralogy indicates derivation from local source rocks and glacial deposits. Clasts are predominantly mica schist, quartzite, feldspathic sandstone and quartz conglomerate, chlorite schist, rare degraded granite and vein quartz, all of which occur within the catchment. Some pebbles are coated with iron oxide and are heavily weathered. There are two possible explanations for the crude sorting and reverse grading. Coarser material may have initially been deposited close to the lake edge but with continuing deposition it became inherently unstable. Slumping may have occurred, transporting the sediment to deeper areas, and during transport material would be crudely sorted due to kinematic mixing. It is also possible that the material was derived from stream deposits with the reverse grading resulting from the growth of small scale 'deltas' on sloping areas of the basin. The occurrence of two graded units would suggest an increase in water depth and renewed sedimentation during the time of deposition.

Above the gravels is an abrupt boundary (966cm) and the next 24cm of finer material suggests a more stable sedimentary environment. The sequence consists of laminated sands/silts (0.125mm-0.04mm) and clays distinguished by colour. The average thickness of laminae is 2mm although some coarser sand bands reach thicknesses of 5mm The sand is quartz and mica rich and decreases in frequency and grain size until at 941.5cm the laminae are composed predominantly of silts and clay. The laminated section of the core is disturbed with overfolds, slumping and faulting (plate D2 and fig. 3.1) representing a phase of instability. It is not known if deformation was syn- or post-depositional. The sediment coherence and the possible existence of a shear plane at the upper surface suggests that sediment movement took place after deposition and initial consolidation. Deposits of partially consolidated material from shallower areas of the lake may have become unstable and with an increasing overburden, they slumped downslope as a coherent mass. Slopes of only 4° (Lewis, 1971) can induce sediment movement. Similar slumping of Lateglacial deposits has been described from Windermere (Smith, 1959; Mackereth, 1966) where it was noted that overlying Postglacial deposits were undisturbed. It has been suggested that the higher cohesive strength of organic deposits makes them less susceptible to slumping (Bennett, 1986b).

Laminated Lateglacial clays have been recorded from a number of sites in Wales (eg. Capel Curig; Crabtree, 1965: Nant Ffrancon; Burrows, 1974) and different interpretations have been suggested for their formation. Not all laminations are attributable to annual deposition resulting from seasonal climatic changes or fluctuations in ice; local factors also have a considerable influence (Saarnisto, 1986). Many laminations described for upland sites resulted from cwm glacier fluctuations throughout the Stadial (eg. Nant Ffrancon; Seddon, 1962: Burrows, 1974). At Llyn Hendref this is an unlikely explanation as permanent ice would have been almost non-existent and, although the laminations indicate some kind of periodicity, there is no direct evidence that this was a result of seasonal climate changes.

There is a possible shear plane between the overfolded laminated sediments and the horizontally bedded deposits above. The overlying material is undisturbed and predominantly thinly laminated clays and orange silts. Stratification gradually diminishes upwards grading into unstructured clay with occasional lenses of black greasy material and bands of gritty orange sand.

Above the slumped sediments are orange laminated clays. Saarnisto (1986) suggests that 'orange' and dark laminations are linked to overturn periods in spring and autumn when bottom waters are oxygenated resulting in the formation of iron oxides. The presence of goethite associated with sandy layers has been described at Llyn Gwernan (Lowe, 1981). In summer and winter, when there is little water movement, sediments are oxygen deficient and iron sulphides are formed. The numerous thin black laminations identified in the Llyn Hendref core may be a result of this, which would also explain the associated hydrogen sulphide smell. It is possible that the laminations are a reflection of local hydrological conditions within the catchment (cf. Smith, 1959) with the sporadic coarser sand bands reflecting flood periods and occasional pebbles indicating the dropstone deposition after freezing of the lake.

The clay mineralogy is dominated by hydrous mica (illite), chlorite, vermiculite, kaolinite and other inter-stratified minerals (illite/vermiculite), typical of derivation from Irish Sea till (section 4.3.3). The assemblage is dominated by magnesium and iron rich minerals. The chemical data suggest that sediment leaching may have occurred on a limited scale but that the source material was also inherently base-poor. During the Loch Lomond Stadial there were large areas of exposed glacial deposits containing primary phylosilicates and rock flour, much of it unconsolidated and easily weathered. This material was transported by slopewash, mass movement, solifluction and stream transport and was then sorted during sedimentation and redeposition within the lake. Derived pre-Quaternary spores (Carboniferous), may have been reworked from the glacial deposits within the basin although it is also possible that they are aeolian in origin (section 3.7.4).

At 903.5 cm a 1cm pod of organic rich material (organic content 10%) was identified and sampled. The resultant pollen count and its stratigraphic position, at the top of a core and as a discontinuous layer, showed it was contamination caused by 'younger' material falling down the coring hole between extractions. In this particular case contamination was readily identified but it illustrates some of the problems associated with the coring procedure. In an organic sequence contamination such as this would not always be easy to recognise and this problem was kept in mind when taking samples for radiocarbon dating.

Within the clays (organic content 4-5%) were occasional inwashed moss fragments. These indicate that although the landscape was relatively bare there were now areas where vegetation was surviving. Sporadic black sulphurous bands occur with degraded mica schist pebbles identified at 855cm and 845.5cm. The massive nature of the upper clay suggests a period of rapid erosion and deposition in deep water. An isolated lens of fine/medium sand at 824cm is well sorted and possibly represents stream input.

Between 800-720cm the sequence exhibits a series of changes indicating that the catchment was gradually stabilising with increased vegetation. Sand bands become increasingly frequent towards 750cm with a corresponding decrease in pre-Quaternary spore frequencies. At 750cm there is an abrupt change with a thin band of olive-grey clay and calcareous nodules underlying 1.5cm of gravel-rich lake mud (organic content 17%) and coarse organic detritus grading into sandy lake mud and then back into inorganics (organic content 4-5%). The absence of aquatic taxa and algae at these levels (fig.7.2) suggests that organics were terrestrially derived. Increasing pollen concentrations could indicate decreased sedimentation rates and pollen counts show that taxa typical of Lateglacial assemblages were now present (section 7.3). The gradually increasing organic content could reflect a decreased inorganic material input, but is likely to reflect increasing plant colonisation around the lake. Leaf fragments suggest that sparse scrub was established around the lake margin and <u>Daphnia</u> cysts, and <u>Chara</u> and <u>Nitella</u> oospores indicate that there was productive standing water.

The overlying laminated sands/silts/clays (742-720cm) are differentiated by both grain size and colour. The coarser sand bands are orange, and although their frequency decreases upward, there is still a relatively high input of inorganic material coarser than 118 microns (fig. 3.4), suggesting that slope processes were still important. The clay and silt content decreases as the organic content increases, and the boundary between the two has been taken at the point where the organic content increases from 4% to 20% (720cm) A gradual transition between Stadial inorganics and Postglacial organics was also noted at sites in Scotland (Pennington et al., 1972) and at Lake Windermere (Smith, 1959).

Just below the onset of organic sedimentation (721-726cm) vivianite is abundant and there is one quartz pebble. Vivianite ($Fe_3(PO_4)_2 8H_2O$) is a secondary phosphate which turns blue when exposed to air. It is common in deposits that contain decayed wood or bone fragments (Hamilton et al., 1979). There was no evidence of bone in the core so the likely source of the phosphorous was the increasing woody material within the sediment.

The basal inorganic sediments are therefore believed to be of Loch Lomond Stadial age and to have been deposited under a severe climate with increased seasonality (Rind et al., 1986) and long winters. At this time the mean annual temperature was rarely above freezing with an average January temperature of -20°C for much of north and west Britain (Lowe and Walker, 1984). Periglacial activity was increased with severe frost action and aeolian activity was important (section 3.7.4). There was increasing aridity (Rind et al., 1986) and the frequency of perennial snow patches increased (Lowe and Walker, 1984). At Llyn Hendref local sediments were rapidly weathered from the surrounding catchment and transported by mass movement, slopewash, solifluction or streams to the lake.

Iron reduction seems to have been a common occurrence resulting in the 'rust' colour of much of the core and this may have been associated with periodic water overturn. The onset of organic sedimentation was a gradual process with vegetation colonisation whilst intense erosional processes were still prominent. The stratigraphic record is difficult to interpret because the lake was originally much larger and may have been separated into a number of deep basins each with its own record. As water levels fluctuated the sedimentary processes responsible for the deposition of material changed making interpretation of the sequence complex. Generally the sequence compares well with other Lateglacial sequences that have been described from North Wales (eg. Tre'r Gof, Anglesey; Botterill, 1988).

LH1 (720-712cm)

Zone LH1 is characterised by a gradual change in input from minerogenic to organic material. At Llyn Hendref the date for the onset of organic sedimentation, (10 285+/-95 BP) indicates the point where organic material is continually observed and the decline in inorganic material is rapid and progressive. The onset of organic sedimentation has been taken as the point at which the organic component is increased to 20% and where an obvious stratigraphic change can be visually identified. Laminated minerogenic material grades into unstructured lake muds with occasional coarse organic fragments. Pollen washings indicate that coarse mineral material is still present but is reduced in frequency and quantity indicating that most mineral matter in this core portion is of silt or clay size. This date for the onset or organic sedimentation is one of the earliest for Wales (section 5.5.3), possibly reflecting gentle catchment topography, low site altitude and also the presence of large inflowing streams. All of these factors would have enhanced organic input. The increasing organic content suggests that there was less severe erosion within the catchment but the inorganic input was still relatively high reflecting the importance of stream input.

At the onset of climatic amelioration shrubs were able to spread rapidly and, with increasing vegetation cover, soils developed interspersed with bare rocky patches. Decomposing organic debris resulted in a supply of plant debris which was transported to the lake. Associated with the increased organic content is a corresponding rise in sodium, potassium and calcium concentrations, perhaps linked with the development of carr vegetation although a preferential enrichment of calcium could indicate a source of calcium-rich ground water derived from Irish Sea till.

It is likely that the lake consisted of more than one basin of deposition and that different processes were operating in each one. The organic sequence is unstructured suggesting that deposition was continual and relatively rapid, possibly affected by annual vertical water circulation and bioturbation. The presence of coarse inorganic and organic material in the core suggests that this was not the deepest area of the basin and that input from vegetation around the lake, and stream input and slope wash, were still contributing to the sediment. The coarse mineral lithologies indicate that glacial deposits provided the silt and sand fraction, and bedrock and erratic blocks yielded coarser pebbles. A steady input of indeterminable grains suggests active stream input. Charcoal counts are high in this zone but it is possible that some fragments are derived coal.

Sedimentation rates are thought to have been decreasing towards the end of the Loch Lomond Stadial and for this zone they are estimated at 0.02cm/yr. This figure may not reflect the general sedimentation rate for the whole basin, particularly if the lake basin was divided into a number of deposition centres. The sedimentation rate here may be an indication of the deposition rate in the deeper areas of the basin whilst in the littoral areas the sedimentation rate may have been greater (eg. as at Hockham Mere; Bennett, 1983c). The sedimentation rate at Llyn Hendref is a reflection of fine material deposition, and cannot be taken as a measure of the erosion rates within the catchment.

LH2 (712-692cm)

The loss-on-ignition results show that organic input increased from 36% to 57% in this zone. A gradual shallowing is suggested by the pollen analysis but this is not reflected in the stratigraphy which remains lake mud. Sediment input was predominantly fine material of local origin with organics derived from the catchment and also from the fringing macrophyte and reedswamp vegetation. Pediastrum values were high so it is possible that some organic material may have been autochthonous. The coarse mineral material identified was a poorly sorted, subangular, immature sand suggesting local derivation. The presence of vivianite indicates the formation of secondary phosphate from plant debris.

Landscape stabilisation therefore continued during zone LH2 but loss-on-ignition results show that there was still a high proportion of inorganic material reaching the lake. Despite woodland development on surrounding slopes, there was continued downcutting into boulder clays and erosion of stream banks and slopewash from rocky outcrops, ensuring a continued supply of mineral material. Gradually erosion rates declined and there was a higher organic input into the lake although this does not produce the expected increase in sodium and potassium values (section 4.2.3). The area was now dominated by Betula woodland and an increased canopy meant reduced precipitation, less run-off and consequently decreased erosion. There was a rich herbaceous flora binding the soil preventing mass movement and slope wash on all except the steepest slopes. The birch woodland (section 7.3) produced mull humus with the accumulation of a thick litter layer although bare uncovered areas probably still occurred.

Sedimentation rates slightly increase in this zone (0.03cm/yr) but with uncertainties associated with data from the age depth curve, this may not be significant. This is also difficult to interpret because of unknown factors such as basin morphometry and the internal dynamics of the lake system. An increasing sedimentation rate would be unusual in a stabilising landscape and the figure calculated for this particular zone may reflect local factors such as redeposition and resedimentation and may not be characteristic of the whole basin. The effect of the apparently increased sedimentation rate was to produce a corresponding decrease in element concentrations (section 4.2.3). The influx diagram suggests there was disturbance towards the zone top, with one episode of redeposition identified implying fluctuating water levels affecting littoral sediments. Areas of exposed shoreline may have been subjected to erosion with material then undergoing sediment focusing. This level of redeposition is associated with increased charcoal abundance suggesting that the charcoal may be derived.

LH3 (692-596cm)

The stratigraphic sequence indicates continued lake mud accumulation with sporadic input of inorganic material. The loss-on-ignition curve shows an increased organic content (rising from 46% to 64%, fig. 4.3), implying that soils were stabilising and maturing as vegetation cover increased, resulting in reduced erosion. Although the organic content of the sediment is high the minerogenic input stays at about 50% reflecting the efficiency of the local stream network in transporting material to the lake basin. The organic content fluctuations result in varying potassium and sodium concentrations. The muds are unlaminated suggesting relatively shallow water and possibly post-depositional disturbance.

Changes in the influx diagram appear to reflect real pollen input variations suggesting that most material was derived from within the catchment area and not associated with erosion and redeposition of littoral deposits. Observed increases in inorganic input coincide with the introduction or expansion of a new taxon; the increased inorganic input at 680cm is associated with rapidly rising *Corylus* values. This suggests that during the immigration of a new taxon, there is some initial disturbance of the soils during the phase of increased competition. It is possible that this association is coincidental and the increased inorganic material is a local phenomena resulting from periodic storm inwash, changing stream input or variations in the hydrological regime within the lake basin.

The estimated sedimentation rate is increased (0.06cm/yr) suggesting increased erosion, contrasting with the loss-on-ignition data, and is inconsistent with the idea of a stabilising environment. The calculated sedimentation rate has to be treated with caution due to problems associated with radiocarbon dating and the extrapolation of data. The influx diagram indicates that this is a relatively stable period with only one clear example of erosion and redeposition (at 616cm) The increased sedimentation rate may represent a shift in preferential sedimentation induced by a changing sedimentary regime. It is possible that increased accumulation rates were due to the redirection of material perhaps in the form of 'plumes' ("density flows produced by inflow"; Hilton et al., 1986), currents initiated by changing water levels resulting in a different internal hydrodynamic system.

It could also be the result of increased organic productivity either within the lake itself or within the catchment. Decreased percentages of Pediastrum suggest that an autochthonous source was unlikely; an allochthonous source is possible as a result of increased productivity associated with greater forest cover. Bennett (1983c) noted an increased sedimentation rate at Hockham Mere, associated with higher organic content and Corylus dominated woodland and suggested that finer organic material of a lower density was eroded and redistributed into deeper water resulting in an apparently increased sedimentation rate.

The aquatic vegetation indicates that there was a general shallowing of the lake as the hydrosere developed; associated with this is evidence that the lake system was beginning to become unstable. A simultaneous decrease in the influx of all taxa at 616cm suggests that pollen percentages at this level were a function of the sedimentary regime with disturbance of the littoral deposits and redeposition over the rest of the lake. This resulted in simultaneous lows in the calcium, sodium and potassium concentrations and was the beginning of an unstable sedimentary regime.

LH4 (596-552cm)

The stratigraphy indicates that lake mud continued to accumulate and the loss-on-ignition results show that organic input reached a maximum (73% at 560cm). Pediastrum values are relatively high at this level and some of the organic material may be due to internal productivity although most of it would have been from terrestrial sources and from fringing lake vegetation. The latter was also responsible for a steady input of sodium and potassium. This was a period of maximum tree cover (section 4.2.3) and minimum soil erosion, so the inorganic material was probably derived from stream input. The pollen washings indicate a continual input of fine sand with the occasional deposition of gravel. Slope processes and mass movement would now be minimum and the carr vegetation and reedswamp would act as an effective sediment trap at the edges of the lake.

There is no evidence to suggest the presence of unconformities or a disturbed sequence, but the pollen influx diagram and the estimated sedimentation rate imply that the sediment regime had changed. Sedimentation rates appear to be reduced (to 0.02cm/yr), with a corresponding reduction in all pollen accumulation rate curves. Changes are not always synchronous and the accumulation rate diagram suggests only one phase of redeposition (at 556cm).

The decreased sedimentation rate and the decreased inorganic input would have been partially due to stable soils and increased tree cover but values of the former are too low to be accounted for solely by these processes. The decreased pollen accumulation rates are also unlikely to reflect a decrease in forest cover as all values are reduced simultaneously, and it is believed that this was a time of maximum woodland canopy (section 7.3). The decreased accumulation rate is therefore taken as an indication of the continually changing patterns of sediment deposition within the lake basin that were hinted at in zone LH 3. The system appears to have become inherently unstable.

The reversion to a lower sedimentation rate suggests that sediment was now being directed elsewhere in the basin. It is also possible that there were sporadic and short lived periods of erosion at this site which have not been identified in the pollen record or in the stratigraphy. It has been suggested that low intermittent rates of sedimentation are characteristic of a relatively high energy environment (Davis et al., 1984) and this may be the case at Llyn Hendref as the lake level gradually shallowed. The lower sedimentation rate produced a corresponding increase in potassium, sodium and calcium concentrations.

Fire disturbance within the catchment is indicated by the charcoal fragment concentrations. At 596cm (7850 BP) charcoal is recorded within the lake sediment but effects of fire are not identified in the pollen record or in the loss-on-ignition data. The low charcoal concentrations and the apparent lack of substrate disturbance implies that the fire did not occur near the lake, but outside the pollen source area with the charcoal transported to the site by stream action and wind. Other records of charcoal (eg. around 556cm) are accompanied by increased inorganic material, decreasing Quercus and Ulmus and increases in taxa of secondary woodland (Corylus, Betula). This indicates that fire affected local vegetation and the substrate. Organic soils were burnt exposing the mineral rich horizons underneath, and openings in the canopy increased the quantity of precipitation reaching the ground. Increased erosion and more effective slope wash transported the mineral material to the lake basin.

Due to the inherent errors associated with radiocarbon dating it is difficult to rely on and interpret the estimated sedimentation rates and the resultant influx diagram. The results suggest that there has been some change in the sedimentary regime but the stratigraphy implies that deposition was more or less continuous in a relatively stable environment. It is possible that there are unconformities within the sequence that have been impossible to identify but which would alter the apparent sedimentation rate. It is likely that sedimentation rates were continually changing throughout the zone with higher rates around the times of fire disturbance and during phases of redeposition. Towards the top of the zone water levels change, the sediment limit is altered and shoreline sediments are exposed and subject to erosion and redistribution within the lake.

LH5-LH8 (552-0cm)

An unconformity has been identified at 552cm and is apparent in the pollen diagram with simultaneous changes in all tree taxa and the introduction of a large number of herbaceous taxa. The stratigraphy changes from fine lake mud to lake mud containing large quantities of coarse organic detritus. The hiatus is verified by radiocarbon dating which suggests that 815 radiocarbon years are missing. As previously described the sedimentary regime of the lake had been becoming increasingly unstable with frequent evidence of resedimentation, uneven sedimentation rates, changing sediment foci and possibly fluctuating water levels. It is difficult to say if the unconformity is a culmination of this instability; other possibilities present themselves:

1) The hiatus may represent a true phase of non deposition, beginning at 5735 BP and lasting approximately 815 years before continual but disturbed sedimentation recommenced. During this break the coring locality was above the sediment limit, due to falling water levels, and was subject to erosion or non-deposition. Once deposition started again, it would have been intermittent with much material derived from redeposited lake mud. The radiocarbon dates in this scenario would therefore date actual events.
2) Sedimentation continued after 5735 BP but then material was displaced in a single or multiple event (date unknown) before deposition recommenced. In this case the hiatus represents a slip plane above which discontinuous sedimentation then took place.

The hiatus could represent a combination of non-sedimentation and erosive events. The above scenarios assume that the date immediately above the hiatus is true and the sediment above represents more or less continuous but disturbed deposition.

3) Deposition may have continued undisturbed until recently, with major sediment disturbance occurring during land reclamation and drainage work. With a drastically lowered water level, large scale sediment erosion and redeposition may have occurred, especially in shallow areas. The unconformity would therefore represent the plane along which sediment was displaced, and the date of 5735 BP has no significance. The sediment above would be either dumped material or redeposited from other areas. The dates above the unconformity would therefore have no significance.

The following evidence has to be taken into account:

1) Simultaneous changes in most of the pollen accumulation rate curves suggest that pollen and sediment were derived from the same source, ie. stream-borne or redeposited littoral sediment.

2) The radiocarbon dates are in chronostratigraphic order but the upper date of 3370 years BP suggests that approximately 5m of sediment were deposited in 1500 years, a sedimentation rate of 0.13cm/yr. This is high and suggests that there was material input other than that derived from the catchment.

3) The large increase in herb taxa above the unconformity suggests that there was a break in deposition during which time deforestation occurred and herbaceous taxa flourished.

4) Fluctuations in the pollen percentage diagram indicate 'smooth' (implying continuous) rather than episodic disturbance.

5) The introduction of cereals at Llyn Hendref is estimated at 4350 BP. This is early when compared with a date of 2950 BP from Llyn Cororion and 3500 BP from Tre'r Gof (Botterill, 1988). This suggests that the sequence is mixed and contaminated.

6) Further evidence for a mixed sequence is the presence of isolated Fagus counts at 536cm and 488cm, (ie. older than 3370 BP). Godwin (1975) records no Fagus grains in conventional zone VIII and Birks (1989) indicates that Fagus did not reach North Wales until 1000 BP. Historic evidence suggests that in the tenth century Fagus was absent in North Wales and observations by Lluyd infer that Fagus was first planted in North Wales in the seventeenth century when it became a commercial product (Linnard, 1979).

The presence of Fagus immediately above the hiatus, at 4985 BP, could be contamination but its occurrence at levels interpreted as redeposited indicate that it is likely to have been introduced during sediment redistribution. Given the estimated date of the first beech in North Wales, this suggests that significant sediment slumping and mixing has occurred and that little of the upper stratigraphy can be regarded as reliable.

7) The increase in coarse material and inorganics immediately above the hiatus suggests that there was significant lake shallowing. The coarse material is unstructured but the sequence generally fines up with decreasing mineral material perhaps indicating a gradual increase in water levels. Occasional sand bands and undisturbed laminae indicate that the whole core is not mixed.

8) There is evidence below the hiatus that the sedimentary regime was already becoming unstable.

The above data suggests that one of the first two scenarios is the most likely. The correct order of dates, the occasional undisturbed level and the quantity of material involved perhaps indicates that hypothesis three is unlikely. Given the data set it is not possible to decide between hypotheses one and two. Between 5735 BP and 4920 BP there was either a phase of non-deposition or at some point after 5735 BP but before 4920 BP there was a phase of erosion. Above this deposition continued but the sediments suggest that the lake was now shallow and that deposition was very rapid. Pollen accumulation rates, increased inorganic material, and the occurrence of cereal and Fagus grains indicate that much of the material was redeposited after initial accumulation. Thereafter the lake level appears to have increased but not enough to ensure undisturbed sedimentation. Sedimentation continued intermittently with only occasional phases of stability.

The radiocarbon dates above the unconformity are unreliable as they may simply give an average age estimate for mixed sediment. A sequential interpretation of the diagram is impossible without a series of closely spaced radiocarbon dates which would indicate if the sediment is completely mixed or if parts are undisturbed. In the absence of radiocarbon dates it is only possible to generalise about vegetational and sedimentological changes since 5735 BP.

In general after 5735 BP, the sedimentary regime of the lake continued with frequent redeposition, gradual infilling by macrophyte vegetation and the encroachment of bog. Internal sediment dynamics would have been continually changing with the frequency of littoral sediment erosion and redeposition, depending on the sediment limit and water depths.

Archaeological evidence suggests that the site was frequented by Bronze Age people who were responsible for the beginning of progressive deforestation (section 7.3). Associated with this would have been increased erosion rates resulting from progressive soil instability. Mineral input would increase as stream transport became increasingly important. As the lake gradually filled areas around the lake would become waterlogged encouraging the spread of mire taxa and colonisation by taxa such as Alnus and Betula.

7.2 LLYN HENDREF : AQUATIC AND HELOPHYTIC VEGETATION

LHA (784-752cm) AND LHB (752-724cm)

In zone LHA, aquatic vegetation was virtually absent but Pediastrum indicates that there was standing water at the site. The lack of aquatic taxa may reflect a combination of factors such as low temperatures, low plant nutrient availability or a high degree of silting and mineral input producing an unstable substrate.

In zone LHB open water is indicated by increased frequencies of aquatic taxa recorded and the presence of Chara and Nitella. Increased internal productivity is indicated by high Pediastrum production. The wetland community around the lake gradually merged with permanently water-logged sites and marginal reedswamps, Equisetum and pioneering Isoetes. A submerged community now existed at the lake with increasing species diversity resulting from increased nutrient availability and possibly clearer water, as indicated by the occurrence of Isoetes.

Myriophyllum possibly flourished in deeper areas of water (>50cm) associated with Potamogeton (perhaps P.crispus, characteristic of quiet deep water with a low organic input; Grime et al., 1988). Shallow water taxa characterised by floating leaves and emergent stalks appear to be absent at this time with limited fringing macrophyte vegetation. This may be that the vegetational succession has not yet had sufficient time to develop and that the lake was still relatively deep.

LH1 (720-712cm)

Llyn Hendref was initially a large area of open water with a high clastic input and internal productivity. Algae were present in large quantities (eg. Pediastrum and Botryococcus) suggesting a relatively high nutrient status and still, undisturbed water. Both Pediastrum and Botryococcus occur in freshwater lakes of a wide range of base status and can either be associated with macrophyte vegetation in shallow water or occur in planktonic mode (Birks, 1970). Daphnia and insect remains (fig. 3.4) suggest an active fauna colonising the lake and the aquatic community suggests mildly acidic water. The chemical results show that the sodium, potassium and calcium input are related to the vegetation rather than the mineral input, and that the calcium concentrations are great enough to support the production of Chara oospores.

Around input streams, the substrate would have been of relatively coarse inorganic material under high levels of disturbance. Reed communities dominated both stream sides and the shallow shore line with plants that were rooted in a predominantly inorganic substratum and were tolerant of seasonal fluctuations in the water level. Typha latifolia and Equisetum (E.fluviatile?) occur, aquatic species characteristic of shallow water (20-150cm) and mildly acidic soils with a high inorganic content (Grime et al., 1988). Typha latifolia is most abundant at water depths of around 600mm and possibly associated with species of Ranunculus which thrive in peaty acidic waterlogged conditions and on bare patches of mud. The reedswamp was probably open with opportunity for other species to become established eg. sedge communities consisting of species of Carex (possibly tufted sedge) and Ranunculus. Equisetum and associated Sparganium (erecta?) and Ranunculus species would have colonised the gently shelving basin edges which had accumulated a more organic soil, and had low silting rates and little disturbance. It is possible that reedswamp development and especially taxa such as Carex and Equisetum, enriched the sediment in sodium and potassium during accumulation and decay.

The reedswamp community would perhaps have dominated shallower bays and the north end of the basin gradually grading into the shallow floating-leaf community that was developing around the lake edge. The floating leaved community would form a niche for the bryozoan, Cristatella, statoblasts of which are recorded in the pollen washings record, (cf. Birks, 1970).

Nuphar records show that there was a community of water lilies probably interspersed with open water and possibly associated with Potamogeton and also Ranunculus; R.circinatus is associated with lily stands in nutrient rich water (Schauer, 1982). High Ranunculus percentages are recorded at the base of the diagram but there are a whole range of species that occupy a large variety of ecological niches making it difficult to know which habitat is indicated.

Potamogeton was also present, perhaps with a gradation between species depending on the local conditions. Species such as Potamogeton pectnatus are tolerant of nutrient rich waters up to depths of around 4m (Schauer, 1982), and this would have gradually given way to species such as Potamogeton perfoliatus which will thrive in depths of up to 6m. Potamogeton natans may have been present as a submerged aquatic in the deeper areas of stagnant water away from the influence of wave action and streams but thriving on a peaty substratum It is an effective colonist and is often associated with species of Equisetum and Sparganium, (Grime et al., 1988).

Deeper areas of the lake supported communities of submerged aquatics with distribution controlled by availability of suitable substrata and light intensity. Potamogeton and Myriophyllum dominated, possibly with species such as Potamogeton perfoliatus forming submerged vegetative patches in areas of the lake where there was still or slow moving water. In more exposed areas Myriophyllum alterniflorum would have colonised a predominantly inorganic substrate with its well developed rooting system anchoring the plants. Myriophyllum alterniflorum is relatively tolerant to exposure and wave action and may have provided a cover and shelter for less tolerant Potamogeton species. Also associated with the deep water community was Myriophyllum spicatum. The present day distribution of Myriophyllum spicatum and Myriophyllum alterniflorum tends to be mutually exclusive, but it is a common feature of the early Postglacial to find them both occurring together. Myriophyllum alterniflorum prefers nutrient poor water in contrast to Myriophyllum spicatum which occurs in still nutrient rich water up to depths of 600cm.

The exact location of particular species and their distribution would have depended on wave action tolerance, exposure, sedimentation rates and substrate type. These variables would be constantly changing through time as the lake gradually filled in. The pollen and spore record for the deep water aquatics suggests a generally low species diversity and a community colonising fine inorganic sediments containing little organic material. Deeper areas of the lake are likely to have been towards the south-west end of the lake but the disturbance of outflowing stream would also have been greatest here. Shallower areas would have been to the north where the greatest expansion of macrophyte vegetation would have taken place.

LH2 (712-692cm)

There are few major changes in aquatic vegetation. The organic input (maximum values are now 54%) reflects a stabilising landscape but the minerogenic input remains relatively high supplying a continual source of nutrients. An increasing macrophyte and reedswamp community contributed some organic material to the lake and also acted as a trap to hold back coarse minerogenic material entering the basin. The changing succession in the pollen and spore record suggests that there was accumulation of peaty and organic rich substrates with a reduction in silty areas and exposed bedrock. Pediastrum values were still high but Botryococcus frequencies are reduced perhaps reflecting their slow growth and intolerance of competition (cf. Birks, 1970).

Deeper water in which a submerged aquatic community thrived would have been slightly reduced and displaced possibly towards the south-west as the extent of fringing macrophyte vegetation increased. Myriophyllum and Potamogeton still thrived but Myriophyllum spicatum and Myriophyllum alterniflorum frequencies were reduced, replaced by Myriophyllum verticillatum. Perhaps the two former species were unable to tolerate increasingly organic conditions. Occasional Isoetes suggests colonisation of stony areas, perhaps along the shallow rocky shoreline; the presence of this taxon could indicate mild lake acidification (Johansen, 1975).

Nuphar species were replaced by Nymphaea as the dominant floating leaf species, perhaps again a reflection of increasing organic content and gradual shallowing of the lake as macrophyte vegetation developed. It would have formed a floating colony of white waterlilies along with broad-leaved pondweed species such as Potamogeton natans and possibly Ranunculus species spreading from the sheltered areas into the open lake. Rising Potamogeton percentages may reflect an increasing area over which the colonies were now distributed or possibly a shallowing of the lake; many species are rarely found in water depths >100cm (Clapham et al., 1987). The floating-leaved community would gradually grade into transitional reedswamp of Sparganium mats and increasing colonies of Equisetum.

The reedswamp vegetation probably expanded slightly accompanying increased accumulation of organic material around the lake edge. Typha latifolia declines, perhaps reflecting the decreased silt content of the sediment and a general drying out on lake margins as the level of the substratum was raised due to material accumulation. Areas once occupied by Typha latifolia would now perhaps be colonised by taxa such as Sparganium erectum or Sparganium simplex growing in standing water, perhaps associated with Phragmites. Typha still occupied wetter localities which were minerogenic rich, perhaps along stream courses. Further away from the lake edge in damp areas, associated with a high water table but with little flooding, would have been Ranunculus and tall stands of herbs such as Thalictrum and Filipendula. Increased

Cyperaceae suggests that there was an expansion of marshy areas around the lake which may have been associated with increased reedswamp development. Drier areas away from the immediate vicinity of the lake and stream banks were dominated by Cyperaceae, Gramineae and Pteridium.

This zone represents the successional development of hydrosere reflecting the increasing organic input resulting in a gradual shallowing of the water.

LH3 (692-596cm)

The stratigraphy shows that the landscape in this zone was stabilising with increased organic input and gradual lake shallowing, and the aquatic record suggests that there were two phases in this process; 1) a continuation of mire development, and 2) an acceleration of mire and bog expansion.

Phase One: Algal percentages decline, perhaps reflecting a reduced nutrient supply as mineral input was gradually decreased and the lake became dominated by floating-leaved macrophytes and fringing reedswamp. Associated with this was an increase in sodium concentrations (section 4.2.3).

Open water persisted with Chara and Nitella thriving. Submerged communities within the lake were reduced as fine organic material covered the remaining areas of bare ground. Myriophyllum alterniflorum was replaced by Myriophyllum verticillatum and Myriophyllum spicatum, although all three did co-exist occasionally. Potamogeton was still prominent, probably as a submerged aquatic with species confined to those able to tolerate the increasingly organic substrate. Potamogeton crispus may have colonised deeper stagnant water grading into Potamogeton natans colonising a thicker organic substrate in sheltered sites.

Increased shallow water areas were now available for colonisation, dominated by Nymphaea. Nuphar may have colonised quieter areas of the basin, protected in bays away from wind and currents, and possibly associated with *Potamogeton* species such as *Potamogeton circinatus*. Increased *Nuphar* and *Nymphaea* indicate continued colonisation of open water and the development of a floating mat community.

Areas of fringing reedswamp were still thriving with increased values for *Typha latifolia* and high values of *Equisetum*. The return of *Typha latifolia* and the absence of *Sparganium* suggest increased stream action with local reduction in areas of standing water and muddy soils. *Equisetum* was still a predominant coloniser in shallow water areas, away from disturbance and associated with increasing organic soils and reduced silting rates. Macrofossils of *Juncus* and *Carex* seeds indicate the formation of sedge tussocks standing in perennial water or possibly rushes growing in more marshy areas. Preferential uptake of potassium by swamp vegetation resulted in enrichment of the sediment.

The marsh community consisted of tall herbs persisting from the early Postglacial. *Filipendula* and *Thalictrum* formed tall stands interspersed with Cyperaceae and *Ranunculus* species, and in the wetter areas *Mentha* type (*aquatica*?) persisted with *Caltha*. *Calluna vulgaris* and Ericales grew in drier areas, and the *Sphagnum* record indicates that bog growth had begun. This is likely to have been on shallow slopes susceptible to bad drainage and waterlogging which result in the accumulation of decaying vegetation.

The vegetational succession at the beginning of zone LH3 was relatively stable, and changes were part of a gradual succession as the lake infilled with macrophyte vegetation and mire taxa. At around 8650 BP there was a change in the aquatic vegetation associated with occasional phases of inorganic inwash and one phase of resedimentation. There was bog expansion and a decrease in the deep water communities as macrophyte vegetation advanced across the lake.

Phase Two: Lake shallowing occurred either due to a decrease in water levels or increased debris accumulation and plant colonisation. Individual deeps may have infilled due to organic deposition resulting in a changing basin morphometry. The loss-on-ignition results show organic input is high although coarse inorganic input is increased in association with rising charcoal records. The landscape was therefore stable but inorganic substrates still persisted, perhaps around the western shore of the lake and around stream banks. Stream transport was still effective and there is some evidence of increasing instability of the sedimentary regime.

Submerged aquatics were reduced with negligible Nitella and Chara perhaps indicating a depletion of calcium rich waters. Myriophyllum species were restricted by shallowing water and competition from emergent or floating leaved assemblages. Sporadic occurrence of Myriophyllum spicatum suggests that the lake water was still relatively nutrient rich, but not enough to support the decreasing algal community. The occurrence of Isoetes indicates a reduction in silting but the continued availability of stony patches. Potamogeton species were still present but probably reflect communities of floating or emergent pondweed with a general reduction in deep water species. Deep water communities were now restricted to isolated patches in deeper areas.

The emergent macrophyte vegetation dominated with an increase in shallow water species. Nymphaea, Nuphar and Potamogeton communities spread with Nymphaea dominating and indicating increased shallow water and continual development of the hydroseral succession. Reedswamp habitats were dominated by Sparganium, Equisetum and Ranunculus. Typha latifolia appears to have been eliminated, perhaps reflecting reduced silting rates and the increasing organic content of the substrate. Menyanthes occurred along the waterline associated with other taxa capable of colonising waterlogged soils (eg. Caltha type, Rubiaceae). The sedge communities appear to have continued to thrive with Gramineae and Cyperaceae assemblages perhaps forming floating mats or tussocks within the carr vegetation or within the developing bog.

It therefore appears that half way through zone LH3, at around 8650 BP, there was a rapid increase in the extent of macrophyte vegetation associated with or causing, a shallowing of the lake water.

LH4 (596-552cm)

Zone LH4 is characterised by aquatic vegetation similar to that recorded at the top of zone LH3 but with a reduction in species diversity. Nitella and Chara oospores indicate that open water still persisted but it was probably reduced in extent. Inorganic input was now at a minimum (34%) reflecting a stabilising landscape and the reduced stream erosion. Nutrient levels were consequently reduced, reflected in decreased internal production with smaller Pediastrum and Botryococcus counts. A reduction in the algal frequencies may also have been the result of increased competition within a decreasing water body.

The decrease in the submerged macrophytes indicates continued shallowing of the water. Myriophyllum verticillatum and Myriophyllum spicatum were still present in small quantities, probably surviving towards the southern end of the lake where deeper water persisted. The presence of Myriophyllum spicatum suggests that the water was relatively rich in calcium but the elimination of Myriophyllum alterniflorum possibly indicates a gradual acidification of lake water as catchment soils were leached. A reduction in Isoetes also suggests increasing acidification and possibly the beginning of local oligotrophic conditions. Nymphaea, recorded as macrofossil remains, still occupied areas of open water but was now limited in extent as carr encroached. Nuphar now dominates but the frequencies are low suggesting that it was sporadic in occurrence.

Areas of reedswamps were still thriving with Sparganium, Potamogeton and Equisetum species. The reedswamp appears to have been a relatively stable community with the taxa gradually spreading outwards onto areas once colonised by the floating leaved macrophytes. As the lake shallowed and the substrate accumulated there was an increasing area for the reedswamp to exploit. Juncus and Carex were still growing around the lake edge possibly with Phragmites. Typha latifolia reoccurs, perhaps around stream banks and the lake edge, in response to disturbance and the exposure of a more inorganic substrate. Disturbance around littoral areas is suggested by the stratigraphy and influx diagram which indicate that limited erosion and resedimentation were occurring.

Menyanthes (aquatica?) is recorded and possibly occurred in floating mats of vegetation dominated by Cyperaceae species. It may also have formed part of the fen vegetation, rooted in the waterlogged soils around the lake edge. Ranunculus, Cyperaceae and Gramineae values generally decline suggesting a reduction in the fen understorey although it is difficult to interpret the results due to the problems of resedimentation. Mire development still continued but reduced values for Sphagnum may be an indication that some areas were subject to lower water levels and drying out with moss only surviving in wetter hollows. Myrica gale was probably now a major component of the surface vegetation.

The aquatic vegetation in zone LH4 is therefore similar to that in zone LH3 with the main changes reflecting decreasing deep water communities and a further expansion of reedswamp in the shallower waters. The increase in reedswamp appears to have produced an enrichment of potassium within the sediment. There would now be extensive areas of reedswamp to the north-east and north-west with the aquatic vegetation pushed out into the deeper water towards the south-west.

LH5-LH8 (552-0cm)

Due to the high probability that the sediment column is mixed above the hiatus (section 7.1), only an estimation of aquatic vegetation development since 5735 years BP can be made; it is impossible to identify individual events or the times at which particular species became abundant or disappeared. Both the pollen washings record and pollen diagrams indicate that there were significant changes in the helophytic and aquatic vegetation during the last 5700 years. Algal production appears to have persisted throughout much of the later Postglacial although periods of either increased or reduced production cannot be distinguished. It is possible that internal productivity increased as mineral input into the lake increased resulting from progressive deforestation (eg. as at Llyn Cororion). Although both Pediastrum and Botryococcus tolerate a wide range of ecological conditions Pediastrum is generally taken as indicating relatively eutrophic conditions but thriving in areas of quiet water (Birks, 1970). Botryococcus is intolerant of competition so would have continue to thrive in areas of quiet open water away from fringing macrophyte vegetation.

Pollen washings indicate that the lake had a thriving anthropod fauna. Nitella and Chara oospore frequencies increase above the hiatus suggesting increased calcium within the lake, although this is not supported by the chemical record. This contrasts with decreased Cristatella and Daphnia remains which are rare above the unconformity, perhaps a reflection of shallower water and loss of habitat. The most significant change is the large increase in frequency of Sphagnum spores and the occurrence of moss fragments washed into the lake. This indicates further development of the hydroseral succession with an encroachment of Sphagnum and the eventual formation of bog.

From the data it is not possible to ascertain the date of bog expansion or to say if mire development was relatively rapid. There was a significant spread of bog and carr at around 8600 BP (LH3) and perhaps this was further accelerated by deforestation at a later date. The spread of bog at the northern end of the lake may a have had a significant effect on the hydrological conditions both within the catchment area and the lake itself.

The most significant changes in aquatic vegetation appear to have been a general decrease in submerged and emergent macrophyte vegetation and deeper water species, and a change in the dominant taxa within the reedswamps. A change in stratigraphy to abundant coarse detritus including Phragmites remains, Alnus and Betula wood and coarse mineral material indicate lake shallowing and increased spread of swamp and fen carr. The bog and carr vegetation around the lake would have graded into a fringing reedswamp and probably dominated in shallower areas to the north and the south west of the lake. Abundant Phragmites remains suggest that it now formed dense stands and extensive beds around the lake edge probably associated with Typha latifolia. The occurrence of Typha latifolia appears to have reduced perhaps indicating increased organic input resulting from soil stabilisation within the catchment. Lake acidity may also have increased slightly compared with the early Postglacial (Typha latifolia favours a Ph of >5.5), or competition from increasing Phragmites and Equisetum may have reduced the bullrush community.

Equisetum values generally increase probably associated with taxa such as Juncus (effusus?) and a variety of sedges and grasses as indicated in the macrofossil record. Typical sedges might have included Scirpus lacustris with floating or submerged leaves, Carex acutiformis (typical of transitional areas between mires and water) or Carex rostrata. These are common waterside species with the latter often growing out into shallow water (Fritter et al., 1975). Equisetum may have included E. fluviatile, growing in shallow (<650 mm) fresh water and wet areas, associated with Potamogeton natans. Sparganium was probably growing in deeper stagnant water with Ranunculus species (eg. Ranunculus peltatus). Equisetum was present, thriving in increased marshy areas provided by the build up of vegetation and associated with Hydrocotyle, Menyanthes, Mentha (aquatica?) and species of Ranunculus. Equisetum arvense may have occurred on the mire surface away from permanently submerged sites. Juncus (bulosus?) may have been part of the aquatic vegetation forming floating mats in areas of fluctuating water levels or close to running water. Isoetes is continually recorded in both the pollen record and macrofossil deposits indicating that it was an increasingly important component of the shallow water vegetation. Its increased presence suggests that for much of the last 5700 years silting was reduced within the lake but that there were still inorganic substrates where it was able to thrive in the absence of competition. The most likely habitats were probably along the west shoreline which are today gravelly and relatively free of fringing vegetation. Associated taxa may have included *Sparganium* and *Myriophyllum spicatum*.

A limited and reduced floating leaved community appears to have survived until the late Postglacial. It is possible that the emergent or helophytic macrophyte vegetation was abundant for a short period and then virtually disappeared with the low sporadic pollen occurrences due to sediment mixing. The pollen diagram and pollen washings suggest that the macrophyte vegetation formerly occupying large areas of the lake ceased to be an important part of the aquatic vegetation. Surviving areas of lilies and associated taxa probably grew away from the dense reed communities and the stony shore, colonising areas towards the southern side of the lake.

Nymphaea was present, but macrofossil records decline, and low quantities of *Nuphar* indicate lake shallowing. There were therefore areas of water lilies in shallow pools or associated with sparse reedswamp. The rarity of *Nuphar* may be a reflection of gradual shallowing and a reduction in silting. Associated taxa would have included species of *Potamogeton* gradually grading into deeper water communities with taxa such as *Sparganium* and *Myriophyllum*. *Sparganium minimum* possibly occurred in deeper areas of quiet water but species such as *Sparganium angustifolium* may also have been present in waterlogged areas.

Myriophyllum verticillatum records are low and infrequent suggesting that at some point in the Postglacial it virtually became extinct at this site, although *Myriophyllum spicatum* and *Myriophyllum alterniflorum* continued to thrive. They are commonly found together in the early Postglacial but it is unusual to find associated records persisting into the later

Postglacial. This suggests there were separate ecological niches within the lake with varying nutrient status. This is also suggested by the presence of Sphagnum and Myriophyllum spicatum at the same site.

The change in aquatic and wetland taxa at Llyn Hendref over the last 5700 years indicates a continuation in hydroseral development, possibly undisturbed until drainage in the 1960's. The stratigraphy, pollen diagram and pollen washings all point to a gradual infilling of the lake, a reduction in water area and possibly increasing eutrophication. Deep water communities were reduced and fringing macrophyte vegetation decreased as first reedswamp and then sedge and fen vegetation encroached. Soil levels were raised as a result of accumulating organic debris and increasing areas of what were once waterlogged vegetation were now becoming land. Sphagnum moss colonised the area, initially by aquatic species such as Sphagnum subsecundum and then probably succeeded by species such as Sphagnum palustre or Sphagnum imbricatum, but the record is difficult to interpret due to the absence of identification to species.

The process of mire development and lake infilling probably proceeded at different rates in different localities depending of the local hydrology and topography. Areas of floating leaved macrophytes and reedswamp persisted in deeper water but in shallow areas (N and NE of the lake) sediment accumulation was probably quicker and swamp carr and then bog vegetation became established.

7.3 LLYN HENDREF VEGETATION HISTORY

LHA (784-752cm)

The cessation of solifluction and the onset of organic sedimentation at Llyn Hendref took place gradually in a landscape that already supported a relatively species rich, but sparse, vegetational community. Pollen concentrations in the basal minerogenics are low, due to rapid sedimentation rates and low local pollen input, and interpretation is difficult due to the long distance pollen component. The basal samples may also be contaminated by the erosion of older sediments within the catchment. A table of pollen counts from the basal sediments is presented (table 3.6) and described (section 3.5.2) but pollen sums are too small to be reliable and the true representation of vegetation remains obscure, although pollen concentrations suggest that the landscape was largely unvegetated.

Zone LHA is characterised by high numbers of indeterminable grains, especially crumpled and corroded, derived from eroded mineral soils containing pollen subjected to bacterial decay (Lowe, 1982). High percentages of damaged grains are characteristic of Late Devensian sites (eg. Traeth Mawr; Walker, 1982b). The pollen washings at these levels are entirely inorganic with both coarse and fine mineral material but loss-on-ignition results show small quantities of organic material. High counts of pre-Quaternary spores (section 3.7.3) indicate that much material was derived from glacial deposits.

At this time most tree or shrub pollen at Llyn Hendref, is thought to be derived or a result of long distance 'background' pollen. Pinus values are relatively high but it is unlikely that Pinus woodland was established in the area. The high percentages result from the openness of the landscape, and production and dispersal bias. It is probable that the Alnus, Quercus and Corylus grains were also windblown components although low frequencies of Quercus and Alnus recorded in Loch Lomond Stadial deposits from Nant Ffrancon (Seddon, 1962) are attributed to contamination introduced during coring. Low counts of Pinus, Quercus, Alnus and Ulmus pollen are also recorded at Clogwyngarreg (Ince, 1981), and low frequencies of Coryloid and Ulmus grains have been identified at Cwm Idwal (Tipping, 1990). The low counts of these taxa in pre-Postglacial sediments at a large number of sites throughout Wales suggests the presence of wind-blown pollen.

Betula, *Salix* and *Juniperus* also have relatively high values in this zone. These could be attributable to regional pollen, but a comparison with other sites (Glanllynnau; Simpkins 1974) suggests that isolated stands of these taxa, possibly in dwarf form, may have persisted throughout the Loch Lomond Stadial.

Herb pollen is generally poorly dispersed and most herb taxa in the basal sediments were probably produced by local vegetation. The herbs present (*Artemisia*, Compositae Liguliflorae, Caryophyllaceae, Chenopodiaceae, Cruciferae, Rubiaceae and *Thalictrum*) are similar to assemblages recorded at other sites in North Wales (eg. Llyn Dwythwch and Nant Ffrancon; Seddon, 1962: Glanllynnau; Simpkins, 1974) and are typical of a Lateglacial assemblages (Pennington, 1977b). Craig (1978) suggests that assemblages such as these are comparable to tundra vegetation and represent the initial stages in primary succession. The assemblages indicate pioneering taxa able to colonise freshly exposed substrates (Walker, 1975); the majority are shade intolerant and characterise disturbed thin soils in areas of stony ground with high solifluction and erosion rates.

Gramineae percentages are high indicating the establishment of open grasslands, perhaps interspersed with scrub or colonising areas around the lake. There is one record of *Hippophaë* which is typical of open habitats and immature soils (Simpkins, 1974), and is indifferent to temperature but requires edaphic and climatic dryness (Iversen, 1954). Heath with sparse Ericales and *Rumex* may have been developing, and a sedge community had already become established with *Ranunculus*. (*Galium*?) and ferns in the damp localities around the lake.

Total pollen concentrations are low (4.7×10^{2}gr/cm^{3}) indicating that the landscape was essentially treeless with only a sparse cover of pioneering herbs. Total herb pollen percentages apparently indicate that the herbaceous element of the flora was abundant but the low herb concentrations (maximum 1×10^{3}gr/cm^{3}) suggest that frequencies were over-emphasised.

LHB (752-720cm)

Zone LHB is characterised by an increase in local pollen input, a reduction in the pollen source area due to increased canopy cover, and the establishment of an aquatic community. The minerogenic input was high (>80%) with both fine and coarse sand. All taxa believed to have been derived from regional sources are reduced as Betula, Juniperus and Salix increase. The input of indeterminable pollen is reduced and lower frequencies of pre-Quaternary grains suggests decreased till erosion. These lower values are real, as reflected in the concentration calculations.

Betula, Juniperus and Salix were all now established at the site. Iversen (1954) suggested that Juniperus in low arctic regions is restricted to dwarf shrub form as it is dependent on snow cover for survival during the winter. Juniperus therefore probably persisted locally through the Loch Lomond Stadial near the lake as a prostrate poorly flowering shrub protected by winter snow (cf. Birks, 1986). Juniperus is a prolific pollen producer in an open landscape with the correct climatic conditions but the pollen is poorly dispersed (Huntley and Birks, 1983) so the low percentages can be taken as an indication that Juniperus scrub existed around Llyn Hendref. The initial low values at Llyn Hendref could be from Juniperus nana occurring in sheltered areas around the lake. The percentage decrease towards the top of the minerogenic sequence could then be due to a decrease in this particular species which was then succeeded by the taller form of Juniperus communis in the early Postglacial.

Records of Betula nana have been recorded in Wales (eg.Elan Valley; Moore, 1970: Mynydd Bach; Moore, 1972) showing that dwarf Betula did survive the Loch Lomond Stadial even at relatively exposed sites and there is no apparent reasons why this plant could not have survived at Llyn Hendref. The declining percentages of Betula in this zone perhaps implies that most pollen was regionally derived but with some birch persisting in scattered patches around the lake. The decrease could also be attributed to the demise of one species (Betula nana) replaced by another (eg. Betula pubescens), in response to the ameliorating climate.

Early records of Salix herbacea, a chinophilous plant characteristic of snow beds (Craig, 1978) and of northern montane distribution (Simpkins, 1974) occur at Nant Ffrancon in Loch Lomond Stadial deposits (Burrows, 1974). It is therefore likely that early Salix pollen records at Llyn Hendref are attributable to Salix herbacea. Salix herbacea is a pioneer species able to colonise bare ground and has seedlings with a high growth rate in the absence of shade and competition (Grime et al., 1988); conditions at Llyn Hendref were therefore ideal for Salix herbacea establishment during the Loch Lomond Stadial.

Increasing Salix values then reflect the growth of an early and local willow scrub community with an associated carr community and a sparse understorey of Ranunculus, Potentilla, Caltha, Filipendula and a variety of ferns. Macro-fossils of Dryopteris sporangia verify the local occurrence of this taxon. Dryopteris is characteristic of skeletal soils and moist habitats in lightly or unshaded localities, (Grime et al., 1988). Other fern types would have been scattered on drier slopes around the lake associated with grasses, Calluna vulgaris and Ericales. Areas which had accumulated thin layers of organic material would be colonised by Sphagnum and Osmunda associated with herbs adapted to growing in boggy accumulations of fine detritus mud. The presence of these taxa indicates the development of a number of floristically diverse habitats directly around the basin.

Pollen concentrations ($7.2x10^3 gr/cm^3$) indicate that vegetation was still sparse with occasional Salix and Juniperus scrub, and Betula as a rare addition. Patches of herbaceous taxa flourished in the absence of shade and competition and Filipendula ulmaria was abundant. Filipendula is often recorded as a thermophilous species (Iversen 1954) but relatively high percentages of Filipendula are recorded throughout the Late Devensian at a number of sites in Britain and Ireland. Godwin (1975) suggests that records for the Loch Lomond Stadial may be attributable to Filipendula vulgaris, a species characteristic of steppe vegetation. The Filipendula records at Llyn Hendref are believed to be Filipendula ulmaria and indicative of an ameliorating climate. Other pollen types (eg. Saussurea cf. alpina) are characteristic of subalpine situations and suggest cooler temperatures. Saussurea has also been recorded in Loch Lomond Stadial deposits from Nant Ffrancon and Llyn Dwythwch (Seddon, 1962), illustrating the co-existence of taxa with different ecological requirements; this is a characteristic feature of the Loch Lomond Stadial-Postglacial transition.

Taxa indicative of open ground persisted with Artemisia colonising areas of well drained rocky substrata and frost-disturbed mineral soils. It may have been associated with Rumex acetosa as in the absence of competition from taller herbs they are both considered early colonisers of raw substrates and habitats of high exposure (Grime et al., 1988). Another taxon intolerant of tall herbs and shade is Achillea type, which would have grown on grassland or on rocky outcrops, encouraged by bare open ground. Plantago maritima appears to have been an important part of the herbaceous community. Plantago maritima has 'both the climatic and edaphic tolerances to take advantage of the absence of competition from taller closed vegetation' (Godwin, 1975), again indicating the open nature of the landscape and emphasising the absence of shade and the persistence of open grassland.

High Gramineae percentages suggest that it was a major component of the vegetation with open grassland interspersed with bare, rocky areas, whilst sedge communities formed a light cover in the damper situations nearer the lake. It is possible that Umbelliferae, Thalictrum and Rubiaceae contributed to the grasslands although they could also have occurred as separate stands of tall herbs (cf. Craig, 1978).

The productive aquatic vegetation (section 7.1) at this time suggests that climate was not the limiting factor on establishment during the Loch Lomond Stadial-Postglacial transition. Aquatic plants react relatively quickly to climatic change compared with terrestrial taxa (Walker, 1975), hence the early development of a relatively rich aquatic community compared with the sparse scrub vegetation.It is therefore likely that terrestrial vegetation was limited by edaphic conditions (eg unstable substrates, high erosion rates) and 'features of primary succession such as slow soil maturation, low productivity and slow development of biomass', (Craig, 1978).

LH1 (720-712cm)

Even before the onset of organic sedimentation the landscape was colonised by an early and distinct herb dominated community associated with isolated stands of scrubby Juniperus with occasional Betula and Salix. Although vegetation was sparse, it was relatively diverse with a range of herbs occupying a wide variety of habitats. From the basal minerogenic sediments at Llyn Hendref it appears that these taxa survived the Loch Lomond Stadial in more sheltered localities, and as the climate improved, with rapidly rising temperatures (Dansgaard et al., 1989), and a decrease in the yearly range of temperatures, both Juniperus and Salix were able to respond and expand quickly.

The Juniperus expansion was both rapid and short-lived coinciding with the onset of organic sedimentation. The initial rise could be interpreted as increased flowering of previously climatically stunted species which were unable to flourish under colder climatic conditions (cf. Godwin, 1975), or it could have been due to an actual expansion of the Juniperus population. Taxa suggestive of climatic amelioration were already established in the area (eg. Filipendula ulmaria) before the onset of organic sedimentation and it appears that the expansion of Juniperus lagged behind climatic improvement.

This cannot be explained by migrational factors only, unless the Postglacial _Juniperus_ curve is attributable to a different species to that present in the Loch Lomond Stadial.

Ince (1981) noted a delay in the _Juniperus_ expansion at Llyn Llydaw and suggested that it was due to factors other than temperature, including edaphic, migrational and altitudinal factors. At Llyn Hendref a similar combination of factors were probably responsible, with edaphic factors playing an important role with high erosion rates and an unstable substrate preventing an earlier expansion. It is perhaps significant that the rise in _Juniperus_ coincided with the onset of organic sedimentation indicating that _Juniperus_ was unable to successfully colonise the area until soils where relatively stable.

Juniperus is a pioneering species and a _Juniperus_ peak is often characteristic of the transition between open grasslands and tree colonisation (Birks, 1972a). _Juniperus_ values at Llyn Hendref rise to 7%, which although low compared with other Welsh sites, can be taken to indicate abundant _Juniperus_ in the regional vegetation (Huntley and Birks, 1983). The values recorded at Llyn Hendref are reminiscent of those from lowland coastal sites such as Glanllynnau (8%; Simpkins, 1974) and Tre'r Gof (10%; Botterill, 1988). Simpkins (1974), suggests that at Glanllynnau _Juniperus_ was probably restricted to dwarf form, hence low pollen percentages, due to the exposed coastal locality. At Llyn Hendref, _Juniperus_ was probably restricted by exposure to strong winds, relatively high ground water levels around the lake and soil instability on steeper slopes. The scattered _Juniperus_ scrub enabled a rich understorey of ferns (including Filicales undiff. and _Dryopteris_) to colonise rocky crevices and stony areas, possibly associated with taxa typical of thin soils (eg. _Lycopodium_, Cyperaceae).

Salix herbacea survived the Loch Lomond Stadial in Anglesey and formed local but isolated populations around Llyn Hendref in the less exposed areas. At the onset of climatic amelioration it spread unrestricted by climate or competition. It is probable that Salix herbacea was quickly succeeded by tree willows, pioneering species with seedlings that have high growth rates (Grime et al., 1988). The Salix expansion was earlier than Juniperus, recorded within the basal minerogenics, and appears to have been unlimited by edaphic factors. Salix reached maximum percentages (11%) at around 10 285 years BP.

Salix percentages are difficult to interpret as much of the willow community would have occupied moist and waterlogged sites around the lake margin. Local pollen would have resulted in pollen over-representation obscuring the role that Salix played in the regional vegetation. Salix probably formed tall, dense shrub stands on the lake margins and it is most likely to have occupied the northern end of the lake where the slopes are relatively gentle resulting in localised waterlogging. Away from the lake, Salix may have colonised moist soils on unshaded south facing slopes. Salix seedlings have a wider range limit of tolerance compared with mature trees and probably occurred scattered over the landscape interspersed with Juniperus scrub although the concentration diagram indicates that there was little interaction between the two.

Within the carr would have been herb communities with taxa such as Filipendula ulmaria and Thalictrum. Both taxa are indicative of moderate levels of bare, unstable soils (Grime et al., 1988) and are often found on lakeside gravels and rocky slopes. Associated taxa would have included Ranunculus (possibly species such as R.repens, characteristic of poorly drained sites and tolerant of large quantities of bare soil), Rubiaceae (possibly Galium, a wetland plant of gentle slopes), Gramineae and Cyperaceae. In damp areas, ferns would have been abundant as indicated by the high percentages of Filicales undiff., Dryopteris and occasional Polypodium and Osmunda. As Salix, Juniperus and Gramineae values increase, Cyperaceae frequencies decline perhaps indicating the encroachment of willow carr onto the open areas around the lake. A fringing carr vegetation would have predominated at the northern end of the lake and in sheltered bays gradually giving way to marginal reedswamp and communities tolerant of deeper water.

Betula produces abundant wind-dispersed pollen and is consequently over-represented in the pollen diagram making it difficult to distinguish between local stands of Betula and regional populations. Values of >25% have been taken to indicate local dominance and values of >50% indicate a birch dominated landscape on a regional scale (Huntley and Birks, 1983). Betula pollen records of 20% at the zone base, suggest that at 10 000 BP, there were local birch stands. Betula is a pioneering taxon, able to tolerate thin soils and has a low warmth requirement and seedlings which mature quickly (Birks, 1986). Seedlings have no preference for aspect but tend to prefer more acid soils that are moist but not waterlogged (Grime et al., 1988). This makes the north-west side of the catchment area particularly suitable for birch woodland colonisation with gentle slopes, relatively acid soils and free drainage.

Betula originally migrated into the British Isles via the east coast and by 10 000 BP it had colonised much of central England, areas of Wales and northern England (Birks, 1989). It is possible that there were scattered populations established in front of the main 'migrationary front' and Llyn Hendref may have been one such area. The increasing frequencies indicate a rapidly expanding population which colonised drier areas of the catchment. It appears to have been unrestricted by the sparse Juniperus and Salix scrub which cast little shade. The concentration diagram indicates that once established Betula was able to out-compete Juniperus and it had invaded parts of the carr. Betula probably colonised stable areas where a layer of mull humus had accumulated, with Juniperus pushed out to marginal habitats.

Betula percentages are still low enough to suggest that the canopy was open but declining Juniperus values indicate decreased flowering potential as Juniperus was reduced to an understorey shrub. A slight recovery in Juniperus values later in zone LH2 shows that it was not totally eliminated from the catchment area. Increased shading would have prevented Juniperus regeneration (Godwin 1975), resulting in local extinction of the latter.

Salix concentrations are slightly reduced with the Betula arrival indicating limited interaction between species. Competition was probably for damp sites on the fringes of the developing willow carr where Betula seedlings were able to tolerate small amounts of shade (Grime et al., 1988). Once established, the increased canopy reduced Salix except in waterlogged areas. After initial decreases in Salix concentrations values stabilise indicating its continued dominance around the lake edge.

Low tree concentrations ($5.3x10^4 gr/cm^3$), indicate an open landscape which enabled a diverse herbaceous flora to thrive and taxa characteristic of immature soils, solifluction and bare stony disturbed ground are still recorded. The Betula woodland was relatively open with occasional patches of exposed bedrock and large areas of thin soils ideal for colonisation by pioneering herb communities. The substrate consisted of a thin layer of tree litter with a discontinuous Bryophyte mat and associated Pteridophytes. Moss fragments in the pollen washings indicate the growth of moss species relatively close to the lake, or represent inwashing by streams. Artemisia, Rubiaceae, and Caryophyllaceae all imply substrate instability and disturbance (Ince, 1981). Artemisia usually occupies well drained sites, is generally absent in shaded areas and occurs in abundance at sites where there is little competition due to soil movement (Grime et al.. 1988). It is an early coloniser of open ground and is commonly associated with Achillea type, typical of rocky outcrops and open habitats with slightly acidic soils. Many Loch Lomond Stadial taxa were still surviving as relicts especially in areas of high soil erosion.

A gradually increasing organic content of the soils is indicated by species such as Rumex acetosa which favours well drained, relatively acidic soils on south facing slopes. It reaches maximum abundance as a patch forming taxon in unshaded sites but flowering is restricted under a canopy (Grime et al. 1988). There would have been extensive areas of sparse grasslands in drier areas of the catchment and Calluna vulgaris and Ericales suggest a heathland component to the vegetation. It is also possible that these two taxa formed understorey in the Betula woodland or colonised steeper rocky slopes around the lake edge associated with a thick undergrowth of Pteridium. Calluna vulgaris is most frequently associated with acidic environments, low species diversity and well drained soils.

High percentages of fern spores (Dryopteris, Filicales undiff., Polypodium) persist and although some spores will be attributable to ferns growing at the lake edge, some will also be from the woodland understorey.

LH2 (712-692cm)

Zone LH2 is characterised by increasing soil stability and an overall increase in vegetation cover as Betula and Salix continued to expand and Corylus migrated into the area.

The concentration diagram indicates that the Betula rise is relatively steady, compared with the rapid rise suggested by the percentage diagram. It is possible that thresholds in soil stability or organic content had to be reached before Betula was able to thrive. Once established, Betula dominated both regionally and locally but the average tree percentages for this zone (60%) indicate that there was still incomplete canopy cover. Betula occurred in small stands or as thinly scattered individuals throughout the area. Pollen concentrations then show that tree cover was gradually increased and the Betula maximum (70%) is indicative of birch dominated woodland (Huntley and Birks, 1983).

Betula probably now occupied all sites within the catchment, excepting rocky outcrops and the lake margin. Fluctuations in percentages are probably due to production and dispersal bias in local communities. Betula colonisation resulted in increased soil stability and mull humus accumulation. Sorbus aucuparia, indifferent to soil types but light demanding (Clapham et al., 1987) also occurs. Sorbus aucuparia seedlings tend to favour north facing slopes and concentrate in rock crevices or skeletal, well drained soils (Grime et al., 1988) and probably occurred as isolated stands associated with the thinner birch wood on the southern side of the lake or on the woodland edge.

Increasing Salix concentrations indicate an expansion of carr vegetation with willow now forming a locally dense canopy. Salix and Betula appear to have occupied almost mutually exclusive niches and if Betula was in competition with scattered Salix it is not reflected in the concentration data. The slight decline in Salix to low, steady values at the top of the zone (9470 BP) could be due to an increased development of Salix-Betula carr as within this association, Salix tends to be poorly represented in the pollen record (Birks, H.J.B., 1973). Increased values for Cyperaceae, Gramineae and Ranunculus could indicate increasing areas of fen or the spread and successful colonisation of already existing areas by an established understorey community. Filipendula concentrations are increased, indicating either herb communities within the fen or meadowsweet associated with damper patches in the birch woodland.

Juniperus values reduce (<1.5%) but are still continuous indicating that it persisted within the catchment. Increased shading from Betula probably reduced the understorey component of Juniperus further but it was still able to occupy isolated and marginal areas. Relatively steep slopes and rocky outcrops with thin soils, too hostile for Betula colonisation, would have been suitable for Juniperus. Juniperus finally disappeared from the catchment with the arrival of Corylus.

Corylus has low percentages (0.38%-0.15%) at the beginning of the zone and only begins to expand at 692cm. The low percentages and over-representation of *Corylus* suggests that it was not initially established at the lakeside, but may have occurred within the catchment. There is still a regional component to the pollen diagram as indicated by the low but steady percentages of *Pinus* (<4%), *Ulmus* (<0.1%) and *Quercus*.

Herb percentages indicate that although there was a contraction of open areas, relatively diverse herb communities still persisted either as understorey components or in open habitats associated with the lake margins and rockier outcrops. The *Betula* woodland understorey appears relatively unchanged except that *Juniperus* was now excluded and there has been a reduction in the number of shade intolerant herbs. *Salix* may have formed a sparse shrubby understorey to the birch woodland associated with *Viburnum* and *Hedera helix*. *Hedera helix* prefers shaded habitats away from waterlogged sites and is characteristic of moderately fertile undisturbed habitats (Grime *et al.*, 1988). *Lonicera* was present as a climber in the more open areas and Bryophytes and Pteridophytes still dominated, with *Rumex acetosella* on the more organic soils. *Dryopteris* values are reduced indicating the gradual accumulation of soil over bare rocky areas and increasing shade. Ericales and *Calluna* were also reduced as competition and canopy cover increased. Increasing shade is also indicated by *Potentilla* which is often recorded on acidic soils of undisturbed, shaded habitats.

Herbs associated with disturbed ground are now rarely recorded with reductions in *Artemisia*, Rubiaceae and the disappearance of *Thalictrum* and Umbelliferae. Cruciferae and *Plantago maritima* suggest that open non-wooded habitats persisted in some localities where shade intolerant taxa and dwarf Pteridophytes where still able to survive.

Charcoal records are frequent and regular throughout the zone but the pollen diagram suggests that fire had little affect on the vegetation. The charcoal may have been produced from limited natural forest fires or possibly from domestic fires (cf. Bennett et al., 1990b) but there is no archaeological evidence of human activity at Llyn Hendref for this time period. Domestic fires would explain the apparent lack of vegetation disturbance.

LH3 (692-596cm)

Zone LH3 is characterised by the Corylus expansion resulting in increased canopy cover. Soils continued to develop, with decreased erosion rates; the increased sedimentation rate observed is therefore likely to have been due to a change in hydrological conditions and sediment focusing, (section 7.1). Minerogenic input into the lake has decreased but the presence of coarse mineral material reflects the continued importance of stream-borne material.

Total tree percentages are apparently reduced (60% to 34%) but this is due to the large Corylus increase (which has been classified as a shrub). Together trees and shrubs make up 90% of the total pollen record and total pollen influx values rise to an average of $1.05 \times 10^4 gr/cm^2/yr$ suggesting relatively dense woodland. A few open areas persisted and herbs continued to flourish in the carr around the lake edge and on thin soils on rockier slopes.

Corylus is the dominant taxon in this zone, favoured by the oceanic climate and unleached, slightly acidic soils. The Corylus rise at Llyn Hendref is extremely rapid and percentages quickly reach 75%, with the time difference between the empirical and rational limit estimated at approximately 470 years. This is comparable to that estimated for Tregaron (Hibbert and Switsur, 1976) and faster than that recorded at higher altitudes (eg. Nant Ffrancon, 940 years; Hibbert and Switsur, 1976). At sites with delayed expansion it appears that the birch woodland was thicker (Moore, 1970) preventing initial Corylus colonisation. At Llyn Hendref there appears to have been little effective competition and Corylus was quick to exploit the ideal soil conditions.

Corylus establishment is often associated with the occurrence of charcoal and evidence of forest fire (Rawitscher, 1954; Smith, 1970); it is fire resistant and sometimes forms a fire climax formation. However, the connection between charcoal deposition and increased Corylus has been questioned by Rackham (1980). The Corylus expansion at Llyn Hendref is coincident with increased charcoal occurrence at the zone base, but with the highest charcoal frequencies occurring throughout the Corylus maximum. From the data it is difficult to establish a direct relationship between the two as the charcoal record is more or less continuous throughout the Corylus presence and peaks in the charcoal do not coincide with increases of hazel. There is no conclusive evidence at Llyn Hendref to suggest that the expansion of Corylus was specifically related to vegetation burning. It is difficult to interpret the charcoal record at this site due to an enlarged source area provided by the stream network with charcoal input perhaps not reflecting local events.

Corylus frequencies are difficult to interpret because it flowers at an early age and produces abundant pollen resulting in over-representation in the pollen diagram. Production bias changes depending on the density of the canopy with subdued flowering in a mixed forest or when Corylus is an understorey shrub. Pollen is more abundant under light shade and pollen frequencies of 25% indicate that hazel was the most abundant arboreal species in the woodland (Huntley and Birks, 1983). At Llyn Hendref, values of over 70% therefore indicate that Corylus was dominant as the canopy forming species; Corylus woodland such as this has no modern analogue (Bennett, 1983a). The Corylus rise coincides with the reduction of Juniperus percentages to zero, as Juniperus was eliminated by increased shade, unable to survive as an understorey shrub or in marginal habitats.

Also associated with the Corylus expansion is an apparent initial decrease in Betula percentages from 50% to 30% but values then stabilise suggesting that the two taxa coexisted. This is similar to the situation described by Birks (1986) and Watts (1973) whereby an invader expands rapidly at the expense of the established taxa and achieves dominance in open areas. This results in declining pollen percentages for the established taxa as the new species expands. As inter-specific competition increases in importance, a gradual balance in seedling establishment of the two taxa occurs and the two species then exist in "a quasi-equilibrium". At this point the pollen percentages of the established taxon show a recovery and stabilisation of values.

Corylus probably out-competed Betula on more fertile sites, with Betula regeneration prevented by less than optimum edaphic conditions and increased shading. Betula seedlings are shade intolerant and were suppressed by the increasing canopy but it was still successful on the thinner poorer soils of the catchment and also on the damp soils around the lake basin. Thus there was the gradual replacement of Betula scrub by a Corylus canopy but the concentration diagram shows that Betula woodland was still frequent despite its initial suppression. Betula concentrations then recover to steady values (average $1x10^5$ gr/cm^3) and it was able to co-exist within the Corylus woodland, both as an understorey shrub and canopy taxon.

The presence of Betula macro-fossil remains in the pollen washings show that birch trees were established around the lake edge. Betula pubescens may have occupied the damp areas around the lake side, co-existing with Salix. The sporadic and short-lived fluctuations in the pollen curve are probably due to variations in flowering and pollen production of local populations.

There also appears to have been some initial competition between Salix and Corylus. Salix values are seen to be reduced from (7% to 0.5%) and the concentration diagram indicates that after an initial decrease, it recovered, only to decrease again. This indicates that Corylus was able to colonise drier areas of the carr, in some instances growing up to the lake edge where drainage was relatively good. Corylus would now be occupying the richer soil sites which were formerly occupied by Salix and tall herb communities, possibly in the southern sector of the catchment. Salix concentrations then stabilised as willow thickets continued to dominate in wet localities that were unsuitable for colonisation by other tree species.

Increasing Alnus values, associated with rising Gramineae and Cyperaceae suggests that the willow carr may have been drying out slightly and was invaded by Alnus seedlings. The initial Alnus establishment may have been linked with the increased shallowing at around 8700 BP as recorded by the aquatic vegetation (section 7.2) although percentages are still low in this zone (<1%) and the first occurrence is recorded at a disturbed level. The Alnus empirical limit is estimated at 7950+/-70 (section 5.5). The first records of Alnus affect the Salix and Betula concentrations but these then recover, indicating that Alnus had little affect on established vegetation. Pinus values are low in this zone and reach 4.2% which is below the minimum percentage required to indicate local presence (Huntley and Birks, 1983). The grains were therefore probably a windblown component from mainland sites.

Zone LH3 is also characterised by the arrival and expansion of both Quercus and Ulmus. Quercus percentages are low and steady and it is difficult to ascertain the difference between regional and local pollen sources. The difference between the empirical and rational limit is approximately 1110 years and the rise in pollen percentages (at 7805 BP) does not occur until after the Ulmus and Corylus maxima. The low early Quercus records suggest that there was a regional source of pollen before oak became established within the catchment area. Quercus is over-represented in pollen diagrams and Andersen (1970), recommended a correction factor of 0.25, although more recent pollen correction studies indicate that Quercus in fact has a lower pollen representation than is suggested by this figure (Bradshaw, 1981a). Percentages greater than 2% have been used to denote the local occurrence of oak and values greater than 10% signifies that oak contributes significantly to the regional vegetation (Huntley and Birks, 1983). The percentages at Llyn Hendref indicate that by 9400 BP there was sporadic local occurrence of oak but it was not until 7805 BP that Quercus became a major component of the forest with pollen frequencies up to 24%.

The delayed Quercus expansion may have been due to the relatively thick birch-hazel woodland under which oak seedlings were unable to grow. The subsequent Ulmus invasion may have opened up the canopy (a situation also recorded at Llyn Cororion) which allowed Quercus to expand. The delayed rise in the pollen record could also be a function of the doubling time and slow growth rate of Quercus (140 years; Bennett, 1983b), or possibly local hydrological conditions. Quercus seedlings are intolerant of desiccation but once they are established they can persist at relatively infertile sites (Grime et al., 1988).

There are two Quercus species that could have occupied sites at Llyn Hendref. Quercus petraea (sessile oak) is most frequent in the north and west of Britain and prefers light sandy soils which are relatively well drained and slightly acid (Grime et al., 1988), it is therefore the most likely species for well drained soils on the catchment slopes. Quercus robur (pedunculate oak) is a pioneer species, most frequent in the south and east of the British Isles, and is most abundant on heavy, wet, rich soils. Quercus robur may have occupied sites nearer the lake on gentler slopes with deeper and wetter soils.

Once Quercus was established it became a major component of the woodland, competing with other deciduous trees. Corylus percentages are reduced as Quercus values increase; this may reflect reduced flowering potential as Corylus became an understorey shrub. The reduction in percentages is small with frequencies still averaging 50%, indicating that Corylus still remained the dominant taxon around Llyn Hendref.

A slight reduction in Betula values implies that there was some interaction between Betula and Quercus, but with Betula remaining important locally. This interaction is particularly noticeable at 928cm (8250 BP) where there is a reduction in the Quercus representation and a corresponding increase in Betula and Corylus values. This level is associated with an increase in mineral input, increased Sorbus values and herbs associated with carr vegetation (eg. Filipendula, Ranunculus, Cyperaceae and Melampyrum). Melampyrum is sometimes associated with fire (Godwin, 1975) but there is no charcoal at this level. It is possible that fire disturbance did occur, affecting small areas of vegetation and mineral soils, but that local factors (eg. wind direction, sedimentary factors) resulted in no charcoal deposition. This is unlikely as increased mineral input suggests enhanced erosion rates which would have also transported charcoal to the basin. It is possible that disturbance was the result of anthropogenic activity or perhaps fluctuating water levels which affected carr vegetation. There is no stratigraphic evidence for a change in water levels and although this would be an early date for human disturbance, as yet there is no evidence of Mesolithic activity in central Anglesey, there is 'circumstantial' evidence for Mesolithic activity in coastal localities (Botterill, 1988).

Ulmus apparently 'arrived' later (9425+/-75 BP) than Quercus at Llyn Hendref but was quicker to colonise with a negligible time lapse between the empirical and rational limit. The early Ulmus maximum, approximately 8600 BP, at Llyn Hendref is a characteristic feature of northern and western sites. It may be a response to a predominantly maritime climate (Moore and Chater, 1969a) but could also be a function of doubling time, which at 70 years (Bennett, 1983b) is half that estimated for Quercus. The Ulmus expansion caused a decline in the Corylus percentages but the latter then recovered and remained dominant. Ulmus would have preferred deep moist soils, rich in clay and with a relatively high level of fertility (Huntley and Birks, 1983). Seedlings are relatively shade tolerant, unlike Quercus, and once established within the woodland they are able to grow above the general canopy and remain as a stable population with little further interaction with other taxa. The values at Llyn Hendref, rising to a maximum of 3.6%, indicate that Ulmus was only of local significance; values of greater than 2% indicate that Ulmus is local and >10% indicates that elm is a 'significant' component of the forest canopy (Huntley and Birks, 1983).

Tree and shrub percentages average 80% (concentrations of $3.9 \times 10^5 gr/cm^3$) suggesting that the area was heavily wooded. The persistence of species intolerant of shade and competition suggests that there were areas still uncolonised by trees; this is supported by the loss-on-ignition data which illustrates that soil instability continued within the catchment. The herb record shows that there were still open areas within the catchment and sporadic Fraxinus and Sorbus aucuparia indicate gaps in the woodland cover. Sorbus aucuparia tends to be under-represented in pollen diagrams and produces relatively few large seeds that are dispersed by birds (Grime et al., 1988). It forms a small deciduous tree or shrub that tends to favour skeletal habitats such as rocky crevices, and although the seedlings are relatively shade tolerant, the mature trees thrive in open areas on the edges of woodland or in canopy gaps. Sorbus has a wide range of edaphic tolerances and is often associated with oak woodland on acidic soils or with gaps in oak and birch woodland (Grime et al.1988). At Llyn hendref it appears to have co-existed with an understorey of Hedera helix and a field layer of grass and ferns, Potentilla erecta and Solidago type. Sorbus probably occurred in gaps left within the Corylus-Betula-Quercus woodland and on woodland margins nearer the lake and on rocky outcrops. It was more likely to be on the well drained soils and may have been able to colonise marginal areas previously occupied by the declining Juniperus.

Isolated Fraxinus counts could indicate that canopy density was reduced as species such as Corylus and Betula were replaced by taller taxa (eg. Ulmus and Quercus). Optimum sites for Fraxinus are sheltered locations with well drained fertile soils (Rackham, 1980) although it can also persist in less favourable sites as a shrub possibly in the understorey and in less dense areas of the forest. It may also have been an occasional species in the wetland habitats around the lake where it survived in shallow zones of moist soil ideal for seedling development (cf. Grime et al., 1988).

Herb percentages for zone LH3 decline (average 9%) but it is difficult to know if this is due to the 'swamping' effect of the increased trees and shrubs in this zone. A rich herbaceous community probably continued to flourish with the shade intolerant varieties occurring in woodland gaps associated with the carr vegetation, or on the open lake shore. Shade tolerant herbs would have occurred as a field layer within the woodland.

Within the woodland would have been species such as Hedera helix, Ilex and Viburnum. Hedera helix is characteristic of woodlands and shaded habitats although it produces little pollen and so the percentages (0.4%) at Llyn Hendref suggest that it was an important part of the vegetation. Hedera helix may have invaded from the woodland edge as it requires unvegetated and unshaded sites for germination and once established it could spread quickly to more shaded areas. Ivy probably formed a carpet in many areas of the woodland extending over stony soils and growing up tree trunks towards the canopy. Increased Hedera helix percentages are associated with the expansion of Quercus and Ulmus suggesting that it thrived as the woodland opened up. The Viburnum record correlates well with the Corylus curve.

The field layer may have included Pteridium, Polypodium, Dryopteris and possibly Calluna vulgaris (although the latter may also have occurred in the carr vegetation) with patches rich in mosses, and plants (eg. Ranunculus and Primula) that flowered before leaf cover became complete in summer. Species such as Plantago maritima, Artemisia and Cruciferae indicate that non-wooded areas persisted and Pteridophytes perhaps reflect exposed sites with thin rocky soils too shallow for tree growth or too steep for proper soil formation. Thalictrum, Gramineae and Ranunculus suggest grasslands and

Cannabaceae, recorded for the first time in this zone, is attributable to Humulus lupulus colonising wetter areas around clearing margins.

The Salix carr had a rich and diverse herbaceous assemblage with species of Filipendula and Thalictrum forming tall herb communities and Cyperaceae, Ranunculus, Caltha type and Mentha type in waterlogged areas nearer the lake. Caltha type is a wetland species of shaded habitats and occurs as isolated plants marginal to water although rarely on sites that are permanently flooded. It is commonly associated with Mentha type; both plants are characteristic of open tall herb communities where other competition is restricted by shade or unstable soils (Grime et al., 1988). Dryopteris was a frequent local taxon, as indicated by the presence of fern sporangia in the sediment. On the unforested rocky slopes around the lake there were mixed communities of Calluna vulgaris, Pteridium, Cyperaceae and Gramineae.

The charcoal record for zone LH3 is discontinuous; between 9400 BP and 9550 BP charcoal abundances are high, and after a gap in the record, charcoal becomes more frequent but less abundant between 8600 BP and 7000 BP. From the pollen record it appears that fire occurrence had no discernible effect on the woodland and there is no evidence to suggest soil disturbance and increased erosion. This could be due to a number of factors. The charcoal may have been brought in by streams from localities on the edge of the catchment where small changes in vegetation would not register in the pollen diagram. If this was the case then the minerogenic content of the sediment would be expected to rise but this is not recorded in the loss-on-ignition or chemical data. It is also possible that the temporal resolution of the diagram is not great enough to discern vegetational change associated with small local fires, and that a time lag between fire occurrence and charcoal deposition confuses the record. This is not possible to prove, but is unlikely as fire occurrence and the effect on vegetation have been correlated for other phases of high charcoal counts. It is also possible that the charcoal was produced from domestic fires and therefore had a negligible effect on the environment. Bennett et al., (1990b) concluded that natural fire is unlikely to have been as frequent as previously thought and that charcoal derived from domestic fires could produce charcoal records similar to those produced by anthropogenic use of fire for vegetation management. If this is correct then it would appear that the site was sporadically occupied by hunter-gatherers from 9890 BP onwards. Large gaps in the charcoal record (eg. 9400 to 8600 BP) would record times when populations moved on, and increased frequency and abundance would indicate continuous occupation.

LH4 (596-552cm)

The interpretation of zone LH4 is complex due to a combination of factors including the expansion of new taxa, changing water levels and a fluctuating sedimentary regime. The most significant feature is the rapid expansion of Alnus from low consistent percentages (around 1%) to 33%, over an estimated 155 years, although the concentration diagram suggests that the rise was more gradual. Alnus appears to have expanded with no constraints imposed by competition, climate or soils; the possible reasons for this rapid expansion are:

Climate Change

An increase in precipitation causing raised water tables and waterlogging is also often quoted (eg. Godwin, 1975) to explain the Alnus expansion. At Llyn Hendref there is evidence for lake shallowing and infilling which would increase the available ground for colonisation but this was part of the natural hydroseral succession and does not necessarily reflect climatic change. The evidence suggests that the lake was shallowing resulting in Alnus out-competing Salix and Betula in wetter areas around the lake edge. Alnus prefers wet soils and will co-exist with Salix in flooded sites and with Quercus and Ulmus along streams and in wet hollows, (Bennett and Birks, 1990).

Anthropogenic Activity

At some sites anthropogenic disturbance, especially the use of fire, has been suggested for the rapid expansion of Alnus (eg. Smith, 1984). At Llyn Hendref, charcoal records are associated with the Alnus empirical limit but these are isolated counts and charcoal abundance is not maintained throughout the rise. It appears that fire was more frequent during periods of low Alnus levels and had little influence on the establishment of alder.

An isolated decrease in Alnus values (to 1%)is associated with a Corylus and Salix high at 5900 BP and an associated increase in diversity and number of herbaceous taxa (including Filipendula, Chenopodiaceae, Solidago type and Artemisia). Increasing herbaceous taxa and higher Pinus values (long-distance pollen) suggest an opening up of the canopy and disturbance around the lake. The woodland dominants appear to be unaffected and there is an increased organic content in the sediment. If fire occurred then it must have been local, affecting only carr vegetation and not destroying ground vegetation and exposing mineral soils. This seems unlikely and the observed changes in the carr vegetation may be independent, reflecting a fluctuating water level as the lake gradually infilled. Alnus is susceptible to drought (Grime et al., 1988) and a drop in water levels would induce the spread of taxa such as Salix, Corylus and fen herbs and cause a reduction in Alnus. Reduced water levels are also suggested by the aquatic vegetation, the sedimentology, (section 7.1) and the presence of coarse inorganic material in the pollen washings.

The evidence suggests that the charcoal was from domestic fires as these would have had little effect on woodland vegetation and soils within the catchment. There is therefore no substantial evidence at this site that Alnus establishment was linked with fire occurrence. Bennett and Birks (1990) note that there will often be the coincidence of charcoal and vegetational change in the early Postglacial due to the rapidly changing vegetation communities.

Bennett and Birks (1990) note that Alnus establishment requires high light intensity and water tables. After comparing 91 sites they concluded that there was no observable pattern in the alder spread across the British Isles and that its behaviour was erratic compared with other tree taxa. This was due to the sporadic manner in which habitats became available and when Alnus was first introduced (10 000 BP) ideal conditions were isolated and scarce. As local hydrology and climate changed, habitats became available for colonisation but these were site specific, hence the random and incoherent pattern of the Alnus spread. At Llyn Hendref this might explain the persistent low percentages followed by a rapid rise. Alnus is over-represented in pollen diagrams with both high pollen production and effective dispersal, and also because of the likelihood of local trees around lakes. Percentages of >2% have been taken to indicate local presence, and only 25% or above can be taken to indicate presence near the lake basin (Huntley and Birks, 1983).

The Alnus rise at Llyn Hendref coincides with an immediate but temporary decline in Betula and Salix concentrations and a gradual Corylus decline. These trends suggest that Alnus competed initially with Betula and Salix in the fen vegetation and interference with Quercus and Ulmus appears to have been minimal. Quercus concentrations decline slightly, suggesting limited interaction, perhaps on the carr edges or on damper sites within the woodland. Alnus then dominated (percentages average at 26%, except for one pronounced low (1%) at 5900 BP) until a final decline around 5735 BP. The species is likely to have been Alnus glutinosa, commonly found associated with Salix and Betula, and characteristic of fen vegetation.

Betula began to decrease as its habitats were increasingly occupied by Alnus, although after the initial invasion pollen values recover slightly (to 10%) suggesting it managed to survive, perhaps in slightly drier areas and along the fen fringes. Macrofossil remains suggest that Betula was still an important component of the local carr vegetation, although it is possible that the macrofossils were transported some distance by streams. Betula was probably also an understorey shrub within the surrounding woodland and it is unlikely that this component was affected by the immigrating alder. After 5850 BP. a minimum value of 4% indicates that Betula became sporadic.

Corylus was initially affected by Alnus immigration but recovery to 30%, at a time when other trees were declining, suggests that it was still a dominant component of the forest. It would also have formed part of the understorey with Betula and continued to thrive in the fen vegetation, thereby enhancing its representation in the pollen diagram. Quercus concentration values are unaffected by the incoming Alnus although the percentage diagram would suggest otherwise. Quercus maintains its dominance as a canopy tree (average percentages 17%) indicating that it was still a significant component of the vegetation over much of the catchment. At around 5850 BP, values decline (to 10%) suggesting that Quercus was then reduced to sporadic local occurrence.

Ulmus values are steady throughout the zone and the percentages of 3-5% show that although it was not a major component of the forest, it was present locally. Concentrations do initially drop suggesting that there was some minor interaction between Alnus and Ulmus but values then recover suggesting that generally the two taxa occupied mutually exclusive localities.

Pinus concentrations in this zone are at a maximum at the base of the zone (6%) before decreasing. The low values indicate that the pollen was derived as a windblown component. It appears that Pinus was never part of the woodland at Llyn Hendref (cf. Llyn Cororion) and the frequencies recorded probably represent the regional status of Pinus. There are sites in North Wales that record high value of Pinus (eg. Llyn

Cororion, section 7.3) but these appear to be associated with localised populations. Pennington (1970) noted large variations in Pinus pollen throughout the Lake District and concluded that distribution was mainly controlled by edaphic factors. At Llyn Hendref the lack of Pinus populations could be due to a number of factors including wind exposure, edaphic conditions, drainage, topography and competition.

Zone LH4 is therefore characterised by relatively stable woodland, but a changing carr vegetation induced by the introduction of Alnus. Quercus and Ulmus were still important components of the woodland, probably more abundant away from the lake, with Betula and Corylus forming the local vegetation. The wetter areas around the lake were dominated by a dense carr vegetation, predominantly Alnus but with some Salix and Betula. The carr understorey appears to have changed very little and Cyperaceae and Gramineae still dominated with tall herb communities (Thalictrum and Filipendula) persisting in open areas. Cruciferae occurred in damper areas associated with Ranunculus, Umbelliferae, Cirsium and Epilobium on moist fertile habitats. Pteridium and Calluna may have occupied drier slopes of the basin, or formed part of the woodland understorey or associated with Cyperaceae and with dry hummocks in developing bog with occasional ferns and Ericales. Dryopteris sporangia remains indicate that ferns were an important component of the carr understorey or grew along stream banks.

The woodland understorey consists of ferns (eg. Polypodium) and in more open areas there was grassland with species of Gramineae, Solidago type and Umbelliferae. Hedera helix is present and may have formed part of the canopy layer in some areas. The presence of open spaces is indicated by Sorbus aucuparia which appears to be closely associated with Corylus percentages. It is possible that Corylus increases are related to the formation of secondary forest colonising gaps, and that species such as Hedera helix and Sorbus aucuparia took advantage of the decreased canopy cover. Restricted open areas still persisted with Gramineae, Compositae Liguliflorae, Rosaceae and Cyperaceae species, but there is a noticeable decrease in shade intolerant taxa. Shrub and tree pollen total on average 94% but this figure is probably exaggerated due to over-representation by Betula and Alnus.

The vegetational record towards the top of the zone is complex with evidence of increasing sediment disturbance and phases of vegetational disturbance. Towards the end of the zone the majority of tree taxa register a decline in values with an associated increase in herbaceous taxa. At 556cm (approximately 5780 BP) this is especially apparent with the decline of all taxa except Corylus, Salix and Sorbus aucuparia.

Associated with this level is an abundant charcoal record and an increased inorganic input perhaps indicating fire disturbance. A decrease in all the pollen counts suggests that burning was not selective and affected the main areas of woodland; clearings were then colonised by secondary Corylus, as indicated by the maximum percentages seen at the top of the zone, and shade intolerant species (eg. Sorbus aucuparia). An increased inorganic input suggests that fires burnt off the organic soils and exposed open ground that was then subjected to increased run-off and erosion. Associated with the disturbance is a rich diversity of herbaceous taxa including increased records of those associated with disturbed and open ground, eg. Achillea type, Cirsium and Artemisia. Gramineae and Cyperaceae values all increase indicating the spread of heathland and grassland vegetation.

After 5780 BP, there is a continued decline in the tree taxa. Fire occurrence encouraged tree decline and promoted the rapid spread of Corylus, forming secondary woodland. It is not possible to interpret whether the woodland recovered and regained its former status as the hiatus truncates the diagram just above this zone; it is possible that a succession to Betula and then Quercus would have followed. It is not possible to state categorically if the fire was anthropogenic or natural. It is unlikely to have been climatically induced as there is no evidence that this period of time was excessively dry compared with the rest of the Postglacial. If fire was caused by human activity, there is no indication whether it was accidental or managed. The levels at the top of this zone show an increase in charcoal frequency and abundance, and many of the herbs could be associated with arable/pastoral activities or could be opportunist taxa taking advantage of the fire gaps.

There is little evidence for Mesolithic man on Anglesey but the lack of archaeological evidence does not necessarily negate the possibility of a limited population within the area. This was a time of rising sea levels and many coastal areas previously occupied were now flooded, with populations forced to move inland. It is possible that this is early evidence for small, localised and temporary vegetation interference. There appears to be no other suitable explanation to account for the sudden increase in charcoal at these levels. The evidence suggests that the charcoal was derived from burning the woodland, and not local domestic fires, with decreases in tree pollen and increased soil erosion as fire was used for clearing or to burn felled wood.

LH5-LH8 (552-0cm)

The vegetational history of Llyn Hendref after 5735 BP is difficult to elucidate as major changes have been obscured by sediment disturbance. The relative frequencies of taxa give some indication as to what trees and shrubs were dominant for much of the later Postglacial, and a comparison with Tre'r Gof (northern Anglesey; Botterill, 1988) helps to trace the possible sequence of events. The main vegetational changes that appear to have taken place are the expansion of carr and mire vegetation, and progressive deforestation.

At Tre'r Gof mire development was initially gradual with increasing Cyperaceae and Filipendula at 4700 BP, and then a rapid expansion in all mire taxa from 3790 BP onwards. This latter phase of expansion coincided with the beginning of progressive deforestation (Botterill, 1988). A similar scenario can be suggested for Llyn Hendref; as discussed (section 7.2) reedswamp vegetation encroached over much of the northern end of the lake with a rapid increase in mire vegetation at around 8650 BP suggesting that by 5735 BP lake infilling had begun. Cyperaceae and Gramineae values are high and an increase in Pteridophyte spores (eg. Osmunda, Polypodium, Dryopteris and Filicales undiff.) indicate the continued development of wet marsh. The frequent occurrence of Dryopteris sporangia above the hiatus verifies the increasing importance of ferns colonising the lake shore. The build up of mire at the northern end of the lake was perhaps enhanced and accelerated by increased run-off during later phases of forest clearance. Gradually the drier areas of the mire surface would have been invaded by Alnus, Salix and Betula.

Anthropogenic influences have been cited as a major factor in bog development (Moore, 1973) although climate change resulting in varying hydrological conditions has also been cited (eg. Godwin, 1975). A rise in sea-level would also alter drainage patterns, especially in coastal areas. At Llyn Hendref the pollen sequence suggests that bog development was part of the natural succession at this site, encouraged by gentle topography, poor drainage, and a gradual infilling by macrophyte vegetation, reedswamp and then carr vegetation. Initiation does not appear to have been encouraged by anthropogenic disturbance. The macrofossil and pollen data suggest that major further expansion occurred above the hiatus but the effects on deforestation of this process remain unassessed. Botterill (1988) notes that at Tre'r Gof the main phase of mire expansion occurred before there was widespread clearance within the catchment suggesting that anthropogenic activity was not responsible for mire initiation although it is possible that it may have accelerated the process. It is possible this was also the case at Llyn Hendref.

On Cors Bodwrog there would have been different vegetation communities depending on local hydrological conditions. In pools and wetter areas species of Sphagnum and Potamogeton would have continued to thrive, and in drier localities Calluna vulgaris, Ericales, Potentilla (erecta?) and scattered Myrica gale may have grown. It is likely that the mire vegetation was left relatively undisturbed during subsequent clearance phases, although the status of Alnus and Corylus may have been affected by consequent hydrological changes. The major influence on mire development and carr vegetation appears to have been drainage projects carried out intermittently since 1960. A comparison of pre- and post-drainage vegetation suggests shows that a number of uncommon macrophyte species became extinct (including Pilularia globulifera, Sparganium minimum, and Elatine hexandra) and a survey in 1983 showed that no full aquatic higher plants survived (Blackstock, 1986). Salix cinerea had colonised the exposed lake bed and 'swampy' vegetation occupied the south-east shore.

Until major deforestation it is likely that the woodland away from the lake remained relatively open and dominated by Quercus, Ulmus and Corylus. Corylus-Quercus woodland probably occupied much of the area with Ulmus growing on richer, deeper soils. Alnus and Betula would have been more prominent around the lake edge associated with the carr. At Tre'r Gof, Quercus was dominant maintaining values of up to 28% before a decline to 10% after 3970 BP. Alnus and Betula would have been more prominent around the lake edge associated with the carr vegetation.

The status of Betula at Llyn Hendref is difficult to ascertain but the relatively low values indicate that it was never a major canopy forming taxa. Betula probably co-existed in the relatively open woodland with Quercus and probably increased in importance as secondary woodland invaded cleared areas. A decrease in Betula cone scales recorded in the pollen washings suggests a decrease in local populations around the lakeside, perhaps due to increased competition from Alnus. The presence of occasional Betula bark indicates isolated communities possible along stream edges. At Tre'r Gof low values (<10%) for _Betula_ are recorded from 6130 BP onwards and then frequencies increase as _Betula_ shrubs spread during deforestation.

Ulmus is recorded in low values but in view of its under-representation it possibly formed an important part of the canopy, thriving on deeper soils to the west and east of the basin. The _Ulmus_ decline is not recorded at Llyn Hendref, either because it did not occur or was 'lost' during sediment disturbance. At Tre'r Gof there was also no significant elm decline although the possibility of selective felling by Neolithic man was not excluded by Botterill (1988). Here the main _Ulmus_ decline appears to have been associated with the decline of other major tree taxa at around 3970 BP.

It has been suggested that _Pinus_ values recorded in zone LH4 show that it was not a local component of the vegetation at Llyn Hendref. It is possible that a subsequent _Pinus_ expansion has been 'lost' in the disturbed stratigraphy, but this is unlikely in view of the low quantities recorded throughout the sequence. At Tre'r Gof Botterill (1988) records maximum _Pinus_ percentages (23%) at 7700 BP. This was interpreted as local pine co-existing with birch but out-competing hazel within the forest. Huntley and Birks (1983) suggest that 25% is the minimum value to indicate local presence over a small area. This suggests that if _Pinus_ did exist in northern Anglesey, it was as small, localised and isolated populations. With low percentages it is also possible that _Pinus_ was absent and that the grains were windblown from another site; maximum _Pinus_ percentages at Tre'r Gof coincide with peak frequencies at Llyn Cororion, a possible source site. The data at Llyn Hendref suggest that _Pinus_ did not grow within the catchment, and values of <5% after 7400 BP at Tre'r Gof indicate that if _Pinus_ had existed on Anglesey, it was now absent.

The presence of _Tilia_ at Llyn Hendref is difficult to asses. Values of 0.48% are recorded but it is a taxa that is consistently under-represented (Bradshaw, 1981a), a problem compounded by the high local pollen input at this site. If Tilia did occupy the site at any time it would appear that it was a relatively minor component of the vegetation, although values of up to 4% at Tre'r Gof suggest that it formed part of the local canopy vegetation in parts of Anglesey.

The pollen data appear to indicate a continuation of the woodland recorded in zone LH4 although clearance may have occurred sporadically with little effect on the overall woodland composition. Secondary woodland (Betula, Fraxinus and Sorbus) may have developed followed by further recolonisation by Quercus.

Alnus and Corylus appear to have dominated the carr vegetation with Salix only surviving as an understorey shrub or on the fen periphery. The frequency of Alnus bark within the sediment (fig. 3.4) reflects the importance of this species in the late Postglacial, although a reduction in leaf fragment abundance suggests that trees were now growing further from the lake edge. It is possible that much of the wood and bark was transported from a distance by streams. Alnus occupied wetter areas with sedge tussocks and thin reedswamp. Reduced Salix percentages indicate that it was now a minor component of the carr vegetation, perhaps shaded out by closed stands of Alnus or unable to tolerate extremely wet conditions. It probably existed as an understorey shrub, with reduced flowering, or along the edges of damp meadows associated with taxa such as Fraxinus. At least three species of Salix occur at Llyn Hendref today encouraged by the reduction of water levels caused by drainage.

The herb record suggests there was a rich fieldlayer of fen herbs including Hydrocotyle, Filipendula, Ericales, Menyanthes, Rubiaceae (Galium?), Cyperaceae, Potentilla (erecta?), Caltha palustre and Sphagnum. Humulus lupulus is recorded and reflects the expansion of fen vegetation. It is also recorded at Tre'r Gof from 6000 BP onwards but became increasingly frequent after 3790 BP. Much of the Corylus/Myrica pollen record may now be attributable to Myrica gale, a species that is common in the area today and thrives on acidic fens and bogs (Schauer, 1982).

The relatively high frequencies and wide diversity of herbs recorded indicate that at some point deforestation occurred with the introduction of both pastoral and arable farming. Progressive forest clearances in northern Anglesey (Tre'r Gof) does not appear to have taken place until around 3970 BP. (Bronze Age), although small temporary clearances were recorded before this (Botterill, 1988). This date may not be directly applicable to Llyn Hendref as deforestation was probably slightly earlier at coastal sites and it was not until the late Bronze Age that bog sites in the central portion of the island were utilised fully (Lynch pers. comm., 1990). Late Neolithic finds at Llyn Hendref may indicate a move to central Anglesey away from the coast, probably due to population expansion (Lynch, per. comm., 1990). During this time clearing probably took place but would have been limited both temporally and spatially.

Implements recovered from Cors Bodwrog suggest that permanent clearing began at some point in the Bronze Age. Late Bronze Age implements from Cors Bodwrog support evidence that there was increasing use of central Anglesey with a preference for bog sites; this may have been caused by climatic deterioration which resulted in 'considerable crisis and dislocation' (Lynch, pers. comm., 1990). At Llyn Hendref it is unclear whether initial clearing was selective, but the high charcoal frequencies suggest that fire played an important part in woodland management. Taxa such as Fraxinus, Sorbus aucuparia, Ilex, Hedera helix, Viburnum and Lonicera all indicate that at some stage there was extensive clearing of the woodland. Viburnum and Ilex can thrive well in abandoned clearings or on the margins of agricultural land and Lonicera is suggested as indicating secondary woodland at Tre'r Gof (Botterill, 1988). Sorbus cf. aucuparia values at Llyn Hendref are relatively high suggesting it was an important part of the vegetation, absent from wetlands but thriving on acid soils and perhaps associated with clearings in the birch and oak woodland.

There are large increases in herbs indicative of the spread of grassland and heath habitats. Calluna vulgaris, Ericales undiff. and Pteridium frequencies are continuous and high, perhaps indicating progressive soil acidification, high frequency of burning, and the abandonment of clearings now too poor to support secondary woodland. The spread of heathland and grassland may have been encouraged by repeated burning used to improve areas for grazing. The charcoal record and loss-on-ignition results indicate that fire was a frequent occurrence, encouraging heathland development and the spread of pioneering taxa such as Fraxinus.

At Llyn Hendref the pollen record includes pastoral indicators, with taxa such as Potentilla type, Succisa pratensis, Plantago lanceolata, Polygonum and Campanula. Succisa pratensis is often associated with infertile pasture and ungrazed grasslands (Grime et al., 1988) and Dipsacus occurs on rough pasture. Caryophyllaceae is often associated with Plantago lanceolata, Cirsium, Ranunculus acris and Trifolium on moderately fertile but disturbed habitats. Pastoral activity around the lake basin was therefore important but there is no accurate date as to when it became an important part of the economy.

The occurrence of cereals shows that at some point there was sedentary anthropogenic activity close to the lake edge. The introduction of arable farming at this site cannot be dated but at Tre'r Gof, cereals were cultivated from 3500 BP with a corresponding decrease in tree taxa and mire vegetation. Other herbaceous taxa indicative of disturbed and arable land at Llyn Hendref include Artemisia (common on disturbed, fertile sites) associated with Compositae

Liguliflorae, Cruciferae and species of Chenopodiaceae. Clearing abandonment and the acceleration of natural soil degradation resulted in the spread of heath and grassland, and increasingly unstable soils.

Charcoal counts are high suggesting that there was extensive burning around the site and within the catchment. Species such as _Rumex acetosa_, _Polygala vulgaris_ and _Achillea_ type took advantage of the open habitats with little competition and were able to colonise increasing areas of bare disturbed soils. It is not possible to estimate clearing size and Botterill (1988) suggests that after a major clearing phase in the Bronze Age there was a period in the middle Iron Age when activity was reduced. It was then only after the Romans retreated that there was further extensive deforestation.

CHAPTER 8

SPATIAL AND TEMPORAL VARIATIONS IN THE EARLY POSTGLACIAL FOREST OF NORTH WALES

This chapter looks in detail at temporal and spatial changes over a small area of North Wales. Distinct variations in vegetational development are identified and the major factors that controlled plant establishment and distribution in the early Postglacial are elucidated. The location of sites discussed in this chapter are shown in figure 5.3; references are included on the accompanying key.

8.1 INTRODUCTION

Radiocarbon dating has shown that vegetational change was diachronous over the British Isles, and Smith and Pilcher (1973) illustrated that most zone boundaries are time transgressive and therefore unreliable for correlation (section 3.4.1); they are only of local chronostratigraphic significance (Birks, 1989). Theoretical forest maps have been produced for the British Isles at 5000 BP (Birks et al., 1975; Bennett, 1989) and they illustrate the high diversity of woodland types that existed at this time with different vegetation types depending on migration factors, local site conditions and competition. Bennett (1988a) also produced a series of Postglacial time/space diagrams for three transects across the British Isles which showed that pollen zones were limited, both in time and space, and that forest composition continually varied as a function of topography and climate. Different regions within the British Isles showed large variations in forest composition 'making it difficult to present a coherent picture of Holocene forest history' (Bennett, 1988).

Using radiocarbon dates for the construction of isochrone diagrams, the spread of selected taxa have been mapped for Europe (Huntley and Birks, 1983) and on a smaller scale, tree taxa arrival and expansion have been studied within the British Isles (Birks, 1989). The latter study suggested possible directions and rates of expansion and concluded that most tree taxa behaved independently producing significant differences in vegetational communities at various points in time. Birks (1989) also comments that isochrone maps covering the British Isles cannot project fine-scale variations due to topography or geology.

Vegetational change and variation on a large scale (eg. Europe; Huntley and Birks, 1983; British Isles; Birks, 1989) have been mapped, but more detailed work (eg. Turner and Hodgson, 1979, 1983) has shown that there are many local deviations to the general pattern. Significant variation over a small area should be suspected where topography, microclimate and geology are highly diverse. Vegetational development is likely to proceed at different rates depending on local climatic and edaphic conditions, and threshold conditions for a particular taxon may occur earlier at one of two adjacent sites depending on the combination of local factors (Smith, 1965).

A study in Cardiganshire (Moore, 1972b) examined five sites at different altitudes, and distinct differences in vegetational communities were identified showing that environmental conditions varied considerably throughout the region. Conventional zone boundaries were used for data correlation, due to the absence of radiocarbon dates. The present study is similar in that it illustrates differences in pollen stratigraphy over a small geographic areas but radiocarbon dates have been used for site correlation.

North Wales is characterised by both diverse topography and geology (section 1.3) with Anglesey and the Arfon Platform forming a lowlying area to the north-west of Snowdonia. Most palynological work in this area has been confined to upland sites (fig. 1.6) and until the present study, Nant Ffrancon provided the only full Postglacial pollen diagram with both good biostratigraphical resolution and reliable radiocarbon dates. Consequently, Nant Ffrancon has been used to illustrate the 'typical' Postglacial vegetational history for North Wales. However, given the topographic extremes and resultant variations in edaphic factors and microclimate, it is unlikely that any one site can be taken as 'representative' of the area especially with respect to the timing of important vegetational events.

In order to look at local vegetation differentiation it is necessary for sites to have a reliable sequence of radiocarbon dates. Using the data from this project and published data (from Hibbert and Switsur, 1976, and Walker, 1978) sites along a transect from the lowlands (Llyn Hendref, Llyn Cororion), through a valley (Nant Ffrancon) to an upland tarn (Melynllyn) have been compared for the early Postglacial. Melynllyn does not lie within the valley system but is the only high altitude site with a series of radiocarbon dates.

General site characteristics are listed in table 8.1. The Nant Ffrancon pollen site lies within a glaciated valley drained by the Afon Ogwen. The valley was previously occupied by a lake, approximately 2.5Km long, but has since been infilled with limnic muds and peat. The valley is relatively sheltered with steep sides dominated by cwms to the west and scree slopes to the east. At the head of Nant Ffrancon is a well defined cwm (Cwm Idwal) which contained ice during the Loch Lomond Stadial and which is now occupied by a small tarn. The local geology is dominated by Ordovician slates and intrusive acid volcanics. Organic soils occupy the valley floor with podsols and peaty ranker soils. Melynllyn is a small oligotrophic tarn at an altitude of 632.5m, occupying a north-east facing cwm excavated from Ordovician shales and slates, and with rhyolites in the steep south-west wall. The catchment soils are podsols and relatively infertile.

Cwm Idwal would have been a more suitable site than Melynllyn as it lies directly at the head of the Nant Ffrancon valley, but the early Postglacial pollen profiles (Ince, 1981; Tipping, 1990) lack sufficient radiocarbon dating for correlation. Another possible high altitude site would have been Llyn Clyd (SH635597, 746.8m, Evans and Walker, 1977) lying in a cwm directly above the valley, but again the pollen profile lacks sufficient radiocarbon dating. Where appropriate, other sites from Wales have been included in the synthesis and locations of these are illustrated in figure 5.1.

8.2 SITE COMPARISON: CONSIDERATIONS

8.2.1 POLLEN SOURCE AREA

The major contrast between the sites is site type and area (table 8.1). These affect the pollen source area and hence the area over which vegetation change is recorded. Potential pollen source areas for the four sites are given in figure A4.1 but these are estimates as they will have varied throughout the Postglacial.

Both Llyn Hendref and Nant Ffrancon would have had a stream-borne pollen component which would effectively increase the pollen source area resulting in increased representation of extra-local and regional sources. At Nant Ffrancon wind-blown regional pollen may have been restricted due to the steep valley sides and sheltered locality. At Llyn Hendref and Nant Ffrancon the site type would have encouraged over-representation of taxa such as Alnus and aquatic and fen vegetation associated with lake infilling.

Llyn Cororion is relatively small and would have recorded local and extra-local vegetational events. Melynllyn had an extra-local pollen source area but a regional component would have been emphasised by the openness of the site. The pollen source area of both of these sites is unlikely to have changed significantly through the Postglacial.

8.2.2 PERCENTAGE CALCULATIONS

Limitations to comparative work result from both data

Table 8.1 Details of sites along the transect

Site	Grid ref.	m.OD.	Site type	PSA	No.of RC.dates	PG.Organics recovered
Llyn Hendref	SH398765	58.5	Lake/mire	R-XL	10	7.2m
Llyn Cororion	SH597688	82.5	Lake	L-XL	11	9.5m
Nant Ffrancon	SH623633	198.0	Valley Bog	R-XL	20	6.2m
Melynllyn	SH702657	632.5	Tarn	XL-L	6	4.8m

m.OD. Metres above Ordnance Datum
PSA Pollen Source Area (also illustrated on fig.A4.1)
R Regional
XL Extra-local
L Local
RC. Radiocarbon
PG. Postglacial

manipulation and the data sets used. In this case two sites have new data, and the results for Nant Ffrancon and Melynllyn have been taken from published work. Consequently percentage data have been used in preference to concentration or influx data.

To allow direct comparison of pollen frequencies, the pollen sums of the sites need to be identical. Both Melynllyn and Nant Ffrancon have different pollen sums: At Nant Ffrancon Corylus was calculated as a percentage of trees including Corylus; at Melynllyn, Corylus was calculated as a percentage of shrubs, herbs and spores. The results from Llyn Cororion and Llyn Hendref were recalculated to make two data sets; one to compare with Nant Ffrancon and one to compare with Melynllyn (table A5.1). It was also possible, to make the tree frequencies (excluding Corylus) from Nant Ffrancon crudely comparable with the other data sets, but it was not possible to recalculate the shrub record (table A5.1)

The tree records from all four sites are therefore comparable, but the shrub records of Melynllyn and Nant Ffrancon are based on different sums. The different pollen sums make a significant difference to the Corylus frequencies (table A5.1) and so Corylus has not been included in figure 8.1. The number reached before counting is stopped also makes a difference to the reliability of the results at different sites, but the error induced by varying sums is not considered significant.

8.2.3 RADIOCARBON DATING

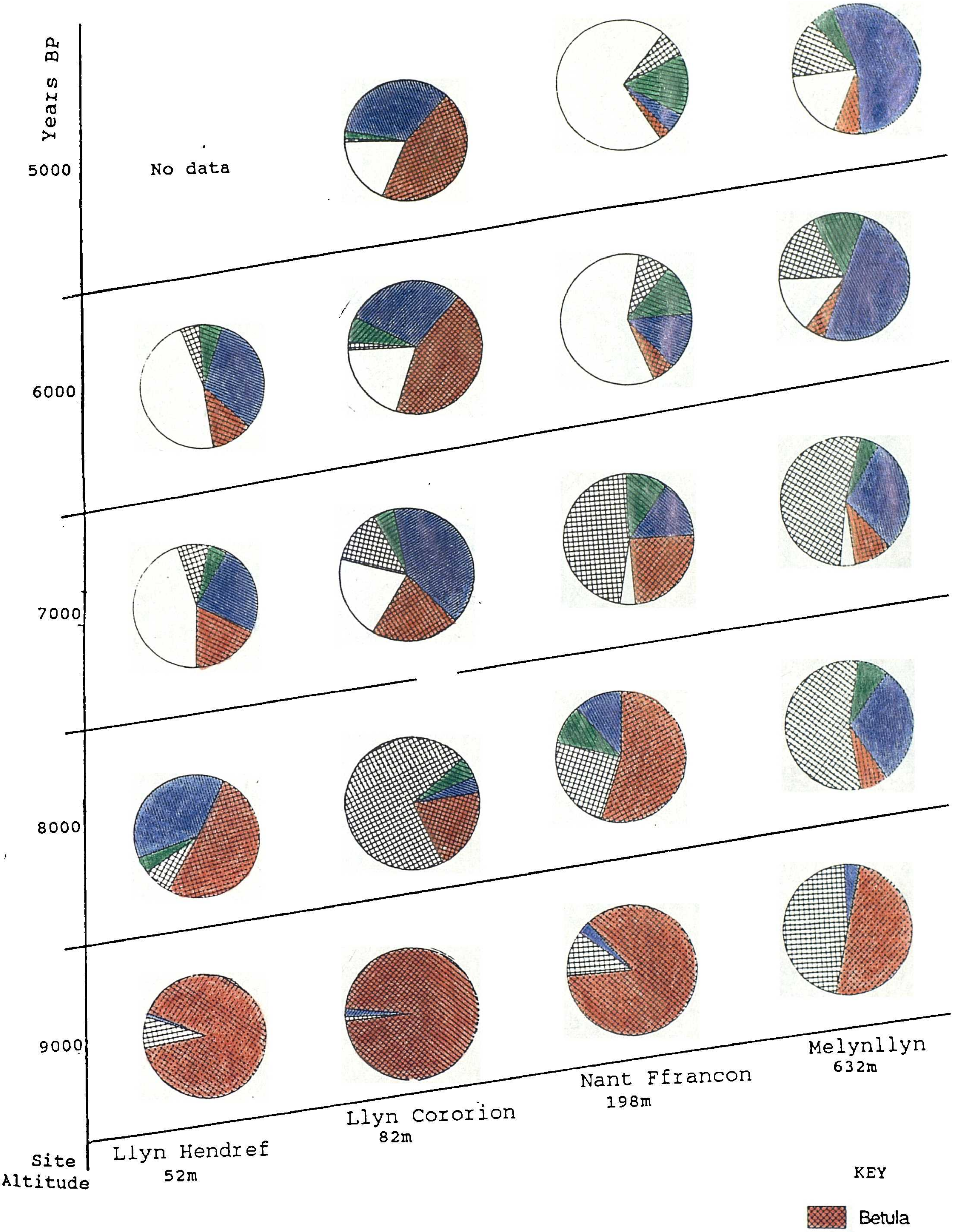
The correlation of vegetational changes relies on the accuracy of radiocarbon dates. The inherent problems associated with dating different organic sediments and depth-age curve construction must be taken into account. The dates from Nant Ffrancon and Melynllyn have not been independently assessed but there is no evidence that at either site there has been sediment disturbance or contamination, and for this study the dates are accepted as correct. Both sites have published depth-age curves, and it would appear that in the early Postglacial, sedimentation rates were relatively constant reducing the potential error associated with data interpolation. The dates for Llyn Cororion and Llyn Hendref are discussed in section 5.5.3 and although those from Llyn Cororion appear to be reliable, some of the age estimates at Llyn Hendref are affected by sediment disturbance (section 5.5.2). The dates discussed in this chapter are shown in table 5.4.

At Melynllyn many dates had to be interpolated due to the lack of specifically dated horizons. The depth-age curve indicates little change in the apparent sedimentation rate in the early Postglacial so interpolation of data should be relatively reliable. Temporal resolution is relatively limited in the early Postglacial, resulting in condensed pollen zones and the overlap of major vegetational changes.

8.3 SITE COMPARISON: DATA PRESENTATION

These data have been presented in a number of ways to illustrate a variety of features. The radiocarbon dates in table 5.4 have been used to construct figure 8.2 which shows variations in empirical and rational limits for the major taxa along the transect. Table A5.1 shows the pollen percentages for all four sites; these have then been plotted as a series of pie diagrams (fig. 8.1). To summarise the data a series of transects from the lowlands to the uplands have been drawn for selected time interval (figs. 8.3-8.7). Time slices of 9000, 8000, 7000, 6000 and 5000 BP were chosen to give an idea of the spatial variations in plant communities throughout the early Postglacial (summarised in table 8.3). This time period covers the immigration of all major tree taxa and the establishment of maximum deciduous woodland before significant and irreversible disturbance by man.

To construct the transects and pie diagrams it was necessary to interpolate taxa percentages at 9000, 8000, 7000, 6000, 5000 BP by using the depth-age curves for each site. Transects



The temporal and spatial variations of selected taxa (<u>Betula</u>, <u>Pinus</u>, <u>Quercus</u>, <u>Ulmus</u>, <u>Alnus</u>) at sites of different altitude

Figure 8.1

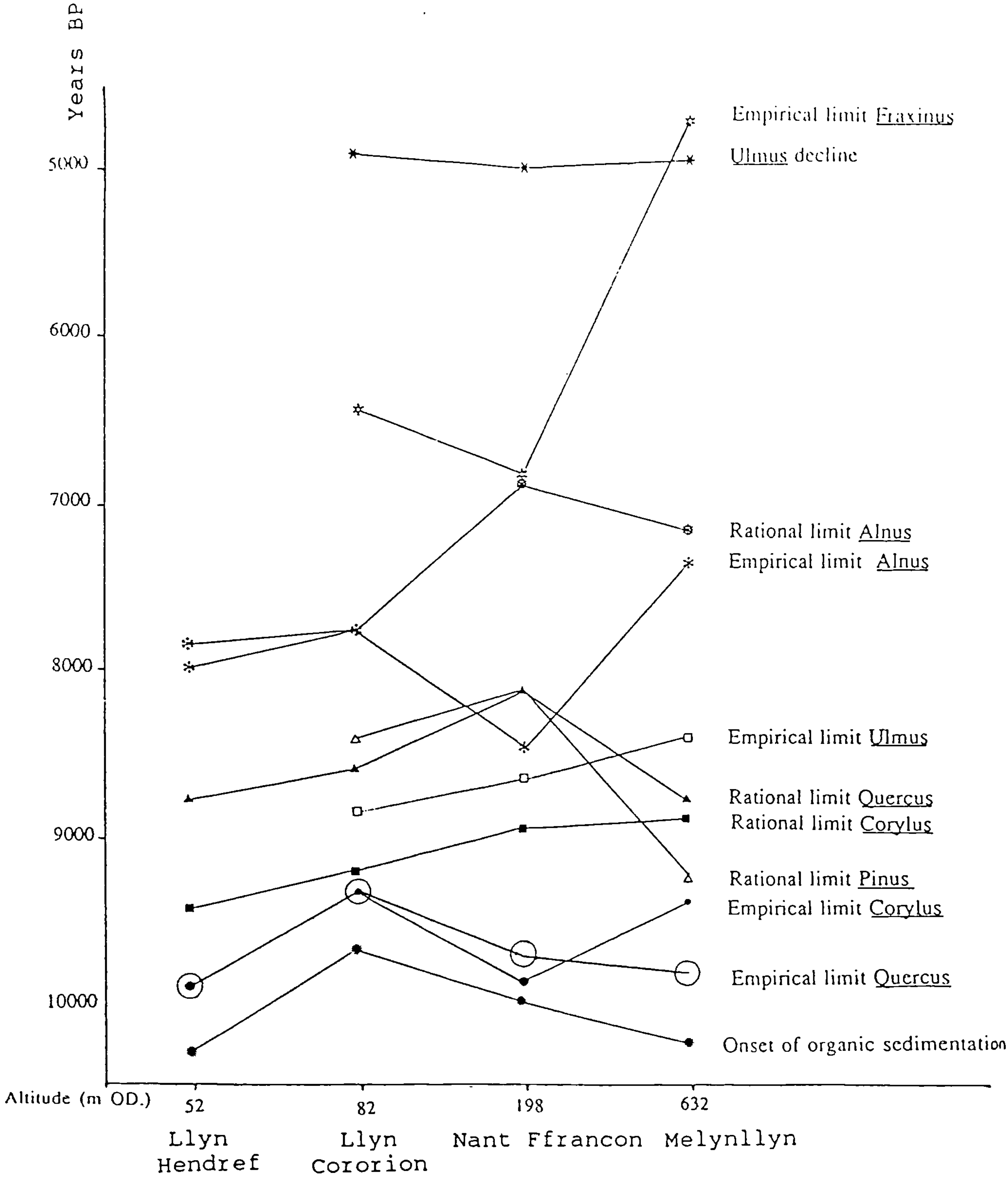


Figure 8.2 Variations in the empirical and rational limits of selected taxa, for sites along the transect

are based on interpretation of percentage data and are not a direct illustration of them; they provide a purely diagrammatic account of the vegetation, based on the author's interpretation and taking local site conditions and pollen representation into account. This is something that cannot be expressed using pie-diagrams. The transects are not intended to show accurate distribution patterns.

8.4 TEMPORAL AND SPATIAL VARIATIONS IN VEGETATIONAL DEVELOPMENT ALONG THE TRANSECT

8.4.1 JUNIPERUS RISE

The earliest Postglacial vegetation of North Wales was characterised by *Juniperus* and *Betula* scrub on the lowlands, which became sparse at altitude and at sites such as Melynllyn and Cwm Cywion (fig. 5.1), is it likely that only herbaceous taxa thrived. The transition from the Lateglacial to the Postglacial is complex and site correlation is hindered by lack of radiocarbon dates and poor biostratigraphic resolution. The onset of organic sedimentation is often associated with a rapid rise in *Juniperus* frequencies (eg. Clogwyngarreg, fig 5.1). At Llyn Hendref and Llyn Cororion there was an immediate rise in *Juniperus* values to a short-lived peak, before a rapid decline. At Nant Ffrancon the *Juniperus* rise began before the onset of organic sedimentation but peak values are not reached until 9920+/-200 BP (160 years later). At Melynllyn the rapid *Juniperus* rise was also associated with the onset of organic sedimentation, with peak values reached at around 9428 BP. The data suggest that limiting factors for colonisation were overcome in the lowlands but in the uplands, *Juniperus* remained restricted or reduced in flowering potential.

After ice-melt at upland sites there appears to have been some delay in *Juniperus* expansion, perhaps due to critical temperature thresholds. Handa and Moore (1976) suggest that temperatures during the Loch Lomond Stadial-Postglacial transition were high enough to cause ice melt within a pingo core (West Wales) and the subsequent collapse of its roof, but were still 'suboptimal for Juniperus flowering'. The threshold for Juniperus flowering in West Wales was not crossed until later, suggesting that temperature was rising slowly and was critical in determining Juniperus establishment.

Ince (1981) argued that edaphic conditions controlled Juniperus colonisation and until there was some degree of soil stability, Juniperus was unable to thrive. This may explain the apparent delay at some sites, but at other localities, Juniperus thrived despite intense soil disruption. At Llyn Hendref Juniperus apparently survived the Loch Lomond Stadial even when soil disturbance was high (section 7.3). At Cwm Idwal, the Juniperus rise occurred before the onset of organic sedimentation and it was already in decline when organic deposition began. Soil instability at these sites appears not to have affected Juniperus expansion or dominance.

The Juniperus rise is apparently diachronous and at most sites in North Wales it coincides with the onset of organic sedimentation. Variation in the timing of the Juniperus expansion or increased flowering suggests that neither climate nor soil stability were limiting factors at all sites. The rapid Juniperus rise and associated onset of organic sedimentation that is often observed may be coincidence. The association could result from condensed sequences due to slow sedimentation rates and/or post-depositional compaction. Preferential pollen preservation, with Juniperus pollen surviving in organic deposits but not in minerogenic material, could contribute to the apparently large pollen increases. Variations could also be due to the locality of refugia during the Loch Lomond Stadial. There were likely to have been numerous isolated Juniperus populations in sheltered localities during the Loch Lomond Stadial and as climate ameliorated these populations expanded and thrived in locally available habitats. The Juniperus expansion in North Wales appears to have been controlled by a combination of migrational factors (rate of spread determined by physiological factors) and site influences.

Factors controlling expansion varied from site to site and at lowland sites the expansion was relatively rapid but short-lived. At Llyn Hendref, Juniperus values reached 7%, comparable to Glanllynnau, 8%, Tre'r Gof, <5%, and Cors Gyfelog, <1% (fig, 5.1), before rapidly declining. Simpkins (1974) suggests that Juniperus never thrived at Glanllynnau and that these low-lying sites were exposed to south-westerly winds which limited Juniperus establishment or flowering potential. Fairhurst and Soothill (1989) note that the stature of Juniperus is dependent on site location, and in exposed or coastal locations, Juniperus may have been limited to a poorly-flowering shrub which was quickly eliminated by the spread of Betula. At Llyn Cororion Juniperus was relatively successful, reaching values of 36%, unusual for a low altitude sites. This may have been due to the site's relatively sheltered locality.

The lowland record contrasts strongly with upland sites where Juniperus was relatively successful. At Nant Ffrancon Juniperus was apparently expanding before the onset of organic sedimentation and reached a peak of 40% at 9920+/-220 BP. It dominated the valley for the next 160 years before a gradual decline as Betula invaded. Its success may have been due to the valley's sheltered situation and steep sides which provided suitable habitats for Juniperus colonisation. It expanded with little competition, and colonised thin mineral soils on scree slopes and stream edges. The Juniperus and Salix scrub was then invaded by Betula spreading from the lowlands. Birch colonised the deeper soils on the valley floor but was unable to out-compete Juniperus on marginal sites where it persisted throughout the Betula phase.

At Melynllyn, Juniperus was apparently successful, possibly because Betula was unable to compete with Juniperus in such a marginal environment. Juniperus frequencies indicate extensive scrub, although frequencies may be slightly over-emphasised due to the openness of the site.

On the lowlands Juniperus expansion and dominance was limited to localised areas where establishment depended on site conditions and Betula competition. At most sites, Juniperus was restricted, although it was temporarily successful in more sheltered localities. At upland sites, Juniperus survived for longer, co-existing with invading Betula and not eliminated until the arrival of Corylus.

JUNIPERUS DECLINE

The Juniperus demise along the transect was diachronous and complex; at Llyn Hendref and Llyn Cororion it had virtually disappeared by 9860 BP. Within Nant Ffrancon, Juniperus persisted until 8930+/-170 BP and survived in the upland areas until at least 8800 BP. At both Llyn Cororion and Llyn Hendref the peak in Juniperus is short-lived and concentration data suggest that this is mainly due to the invasion of Betula. Betula was highly successful at colonising the coastal plateau and Juniperus was quickly suppressed by the increased shade and competition. At both sites Juniperus had been eliminated by the time Corylus was established.

At Nant Ffrancon, Juniperus only underwent a gradual decline as Betula percentages reached a maximum. This suggests that Juniperus persisted in marginal habitats and was still an important component of the vegetation during the Betula invasion. It is only on the expansion of Corylus that Juniperus was finally eradicated. At Melynllyn Juniperus also persisted throughout the Betula development. The Juniperus peak coincides with the empirical limit of Corylus (9428 BP), and Juniperus only declined as Corylus expanded.

The persistence of Juniperus at higher altitudes partly reflects the inability of Betula to displace it and partly the late Corylus expansion. Moore (1972a) discussed the relationship between the Corylus rise and Juniperus decline and identified four scenarios recorded in pollen diagrams. These have been modified (radiocarbon dates have been added) and are shown in table 8.2.

Table 8.2. The relationship between the Juniperus decline and Corylus rise (modified from Moore, 1972a).

1) The onset of the *Corylus* rise coincides with the *Juniperus* decline.

eg. Gwarllyn	312 mOD.	

2) Falling *Juniperus* values coincide with rising *Corylus* percentages.

eg. Cwm Cywion	415 mOD.	
Gwernan	170 mOD.	(*Corylus* rise 9070+/-70 BP)
Tre'r Gof	(lowlying)	(*Corylus* rise ca. 8700 BP)

3) The rise in *Corylus* begins immediately after the fall in *Juniperus*

eg. Nant Ffrancon	198 mOD.	(*Corylus* rise 8930+/-170 BP)
Melynllyn	632 mOD.	(*Corylus* rise ca. 8900 BP)
Traeth Mawr	330 mOD.	
Glanllynnau	<15 mOD.	
Llyn Llydaw	440 mOD.	
Cwm Cywion	600 mOD.	(*Corylus* rise 8365+/-200 BP)
Clogwyngarreg	235 mOD.	(*Corylus* rise 8700 BP)

4) The rise in *Corylus* is delayed until after the fall in *Juniperus*.

eg. Llewesig	368 mOD.	
Llyn Cororion	82 mOD.	(*Corylus* rise 9215+/-65 BP)
Llyn Hendref	52 mOD.	(*Corylus* rise 9420+/-65 BP)
Clarach Bay	Coastal	
Cwm Idwal	370 mOD.	

Moore concluded that these relationships reflected the migration of Corylus, eg. at Gwarllyn, where the Corylus rise is associated with the Juniperus decline, Corylus was early to arrive. Moore's work assumes that the Juniperus decline was synchronous, and that the Corylus rise was diachronous. However, this study suggests that the Juniperus decline was probably diachronous and therefore may have been late at Gwarllyn. The Juniperus decline appears to be dependent on the success of Betula. At sites where Betula is successful (eg. Llyn Cororion) there is a delay between the Juniperus fall and the Corylus rise; where Betula is less successful then Juniperus persists longer and the Juniperus and Corylus frequency curves overlap.Biostratigraphic resolution is also important because in a condensed sequence there is more likely to be overlap between the Juniperus curve and Corylus frequencies.

Further radiocarbon dates for the Corylus rise (table 5.4) show that the relationship between Corylus and Juniperus curve does not depend solely upon Corylus expansion. Using Moore's conclusions, sites in group 2 (table 8.2) should theoretically have earlier dates for Corylus arrival compared to sites in group 4, but in fact the dates are later. Other coastal sites which would be expected to have simultaneous Corylus and Juniperus rises show a delay between the two (eg. Clarach Bay) comparable to higher sites (eg. Llewesig).

The relationship between the Corylus and Juniperus curves is therefore complex. More dates are needed for the Juniperus peak and the rational limit of Corylus, and sites with good biostratigraphic resolution and reliable radiocarbon dates are required before any general or regional pattern can be elucidated.

8.4.2 CORYLUS

The expansion of Corylus is a distinct feature of pollen diagrams from North Wales. Deacon (1974) proposed a glacial refugium to the north-west of Britain, and Moore (1972a) suggested that Corylus arrived via the west coast, spread eastwards into Wales and northwards into Scotland. Birks (1989) presented an isochrone map for the spread of Corylus into the British Isles which supported the idea that Corylus first arrived via the Irish Sea Basin, with initial establishment along the west coast of Wales. Birks (1989) suggests that the most likely dispersal mechanism was water, with nuts carried by currents from the western European coast and deposited along the Welsh coast. In the presence of fertile soils, little competition and a mild climate, Corylus rapidly spread and became dominant.

The early arrival of Corylus on the west coast is supported by empirical limit dates at Clarach Bay (9600 BP), and the Dovey (between 9870 BP to 9610 BP) although earlier dates have been recorded from sites further inland, at higher altitudes and from further north. Llyn Hendref has an age estimate at 9890+/-90 BP, Tregaron yields 9747+/-220 BP and Nant Ffrancon has a date of 9870+/-200 BP. Problems with such dates include the definition of arrival time (empirical or rational limit) and when expansion and dominance can be said to have taken place. Birks (1989) argues that the empirical limit of Corylus is difficult to identify and his isochrone map is based on the rational limit. This provides a minimum date for the presence of Corylus thus the map may reflect the pattern of expansion of Corylus, not necessarily its arrival. Using the ideas of Bennett (1983b), the empirical limits suggest that Corylus was present in North Wales early in the Postglacial.

Both Llyn Cororion and Llyn Hendref have low but frequent counts before the empirical limit and it is possible that small isolated populations existed before environmental conditions were suitable for Corylus expansion. Conditions on the coastal plain would have become favourable before higher altitude sites, and therefore the rational limits here have an early age estimate. This is supported by figure 8.2.

The Llyn Hendref date (9890+/-90 BP) is one of the earliest empirical limits for Corylus in Wales and supports the idea of early arrival at lowlying sites. The later date at Llyn Cororion (9365+/-65 BP; discussed in section 5.5.3) suggests that Corylus was initially restricted due to the success of Betula or to migrational factors. During the early Postglacial Llyn Cororion was some distance from the sea; the Menai Strait was not yet flooded and the mountains may have acted as a topographic barrier to Corylus advancing from the south-west.

The early date at Nant Ffrancon (9870+/-200 BP) is difficult to explain in terms of migrational factors. It is similar to that from the Dovey Estuary (between 9870-9610 BP) and Llyn Hendref (9890+/-90 BP) and it may be possible that at some sites the arrival (empirical limit) of Corylus occurred by chance dispersal by birds. Melynllyn has an estimated empirical limit of 9428 BP; this later dates was probably a function of altitude and harsher environmental conditions, with a time lag between the arrival of Corylus in the lowlands and its spread into the uplands. The date at Melynllyn may be atypical for the Snowdon area, because migration via the Vale of Conwy may have promoted a more rapid spread of Corylus up the eastern side of Snowdonia compared with central upland sites.

Corylus consistently shows later rational limits at higher altitudes (fig. 8.2), suggesting that although it was relatively early in arriving at some sites, expansion was delayed until environmental conditions were suitable. The series of dates from the lowlands to the uplands suggests that the change in conditions was time-transgressive, occurring earliest on the coastal plain. The relationship of rational limit with altitude may in part reflect migrational features (eg. a late arrival at Melynllyn), but this does not explain the rapid expansion at Llyn Cororion or the delayed expansion at Nant Ffrancon. A climatic factor such as temperature may be the control; for example a decrease in the number of frost days would have maximum impact on the lowlying sites. By 8800 BP conditions were suitable throughout Snowdonia for Corylus colonisation, and only local factors (eg. soil) limited populations.

At all sites, Corylus at some point formed a dominant component of the vegetation. At Nant Ffrancon and Llyn Hendref, Corylus remained dominant associated with lake infilling, whilst at Llyn Cororion Corylus became subordinate when Quercus and Ulmus invaded

8.4.3 QUERCUS AND ULMUS

The empirical and rational limits of Quercus and Ulmus are discussed together as they are inter-linked. Quercus was present in south-west Britain around 9500 BP and spread at 350-500m/yr until 8000 BP and 50m/yr thereafter. Ulmus arrived via the south-east at around 9500 BP and spread at 500-600 m/yr, so that by 9000 BP it covered most of central England and Wales except for the coastal plain and mountains of North Wales (Birks, 1989). North Wales is an area where the two taxa have approximately the same rational limits. At all sites along the transect the general frequency pattern of the two taxa is similar; the empirical limit of Quercus was relatively early but with a delayed rise; the Ulmus empirical limit was later, but with a rapid rise (fig. 8.2).

The empirical ages of Quercus at Llyn Hendref, Nant Ffrancon and Melynllyn are early (9890 BP, 9745+/-200 BP, and 9857 BP respectively) compared with Llyn Cororion (9365+/-70 BP). The date at Llyn Cororion is comparable with an estimated date of 9300 BP for Cors Gyfelog on the Llŷn Peninsula, another low-lying site. At 9000 BP, Quercus frequencies increased with altitude; Llyn Hendref (0.5%), Llyn Cororion (2%), Nant Ffrancon (3%) and Melynllyn (4%) but frequencies are low and it is difficult to ascertain if Quercus was actually present. Huntley and Birks (1983) suggest that percentages >2% are necessary to indicate a local presence (depending on other taxa present), and so low percentages at Llyn Hendref and Llyn Cororion suggest that Quercus was not yet established at lowland sites. The low percentages at Nant Ffrancon and Melynllyn could have been a windblown component; Melynllyn was still a relatively open site. If it is possible that Quercus was present even at very low pollen percentages then the Quercus empirical limit could indicate the presence of small and localised populations. If this was so then initial Quercus distributions had no direct relationship with altitude and were probably dependent on competition and availability of habitat.

The Ulmus empirical limit appears to be directly related to altitude (fig. 8.2) with progressively later dates at upland sites. The date at Llyn Hendref is unreliable (section 5.5.2) but there are approximately 200 years between the empirical and rational limits at other sites along the transect. Although values are low, the empirical limit of Ulmus may represent the initial presence of Ulmus at sites, and if so, then the delay in arrival in the uplands may be due to a slow rate of spread.

The rational limit of Ulmus and Quercus is a more certain indication of species presence. On the coastal plain (Llyn Cororion) Ulmus was established before Quercus (rational limit of Quercus 8660+/-60 BP, Ulmus 8845+/-70 BP). At Nant Ffrancon the rational limit for the two taxa coincides (8120+/-120 BP) suggesting delay in the Ulmus expansion. At Melynllyn the rational limit of Quercus (8800 BP) is approximately 375 years before Ulmus (8428 BP), suggesting that Quercus was able to establish at this relatively open site before Ulmus reached such altitudes. This may have been due to migrational factors, but the expansion and success of Ulmus may have also been limited by site exposure whilst Quercus was encouraged by the lack of competition.

The delay between the empirical and rational limit of Quercus is approximately 1110 years at Llyn Hendref, 975 years at Llyn Cororion, 1625 years at Nant Ffrancon and 1057 years at Melynllyn; a considerable delay at all sites suggesting that there was some limiting factor on Quercus establishment.

The most probable factors influencing Quercus establishment were canopy density and woodland shade, under which Quercus was unable to compete. Both Llyn Hendref and Melynllyn were relatively open and Quercus was able to invade relatively easily, compared with Nant Ffrancon where a dense Corylus-Betula woodland was established. At Melynllyn, Corylus and Quercus were expanding together and Quercus was able to establish before maximum canopy cover developed.

At Llyn Hendref and Llyn Cororion, Quercus percentages are maintained at between 20-40% for much of the Postglacial and it is suggested that Quercus was relatively more successful on the Arfon Platform compared with Anglesey. The importance of Quercus varied, with reduced records at more exposed or waterlogged sites, as illustrated by the low Quercus frequencies from the Llŷn Peninsula and Anglesey (Botterill, 1988). At these sites it appears that Alnus was the dominant canopy former and that Quercus was a local phenomenon. Away from the boggy areas it is possible that Quercus was more frequent, and that Llyn Cororion illustrates what was more typical of the regional lowlying vegetation.

At Nant Ffrancon, Quercus was only a minor woodland component. Values of between 12-16% are recorded for 8500-6500 BP, suggesting that Quercus was present but never dominant. Nant Ffrancon was originally a large lake and much of the valley bottom would have been waterlogged and this, and steep valley sides may have limited available habitats. Quercus may have formed a minor component of the vegetation on drier stable soils at slope breaks or alder carr edges. At Llyn Peris, a valley parallel to Nant Ffrancon and at an altitude of 100m, Quercus values were initially high (30%) and then reduced to around 20% when Alnus was established. At this valley site, Quercus was more successful compared with Nant Ffrancon. This may be due to the topography as the Llyn Peris-Llyn Padarn lower valley is relatively open with gentle slopes and a wide valley floor compared to the steep unstable slopes of Nant Ffrancon. At Cwm Cywion (above Nant Ffrancon, altitude 600m) Quercus frequencies never exceed 10% suggesting it was a minor component of the vegetation at this altitude.

At Melynllyn *Quercus* appears to have been the dominant taxon for much of the Postglacial. Values gradually rise and after 7150 BP are consistently above 30%. Maximum values of 70% are recorded shortly after 4755+/-90 BP although it should be considered that the values may be exaggerated due to the openness of the site.

At Llyn Hendref the time lag between the empirical and rational limits of *Ulmus* is negligible, suggesting that conditions were suitable for immediate establishment. A similar situation occurred at Llyn Cororion contrasting to Nant Ffrancon where there was a delay of 520 years between the empirical and rational limits. This could perhaps be explained with reference to the behaviour of *Corylus*. At lowland sites *Corylus* was established relatively early, and the empirical and rational limits of *Ulmus* do not occur until after the *Corylus* maxima. In contrast, at Nant Ffrancon, *Corylus* was relatively early (empirical limit) but expansion was delayed such that *Ulmus* was present before high percentages of *Corylus* were reached. Therefore at the valley site the early *Ulmus* populations competed with expanding *Corylus* woodland rather than established woodland. *Corylus* was relatively successful at Nant Ffrancon and *Ulmus* was probably out-competed. The *Ulmus* curve at Nant Ffrancon shows that expansion was relatively gradual, suggesting a low rate of spread, compared with the lowlands. As well as competition local site factors could also have been very important. The sporadic occurrence of *Alnus* may indicate site wetness, which may have inhibited the spread of *Ulmus* which prefers fertile but well drained soil.

At all sites *Ulmus* was apparently later to arrive than *Quercus*, but its expansion occurred before *Quercus*. This may be a function of their relative doubling times (70 years for *Ulmus* compared with 140 years for *Quercus*; Bennett, 1983b) but it may also reflect the ability of *Ulmus* to grow under shade and hence compete successfully with the *Corylus*-*Betula* woodland that was widely established in the region. At Llyn

Hendref and Llyn Cororion, maximum values of Ulmus are quickly reached. At Llyn Hendref values average at 3.5%, with slightly increasing values towards 5735 BP. At Llyn Cororion values average at 5% but are frequently up to 7%, with maximum values around 6350 BP. These frequencies indicate that on Anglesey and the Arfon Platform, Ulmus was an important component of the vegetation but was never a forest dominant. It probably thrived on fertile, deeper soils with little competition (section 6.3 and 7.3).

At Nant Ffrancon the Ulmus rise is delayed compared with Llyn Cororion; average pollen frequencies at the former are 8% and maximum values are reached at approximately 6035 BP, slightly later than on the coast. Ulmus appears to have thrived at Nant Ffrancon whilst Quercus remained restricted. At Melynllyn values reach 15% at about 5250 BP suggesting that Ulmus was a significant component of the vegetation. Ulmus percentages are likely to be over-represented due to the openness of the site but Ulmus does appear to have been most successful at this site, perhaps reflecting the inability of Corylus to become dominant.

8.4.4 PINUS

Pinus is over-represented in pollen diagrams due to high pollen production and efficient dispersal and, even in the absence of trees in the Lateglacial and Postglacial, pollen counts are recorded at most sites. This over-representation renders an empirical limit as meaningless and it is not a feature recorded in Postglacial diagrams from North Wales. Values of 20% (Bennett, 1984) or 25% (Huntley and Birks, 1983) are required before local presence can be suggested but without macrofossil evidence even this remains subjective. All four sites along the transect have continuous values in the early Postglacial (<10% at Llyn Hendref and Llyn Cororion, Nant Ffrancon <20%, and Melynllyn <50%). Nant Ffrancon and Melynllyn were open sites and hence had a greater representation of windblown pollen.

Birks (1989) suggests that Pinus spread from south-east England but that the rate of spread was relatively slow (initially 300-700m/yr slowing to 60-100m/yr) compared with Ulmus and Quercus. By 8000 BP Pinus had reached most of Wales except the Llyn Peninsula, Anglesey and south-west Wales. Bennett (1984) notes 'the result is that no pollen diagram from England, Wales or Ireland shows dominance of P.sylvestris where it appears after the arrival of Quercus and Ulmus, suggesting that they were able to exclude P.sylvestris as a forest dominant'. This appears to be true for many North Wales sites but data from this study suggests that factors other than competition may have restricted Pinus establishment.

The percentage diagram from Llyn Hendref and Tre'r Gof suggest that Pinus was either absent or at least scarce over much of Anglesey and never formed part of the woodland. High ground is limited on Anglesey but there were other habitats it should have been able to colonise (eg. mire edges, river valleys); this suggests that other factors caused its absence. At Tre'r Gof, Pinus establishment may have been restricted by dense shading from the dominant Corylus woodland (cf. Carlisle and Brown, 1968). Beales (1980) noted that Pinus was unable to grow under Corylus woodland. The spread of Pinus may also have been limited by climatic conditions such as exposure to south westerly winds.

Cors Gyfelog (Llŷn Peninsula, fig. 5.1) has a similar record (Pinus values <12%) despite a generally open woodland. The landscape was relatively open (arboreal pollen = 60%), and so competition from Ulmus and Quercus does not appear to have been a problem but Pinus still did not establish. This may indicate direct competition with Corylus out-competing Pinus on fertile soils and with few marginal habitats available, Pinus was unable to survive. Climatic conditions (eg. wind exposure, high rainfall) may also not have been favourable for Pinus growth.

At Llyn Cororion the Pinus rational limit (8425+/-70 BP) occurred after Quercus and Ulmus had reached maximum frequencies, again indicating that the latter taxa had little effect on Pinus establishment. The rapid Pinus rise suggests that edaphic or environmental limitations were minimal. Corylus woodland had largely been replaced by Quercus and Ulmus, and Pinus was able to colonise its own separate niches. Maximum Pinus frequencies (68%) were reached just before 7745 BP and indicate that Pinus was well established in the local vegetation.

As discussed in section 6.3, it is difficult to envisage Pinus invading the temperate woodland, but the concentration data suggests that Corylus and Quercus were disrupted by the immigrating Pinus. It has been suggested that lake shallowing may have increased the availability of suitable habitats for Pinus around the lake (section 6.3). A high incidence of fire occurred in the catchment during the Pinus increase. Bradshaw and Browne (1987) noted that Pinus can survive low intensity fires better than Corylus, Betula and Quercus, and it is possible that at Llyn Cororion this encouraged establishment of a local pine community. At Crose Mere (Beales, 1980), an expansion of Pinus after the establishment of Quercus and Ulmus is also recorded, and Beales suggested that Pinus occupied areas that were previously waterlogged and devoid of woodland. On drying out, due to lake lowering, there was an initial colonisation by Betula followed by a Pinus invasion.

At Llyn Cororion, Pinus dominated the lakeside vegetation for at least 600 years before the first major decline; a rapid decrease coinciding with the Alnus rational limit. A second decline occurs at around 7050 BP. The concentration data indicates that the Pinus was quickly restricted to isolated trees or small stands in marginal areas, and former habitats were quickly occupied by Corylus and Alnus. The success of Pinus at Llyn Cororion reflects the sheltered locality, and the high incidence of burning coincident with lake level changes.

At Nant Ffrancon the rational limit for Pinus is estimated at 8120+/-120 BP, occurring after the rational limits for Quercus and Ulmus but before their maximum values. The late rational limit may partly reflect migrational features but the rise in frequencies is also gradual (cf. Llyn Cororion) occurring over >1000 years, before values of 45% (at 7000 BP) are reached. A gradual increase in local populations is implied, but with a later expansion date compared with the lowlands. The open oak woodland appears to have been unaffected by the Pinus invasion but Corylus and Betula may have been replaced reflecting changes in mire vegetation; this is difficult to confirm without concentration data. Declining Salix values coincident with the rational limit of Pinus also suggest changes in the fringing mire surface, which encouraged Pinus expansion. A similar situation has been discussed by van Leeuwaarden and Janssen (1987) where Pinus colonised previously barren areas . They suggested that lake and ox-bow infills were quickly colonised by invading Pinus populations.

Pinus apparently existed at Nant Ffrancon for >1000 years before a rapid decline coincident with the Alnus rise. By 6725+/-100 BP. Pinus was probably absent from the main valley but possibly survived on higher slopes and cwms. Cwm Cywion (lying above Nant Ffrancon) records the rational limit of Pinus after the Quercus and Ulmus rise, although the frequencies of the latter are low. Again the rise is gradual from 8365+/-200 BP onwards and appears to be limited by the simultaneous but very rapid rise in Corylus.

Pinus frequencies at Melynllyn are high (>20%) throughout the Postglacial, but the openness of the site probably emphasises the long distance pollen component. The rational limit occurred at around 9000 BP, earlier than on the lowlands or in the valley. This may reflect the general migration route of Pinus westwards across Wales, and the ease with which Pinus became established at relatively open sites with harsh climates and reduced competition.

At Melynllyn, Pinus was expanding before Quercus and Ulmus were established. This situation is therefore in sharp contrast to the trend recorded in the lowlands. Pollen percentages suggest that Pinus did form local communities at this altitude but not as a thick canopy. Corylus was never dominant and Pinus was therefore able to invade, and thrived in the relatively extreme climate and on the poor soils; Pinus sylvestris grows well on thin organic soils and has a high competitive ability on soils with nutrient deficiencies (Carlisle and Brown, 1968). Maximum values of Pinus were maintained for around 1750 years, co-existing with Quercus and Ulmus, and only declining at around 7378+/- 160 BP coinciding with the rational limit of Alnus. The percentage diagram suggests that by 4755+/-90 BP Pinus was absent from this site.

Walker (1982) questioned the regional distribution of Pinus and suggested that there was considerable variation in abundance throughout Wales. Along the transect altitude cannot solely explain variations in Pinus distribution. Other factors including competition and local sites conditions were of major importance. Pinus can grow on a wide range of habitats (Bradshaw and Browne, 1987) and its distribution is a response to the 'behaviour' of competitors.

During the early Postglacial Pinus was important in marginal habitats such as on high ground, raised bogs and valley peats (Bennett, 1984). The relationship between Pinus, other taxa and edaphic conditions is therefore complex and it may be that no definite pattern exists and that the success or failure of Pinus was site specific and not related to one environmental constraint.

At sites where Corylus, and later Alnus, were dominant or where Corylus was late to expand (Nant Ffrancon), the Pinus rational limit was delayed and the rise was gradual. Often Pinus failed to establish, suggesting that where Pinus and Corylus competed Pinus was unable to succeed until the Corylus forest had been displaced by Quercus and Ulmus. Thick Corylus woodland may have prevented Pinus from growing and Corylus may have been partially successful on marginal sites, further reducing the available habitat for Pinus. Once the Corylus canopy had been broken up, Pinus was able to compete for the marginal habitats on which _Quercus_ and _Ulmus_ were unable to colonise.

At Llyn Hendref and Tre'r Gof, _Corylus_ was dominant over _Quercus_ and _Ulmus_ and again _Pinus_ was unable to expand. Anglesey and some coastal plain areas remained free of _Pinus_ due to a combination of factors. Without the creation of a new and marginal habitat _Pinus_ was unable to compete with _Corylus_ woodland (Anglesey and the Llŷn Peninsula) or mixed _Quercus_-_Ulmus_ woodland (Arfon Platform). At Llyn Cororion, _Pinus_ became established and thrived for 600 years but only because there were local changes in environment and the creation of new habitats. The situation in the lowlands was therefore complex and _Pinus_ appears to be only successful at sites where a new ecological niche was created by changing conditions (fire, hydrological changes). _Pinus_ was relatively more successful in the uplands. At higher altitudes deciduous tree cover was limited due to edaphic conditions and the harsher climate and there were therefore large areas of 'marginal habitat' available for colonisation by _Pinus_.

At Melynllyn _Pinus_ was able to replace _Corylus_ and _Betula_. Carlisle and Brown (1968) state that _Pinus_ and _Betula_ have similar site tolerances and where soils could favour either species, _Pinus_ is able to out-compete _Betula_. It is possible that at this site _Betula_ was near to its altitudinal limit and gave way to _Pinus_. _Pinus_ was dominant in the uplands for a longer time period than at lower altitudes (600 yrs. at Llyn Cororion, 1230 yrs. at Nant Ffrancon and 1650 yrs. at Melynllyn). The main _Pinus_ decline is diachronous and is always associated with the _Alnus_ rational limit. This association suggests _Alnus_ directly replaced _Pinus_ at all altitudes, but that at some localities the latter was able to persist locally in marginal habitats.

In the lowlands _Pinus_ populations were therefore sporadic and localised with occurrence depending on site conditions and competition. _Pinus_ was relatively more successful in valley situations (Nant Ffrancon) where marginal habitats existed in the form of valley bogs, high land and steep slopes. At upland sites Pinus exploited the open scrub and was able to thrive in the harsher climate and on poor, dry soils.

8.4.5 ALNUS

The rapid rise in Alnus recorded at many sites was initially used to define the lower boundary of zone 7 (Godwin, 1940) but the rise has been shown to be diachronous, varying between 7500 BP and 5000 BP (Smith and Pilcher, 1973). The earliest empirical limits are recorded from lowland and coastal sites, but Smith and Pilcher (1973) concluded that it was impossible to comment on 'the relative times of establishment and earliest expansion of alder' in England and Scotland. Chambers and Price (1985) identified sites in West Wales which yielded early rational limits prompting the hypothesis of an eastward expansion of Alnus from western refugia.

If it is acknowledged that Alnus may have been present at some sites before the rational limit then the rational limit only provides a minimum date for its presence. Chambers and Elliott (1989) concluded that Alnus could be established but not be palynologically recorded. Low frequencies of Alnus pollen may therefore indicate significant alder populations in favoured localities. Bennett and Birks (1990) mapped the spread and increase of Alnus across Britain using both the empirical limit and date of maximum values and found that no coherent pattern could be identified. It was concluded that the spread of Alnus depended on the availability of suitable habitats.

The pollen curves for the four sites along the transect reflect many of the points discussed above. The empirical limits for Llyn Hendref and Llyn Cororion are similar (7950+/-70 BP and 7745+/-65 BP respectively) as are the curve forms. Llyn Cororion has occasional and sporadic counts, with the earliest around 9000 BP, possibly suggesting small populations prior to the empirical limit (cf. Chambers and Elliott, 1989). The rational limit at Llyn Cororion appears to be slightly later but there is an almost continuous curve below it suggesting that if the pollen sum had been higher, the limit may have been slightly earlier.

The rise in Alnus at both sites is rapid. At Llyn Hendref, Alnus competed with Betula and Salix within the fen community and lake level fluctuations (section 7.3) created waterlogged areas suitable for invasion. Once established, Alnus was locally successful for the remainder of the Postglacial. At Llyn Cororion the Alnus rise is slightly more complex due to fire and forest disturbance which coincide with the rational limit. These factors appear to be site specific and enabled Alnus to replace Pinus as the dominant species fringing the lake.

The behaviour of Alnus at these two lowland sites is also reflected at Tre'r Gof and Cors Gyfelog. The former has low counts from the early Postglacial suggesting that Alnus was first established in coastal areas. However, it was some time before further expansion was possible. Alnus values here reach 30% and appear to displace Betula and possibly Salix. Values remain high until major deforestation after 3790+/-70 BP. On the west coast of Wales, Cors Dolfriog has a similar date for the rational limit of Alnus (7590+/-90 BP). Edwards (1980) suggests that Alnus found an early route along the valley from the coast and then quickly became established at this low altitude site.

At Cors Gyfelog the Alnus rise was rapid and occurred at 7250+/-60 BP resulting in minor reductions in Salix and Betula. Alnus and Corylus then dominated this site for much of the Postglacial. The Crose Mere diagram (Beales, 1980) contrasts with Llyn Cororion, having an empirical limit at c.8150 BP, slightly earlier than Llyn Cororion. The rise is also relatively gradual with maximum values of 20% reached at around 6600 BP. Beales (1980) suggests that the presence of suitable damp soils was the most important determinant of distribution; the delay was attributed to dry soils.

Alnus was generally slightly later arriving at lowland sites in the north compared with the west coast, but earlier than in South Wales. It became an important component of the vegetation at all sites discussed, but the period of initial expansion varied depending on local conditions. Published work does not contain enough detail to deduce the exact causes of the Alnus rise, but Llyn Hendref and Llyn Cororion indicate that water level fluctuations, fire occurrence and anthropogenic disturbance may have been critical influences. Alnus either competed with Pinus (Llyn Cororion) or with the Betula-Salix carr (Llyn Hendref) and the mixed oak-elm woodland remained intact with Alnus also present as an understorey shrub in wetter areas.

The timing of expansion was dependent on local conditions, but by 7500 BP lowland lake (Llyn Cororion) and mire (Llyn Hendref) sites were dominated by Alnus fen and these wetland woods persisted for much of the Postglacial. Alnus also occupied the valleys (Nant Ffrancon) but late expansion is suggested by the rational date of 6880+/-100 BP. A small and local alder population probably existed from 8450+/-150 BP onwards occupying stream and lake edges and water-logged localities within the carr. It was possibly competition with established carr vegetation that prevented Alnus from becoming dominant for at least 1570 years. Eventually Alnus was able to expand and displaced Pinus and Betula. It is difficult to ascertain the major influence on the alder expansion at Nant Ffrancon but they were probably similar to those on the lowlands. The lake was gradually infilling and a change in hydrological conditions may have encouraged the Alnus spread. The alderwoods probably invaded the infilling lake and also fringed streams and the bases of steep slopes. Alnus then dominated the valley until the late Postglacial.

At Melynllyn, Alnus has an empirical limit of 7378+/-160 BP with a gradual rise in pollen frequencies to 20%, which are then maintained for much of the Postglacial. Maximum values (approximately 40%) are not reached until after 2150 BP when Pinus declines and Betula frequencies are suppressed. Without concentration data it is difficult to ascertain the true status of Alnus at this site. Alnus pollen is over-represented in pollen diagrams due to high productivity and efficient dispersal, so the frequencies may reflect a wind blown component from lower altitudes.

The present day ecological requirements of Alnus suggest that Alnus was unlikely to have been important at high altitude sites, and that the majority of the pollen recorded is attributable to a wind blown component. Viable seed is not formed at altitudes above 305 m (McVean, 1956) and fruit production is limited by harsh climates including frost and high wind exposure. Early pollination and exposed female catkins limit Alnus ability to produce seed in severe winter conditions or at high altitudes (Grime et al., 1988). The seedling's susceptibility to drought and cold periods in spring, and the high light intensity and humidity required for seeding establishment limit the number of habitats in which mature trees can thrive (Grime et al., 1988). The present day altitudinal limit of Alnus is 488m (Bennett and Birks, 1990). The gradual Alnus expansion is unlikely to reflect true Alnus establishment at high altitudes and it is likely that climatic factors limited populations to a few isolated and stunted individuals.

Alnus appears to have been present to at least 275 m (Llyn Dwythwch) but only low values (<20%) were recorded at Llyn Llydaw (440 m). At Cefn Gwernffrwd (395 m, an upland basin peat site in mid-Wales) the Alnus rise was relatively late (rational limit of 6815+/-85 BP) but percentages (25%) suggest local dominance. At this plateau site, Alnus probably thrived as part of the upland woodland, dominating on wetter areas around the mire. Western and northern sites suggest that the altitudinal limit for Alnus lay somewhere between 350-440 m, below that postulated for Pinus and Betula.

Valley alderwoods therefore formed an important component of the vegetation, but the dominance of Alnus varied occurring later in the valley system. Llyn Hendref and Llyn Cororion verify that there was an early Alnus rise in North Wales. Once

Alnus was established at a site it then remained dominant for much of the Postglacial with regeneration occurring adjacent to parent trees, at the margins of woodland (cf. Bennett and Birks, 1990) or on areas provided by mire development. At higher altitudes *Alnus* gave way to *Betula* and *Pinus*.

8.4.6 TILIA

An isochrone map of the empirical limit of *Tilia* (Birks, 1989) shows its migration from south-east Britain towards the north-west. The first *Tilia* arrived c. 7500 BP, and initially spread rapidly (400-500 m/yr) but slowed towards north-east England and Wales. It reached North Wales by 6500 BP but the migration rate was reduced, perhaps because the mountains formed a topographic barrier and climatic conditions were near the critical threshold for establishment.

Before human interference *Tilia* was a major component of the woodlands in south eastern and central England (Birks *et al.*, 1975) and at 5000 BP (Bennett, 1988) was the dominant canopy species on fertile non-calcareous soils (south east and central England); it extended to south Cumbria, north Yorkshire and east Wales. Outside these areas *Tilia* existed only as small local pockets within the woodland. In the early Postglacial *Tilia* may have had a wider distribution than at present.

Pigott and Huntley (1978) discussed the modern *Tilia* distribution in the Lake District and concluded that relict stands persisted from mid-Postglacial times. Many trees occupy rocky ravines and slopes that have never been intensely disturbed. However, species now fail to regenerate and fertile seeds are rarely produced. It is suggested that between 6000-5000 BP, (when *Tilia* was established), summer temperatures were at least 2^{0}C higher than today. In the Lake District most populations occur between 0-160 m.OD. (Piggott and Huntley, 1978) with only a few stunted specimens over altitudes of 220m. The best specimens are located in deep soils on level ground occupying hollows filled by glacial drift, but the majority of trees (85%) occur on steep slopes and cliffs (Piggott and Huntley, 1978).

Tilia is a moderate pollen producer (Godwin, 1975) but its grains are relatively heavy and insect pollinated, resulting in under-representation in pollen diagrams. It is therefore difficult to reconstruct true abundance of lime in contemporaneous woodland. Huntley and Birks (1983) suggest that any pollen, irrespective of quantity, indicates the presence of lime. Values of 1% reflect a sparse local presence, 5% reflects local abundance and over 10% indicates a Tilia dominated canopy. At Rhosgoch Common a core peripheral to the lake edge yielded 20% Tilia and a central core recorded only 10%, (Bartley, 1960). Central cores therefore appear to underestimate the presence of Tilia and the correction factor of x2 (Andersen, 1970) may be too low at sites with regional pollen source areas (eg. Llyn Hendref and Nant Ffrancon).

Site comparison along the transect shows that Tilia distribution was uneven. The status of Tilia at Llyn Hendref is difficult to verify due to the disturbed sediment record, but sporadic grains after 5738 BP suggest that occasional trees may have existed in the mid-Postglacial. Tre'r Gof (Anglesey) has a complete Postglacial record showing sporadic counts from 7400 BP onwards with frequent occurrences (<1%) after 5700 BP (Botterill, 1988); sufficient to suggest isolated trees in more sheltered localities.

Llyn Cororion appears to be atypical, having a well-defined Tilia curve. There are sporadic counts from 6400 BP onwards suggesting isolated stands were established before the rational limit at 5650 BP. This date is later than at Tregaron (5986+/-100 BP) supporting the late establishment of Tilia in North Wales. The expansion of Tilia at Llyn Cororion was relatively slow, probably due to limitations imposed by competition and climate. Maximum values (3%) coincide with the beginning of the Ulmus decline (5050 BP) and indicate that Tilia was an important component of the local vegetation. Tilia replaced Ulmus and Corylus with little change in the established oak woodland.

A comparison with other lowland sites suggests that _Tilia_ was only abundant locally. At Cors Gyfelog (Botterill, 1988) there are three isolated _Tilia_ counts. Crose Mere is similar to Llyn Cororion; the empirical limit for _Tilia_ occurs just after 7373+/-110 BP with maximum values (2%) at 5296+/-150 BP. Percentages then gradually decline and only sporadic counts are registered from 3714+/-120 BP onwards. The concentration data again indicate that _Tilia_ replaced _Ulmus_ and _Corylus_. At favourable locations _Tilia_ was locally dominant for a few hundred years. Llyn Cororion and Crose Mere both lie on till with brown earth soils of low base status and isolated gley patches. The low altitude location with relatively deep soils may have provided ideal edaphic conditions for _Tilia_ establishment. The conditions at these sites is similar to those described by Piggott and Huntley (1978) in the Lake District where the best _Tilia_ specimens were found.

At Nant Ffrancon there are occasional counts of _Tilia_ from around 6000 BP onwards with the empirical limit estimated at 5560 BP and maximum values reached by 5050+/-70 BP, again coincident with the _Ulmus_ decline. Values are low (<5%) but the continuous curve suggests that _Tilia_ was present at this site, probably replacing _Corylus_ and possibly _Ulmus_. _Tilia_ was probably restricted to rocky slopes near streams or as isolated trees on the valley sides. In Lake District valleys, _Tilia_ is generally restricted to stream banks and roches moutonnees. The situation in Nant Ffrancon may have been similar with _Tilia_ being locally present but never dominant.

At Melynllyn, sporadic _Tilia_ counts are recorded between 7000 BP and 2062+/-60 BP but values are low and discontinuous. It is difficult to determine if _Tilia_ existed at this site, and given the present day ecological requirements it would appear unlikely. Small isolated but stunted trees may have survived in sheltered localities but would never have been dominant in the upland areas. Above 400m _Tilia_ was almost non-existent; at Cwm Cywion, Llyn Goddionduon and Clogwyngarreg there are no counts recorded (this may be influenced by pollen source area) whilst at Llyn Clyd, Llyn Glas, Llyn Dwythwch and Llyn Llydaw (fig. 5.1) only low and sporadic counts have been recorded.

The Tilia decline has attracted much attention and was originally believed to have been climatically controlled (Godwin, 1975), but recent work suggests that it was a direct result of anthropogenic activity. Godwin (1975) places the Tilia decline at around 3000 BP but radiocarbon dates from south Yorkshire (Turner, 1962) shows that the decline was diachronous, caused by different cultures operating at various times within the area. Lime was selectively felled for its nutritious leaves and for access to fertile soils on which it grew. It appears that after the decline environmental conditions had changed sufficiently for regeneration to be inhibited.

The decline of Tilia at Llyn Cororion was complete by 4200 BP (early compared with Crose Mere, 3714+/-129 BP and Whixall Moss, 3227+/-115 BP) but the reason for its decline remains obscure. Fire may have encouraged its final decline and could account for its failure to regenerate, but there is no unequivocal evidence that anthropogenic factors were responsible (section 6.3). Gaps created by the Tilia decline were filled by Fraxinus and Corylus.

Tilia therefore had an uneven distribution in North Wales with only localised occurrence within the mixed oak woodland. It was scarce on Anglesey whilst on the Arfon Platform it was common in some areas and absent in others. It was able to survive in more marginal habitats within the valley, in rocky locations and where there were well-drained soils. The climate here would be moderated by the shelter provided by the valley sides. At higher altitudes Tilia was absent except perhaps for isolated stunted individuals in sheltered localities.

8.5 CHRONOLOGICAL SUMMARY

The preceding sections highlight the major differences in the

Key

For figures 8.3 - 8.7

Juniperus

Betula

Pinus

Corylus

Quercus

Ulmus

Alnus

Tilia

Salix

Marsh (Lake infilling)

Sea level

Figure 8.3 The spatial variation of forest composition along the transect at 9000 years BP

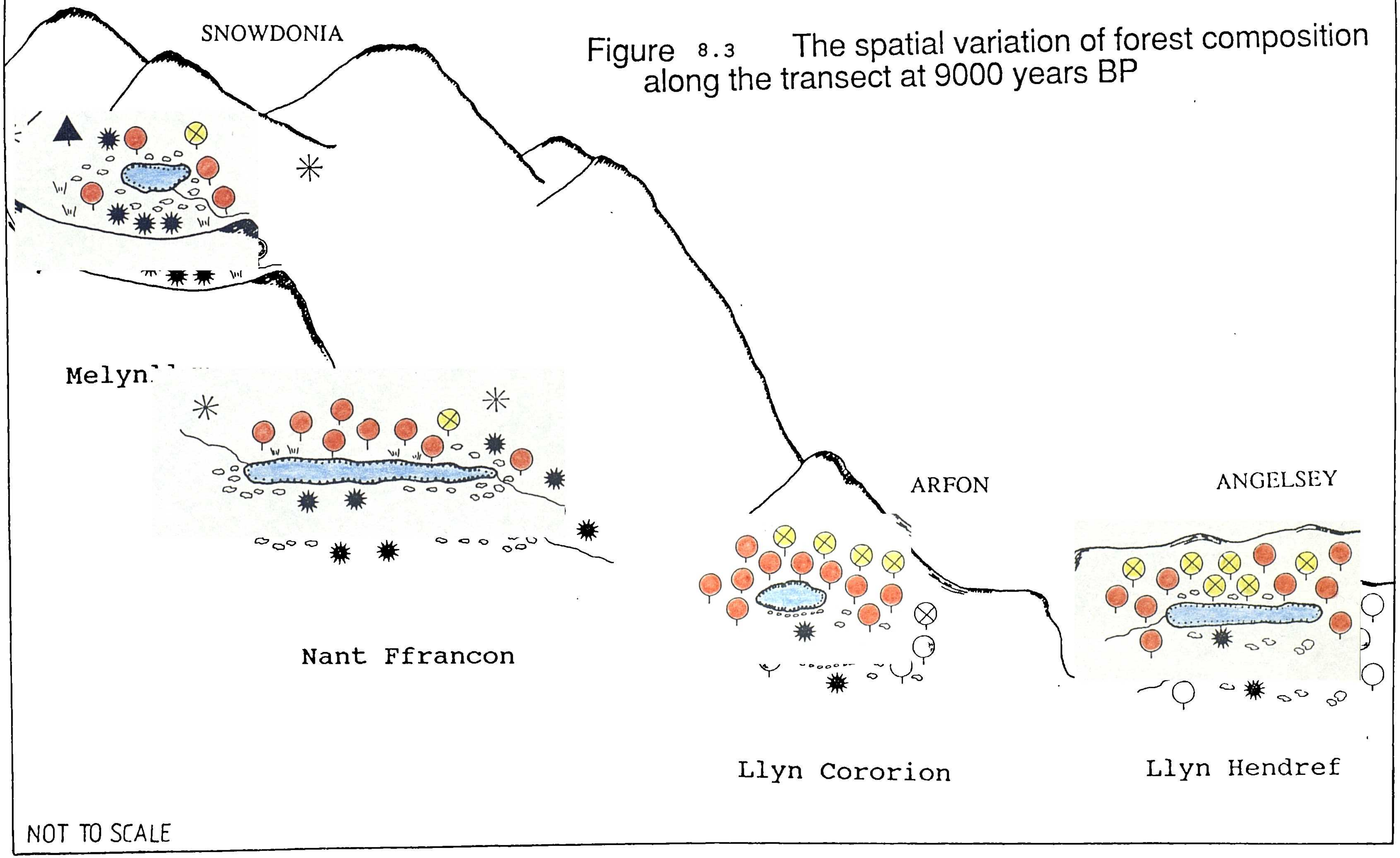


Figure 8.4 The spatial variation in forest composition along the transect at 8000 years BP

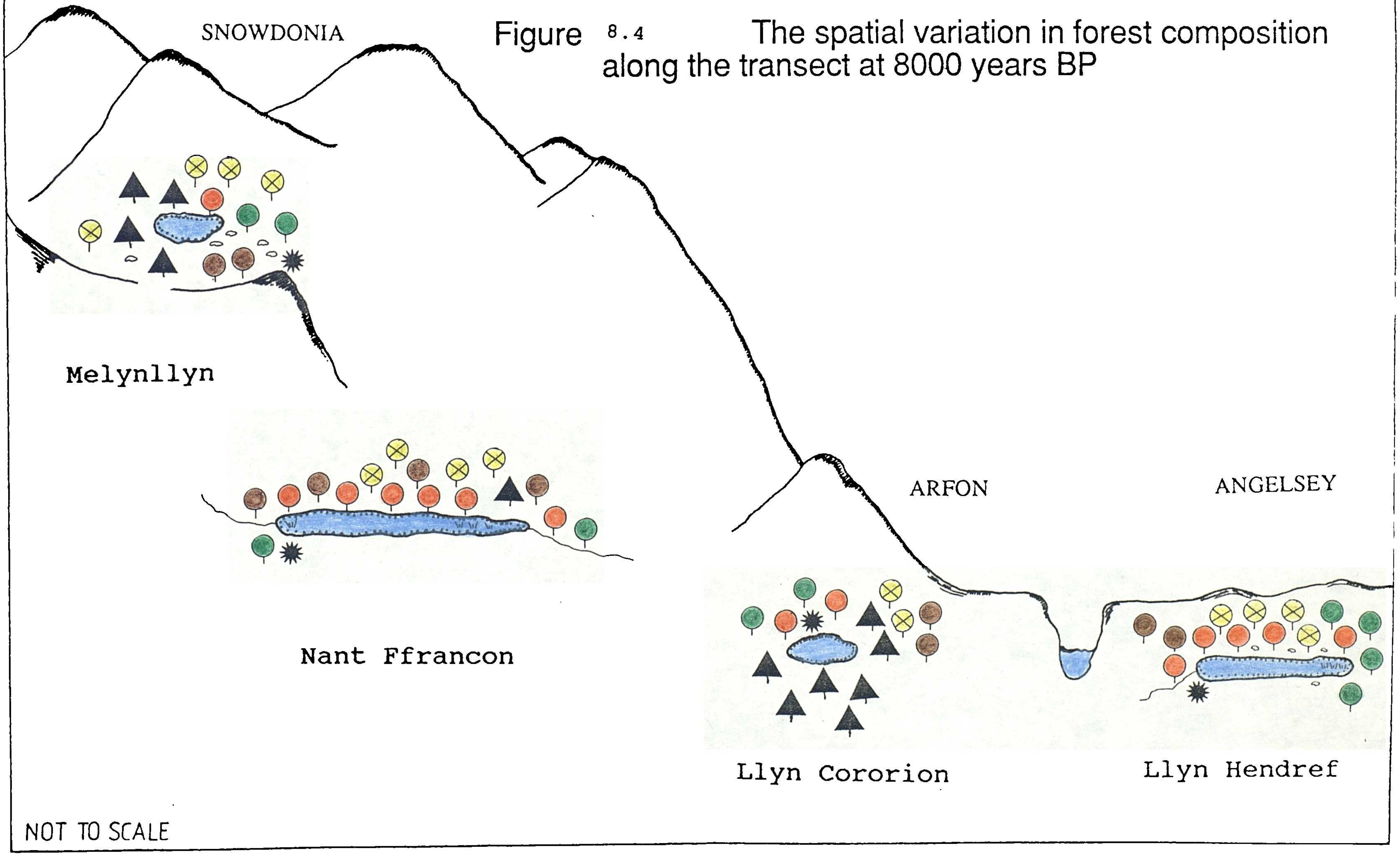


Figure 8.5 The spatial variation in forest composition along the transect at 7000 years BP

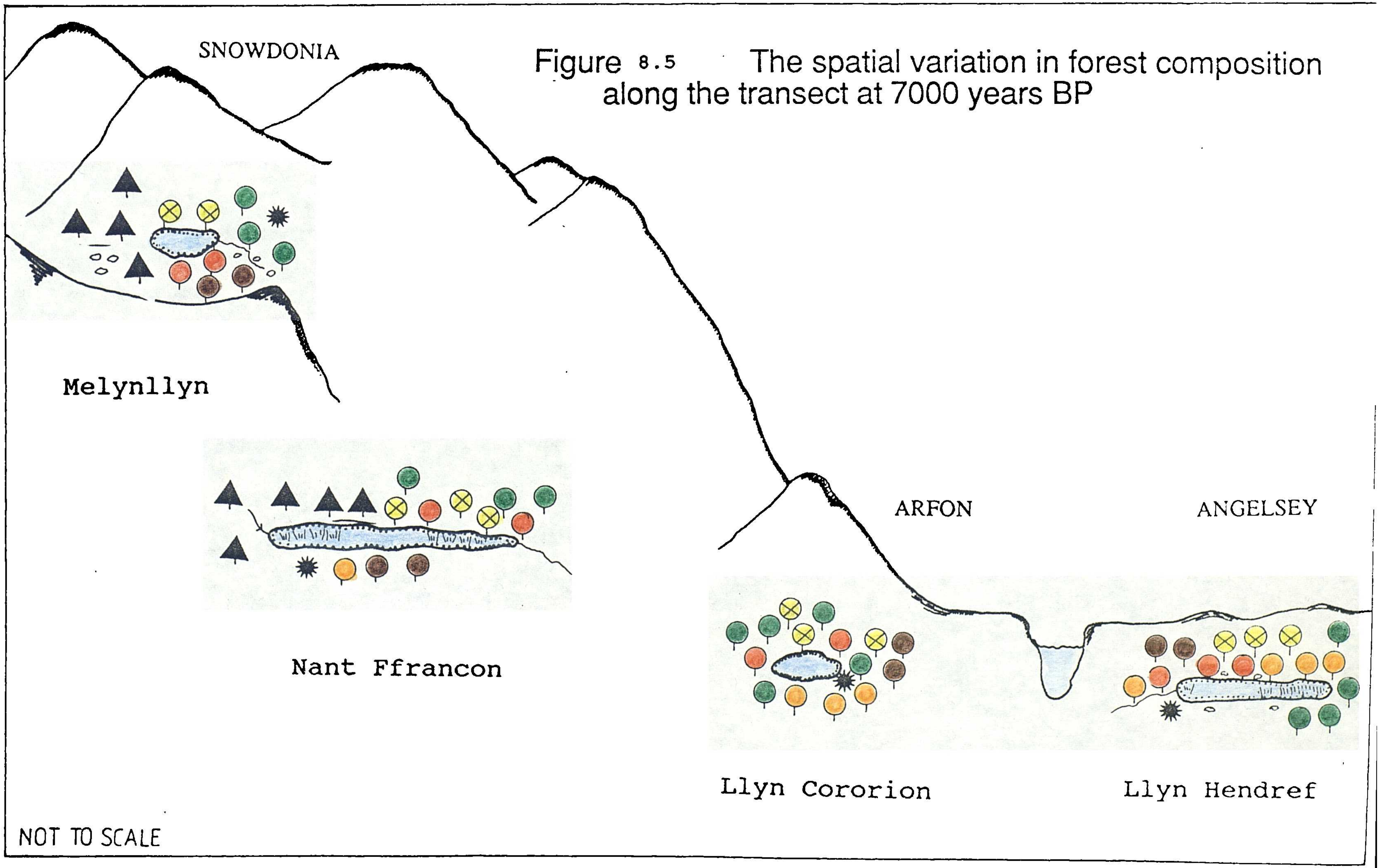


Figure 8.6 The spatial variation in forest composition along the transect at 6000 years BP

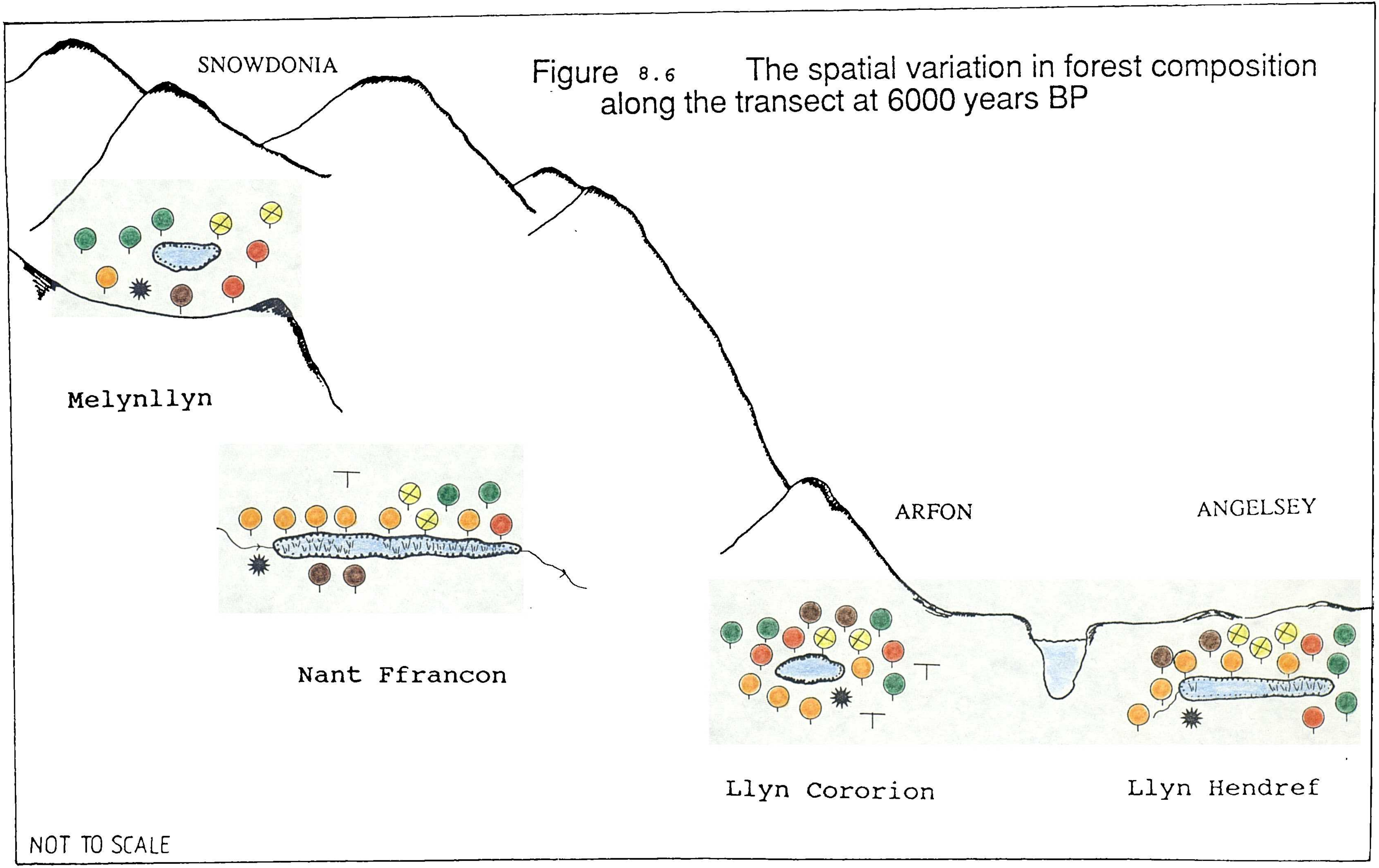


Figure 8.7 The spatial variation in forest composition along the transect at 5000 years BP

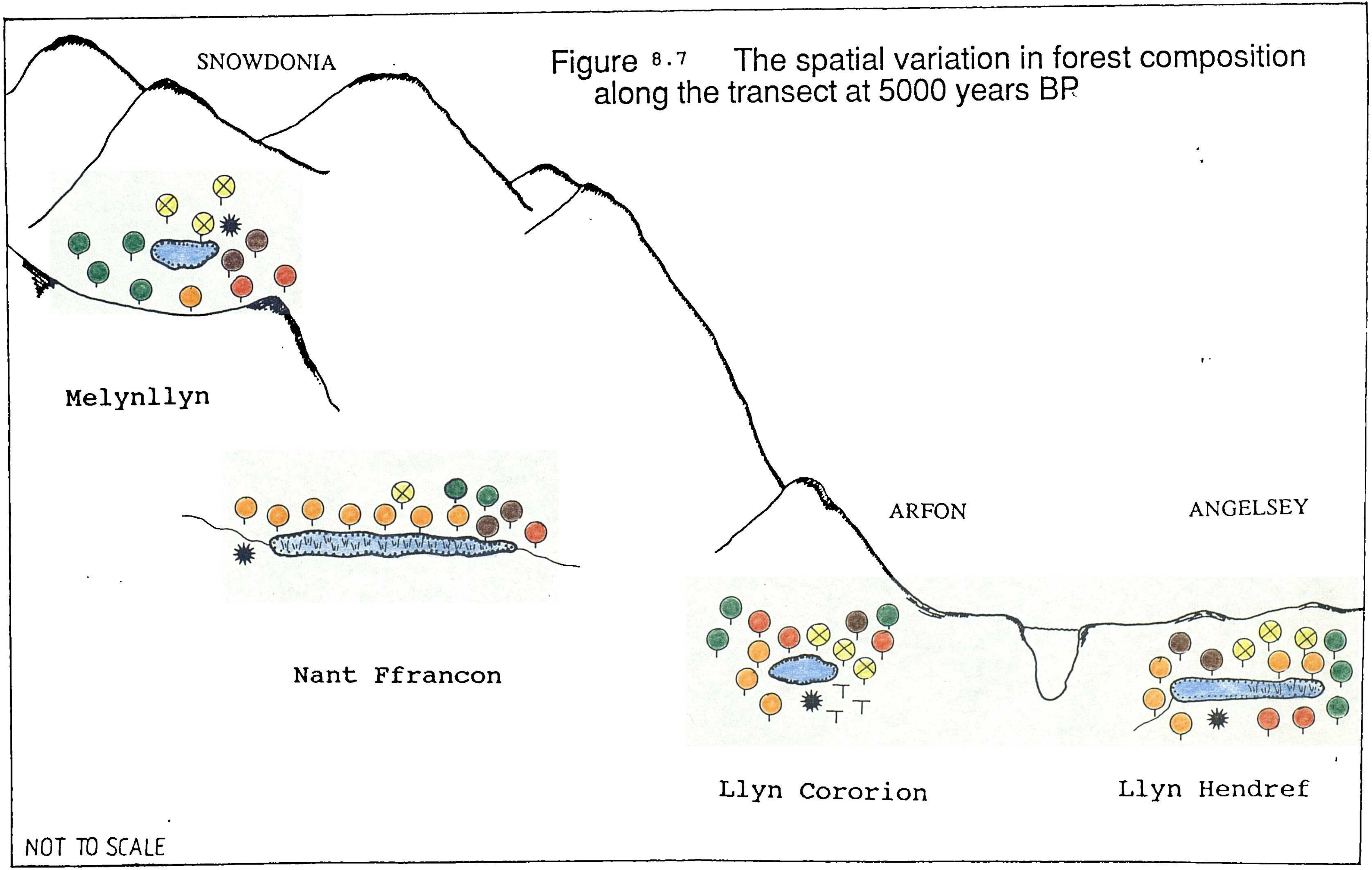


Table 8.3 Main vegetation types along the transect at selected time intervals

Years BP	9000	8000	7000	6000	5000
Site					
Llyn Hendref	C-B	Q-B (U-C)	A/(Q-U)	A/Q-U-C	A-C/(Q)
Llyn Cororion	B-C	Q-U/B-P	A/Q-U	A/Q-U-T	Q-B
Nant Ffrancon	B(J)	B-Q-U (C)	P/Q-U-B	A/Q-U	A/Q-U
Melynllyn	B-J	P-Q (C)	P-Q (C)	Q-U	Q-U

C Corylus   T Tilia
B Betula   A Alnus
Q Quercus   U Ulmus

/ indicates two vegetation types
() indicates a subordinate taxon

timings of arrival and expansion of the main tree taxa. A comparison of pollen curves from Llyn Hendref, Llyn Cororion, Nant Ffrancon and Melynllyn show that the shrub and tree pollen curves are similar, but that similar events took place at different times. The distribution and dominance of species also varied resulting in different vegetational assemblages existing at varying altitudes at the same time. The pie charts (fig. 8.1) give an impression of this but are unable to illustrate the general vegetation abundance. The transect diagrams are intended to give a more realistic picture of vegetational variation and to summarise the main differences. Five 'time slices' have been chosen, from 9000 to 5000 years BP, and for each the contemporary vegetation along the transect is described. The vegetation is represented diagrammatically in figure 8.3 to 8.7, and the main vegetation types are shown in table 8.3.

8.5.1 9,000 BP

By 9000 BP all four sites were wooded but there were already vegetational differences due to migrational factors and edaphic conditions. On Anglesey (Llyn Hendref) the woodland cover was relatively extensive with a canopy dominated by Corylus and Betula. Salix was a minor component, locally dominant in the carr vegetation and in wet hollows around the lake. The Corylus expansion was early, favoured by the westerly location, proximity to the sea and lack of competition. Extrapolated data from Tre'r Gof suggests that Corylus establishment was slightly later in the north of Anglesey but that Corylus woodland was extensive across the island whilst Betula was relatively restricted.

On the Arfon Platform (Llyn Cororion) the Corylus arrival was delayed. Betula woodland was dominant and was perhaps initially able to exclude Corylus. Just before 9000 BP Corylus expanded rapidly, becoming a dominant component of the vegetation along the coastal plain. In more exposed sites (eg. Cors Gyfelog) Corylus values are lower and Betula dominated. Around Llyn Cororion Salix formed a local component of the vegetation. _Quercus_ values reach 2% suggesting either a regional pollen source or possibly early and isolated individuals.

It appears that Nant Ffrancon was less densely wooded than low-lying areas, and _Betula_ was the dominant tree type. The late _Corylus_ rise allowed _Betula_ woodland to persist whilst _Corylus_ woodland was well established in the lowlands. This was probably due to the time lag between _Corylus_ arriving on the coast and completing its migration to higher altitudes. _Juniperus_ was still surviving in the valley in contrast with its elimination at lower altitudes. By 9000 BP it was declining and was gradually restricted to marginal habitats by the expanding _Betula_ woodland. Scree slopes to the east and the cwms to the west would have provided suitable habitats and the pollen diagram from Cwm Cywion (above Nant Ffrancon) suggests that _Juniperus_ survived here until at least 8365+/-200.

Melynllyn was still relatively open at 9000 BP but is difficult to interpret as much pollen is probably attributable to wind-blown grains from lower altitudes. High _Pinus_ percentages (46%) suggest _Pinus_ was present, but it is more likely that the pollen was a regional component emphasised by the lack of local pollen. The site appears to have been dominated by _Betula_ and _Juniperus_, which persisted for over 1000 years. The later arrival of _Corylus_, harsh climate and lack of competition ensured the continued success of _Juniperus_ at higher altitudes. Ince (1981) suggested that at Cwm Cywion (600 m) birch may have been close to its altitudinal limits ensuring the continued survival of _Juniperus_. _Salix_ also appears to have been more important at this site, compared with lower sites, perhaps again due to the lack of competition.

Corylus domination began early on Anglesey whilst _Betula_ was still the canopy-former along the coastal plain and in the valley. By 9000 BP _Corylus_ became important at Llyn Cororion whilst _Betula_ still dominated at Nant Ffrancon and _Juniperus_-

Betula persisted at higher altitude.

8.5.2 8,000 BP

By 8000 BP there had been significant changes at all sites, due to the continuous immigration of new taxa. Ulmus and Quercus expanded at all sites, and Pinus had become locally important. At Llyn Hendref the expansion of Quercus and Ulmus were relatively early and by 8000 BP mixed Quercus-Betula woodland dominated, with Ulmus in favoured localities and Corylus still prominent as both an understorey shrub and a canopy tree. Woodland cover had increased slightly.

At Llyn Cororion mixed Quercus-Ulmus woodland was established with Betula reduced to an understorey shrub or surviving in marginal habitats. This woodland remained relatively undisturbed by the subsequent Pinus invasion. By 8000 BP, Pinus was dominant at the lakeside whilst Quercus-Ulmus woodland persisted on the coastal plain. Pinus was limited spatially and did not form part of the regional tree cover on the coastal plain. Corylus was now reduced to an understorey shrub; in contrast to Llyn Hendref where it remained important. The vegetation on Anglesey appears to have been more diverse than that on the Arfon Platform. Corylus and Betula persisted whilst on the mainland Quercus and Ulmus were more important.

At 8000 BP the vegetation in Nant Ffrancon was similar to that at Llyn Hendref. Betula was still important and Ulmus and Quercus were locally dominant. There was a Pinus expansion but this was slow with only a gradual rise in values. Pinus reached its maximum extent on the lowlands just after 8000 BP; in the valley Pinus existed but was still restricted. At Melynllyn, Betula was a minor component of the vegetation and the site was dominated by Quercus and Pinus. Corylus was also important and pollen values suggest that some Ulmus trees were present.

The vegetation at all sites contains basically the same components, except for the absence of Pinus at Llyn Hendr f, but the importance of each taxon varied depending on migrational factors (Corylus) or edaphic conditions and availability of habitat (Pinus).

8.5.3 7000 BP

The major changes which occurred between 8000 and 7000 BP was Alnus establishment on the lowlands and Pinus expansion in the valley. At Llyn Hendref Alnus invaded and quickly dominated vegetation around the lakeside, replacing Salix and Corylus. The pollen diagram suggests reduced Betula, Quercus and Ulmus, but away from the lakeside the latter two taxa probably persisted as the dominant vegetation type.

At Llyn Cororion local alder carr was becoming established, replacing Pinus as the dominant local tree type. Away from the lake mixed Quercus woodland, characteristic of the Arfon Platform, persisted. Ulmus thrived in distinct pockets and Betula persisted as an understorey shrub and within the carr. Corylus was able to thrive with alder within the carr, or was able to flower more freely.

The situation at Nant Ffrancon was similar to that recorded at Llyn Cororion 1000 years before (fig. 8.1). A delayed Pinus expansion meant that Pinus was now dominant, replacing Betula and colonising drier areas of mire. Corylus was reduced in importance and Betula survived as an understorey shrub and in marginal habitats. Quercus and Ulmus remained unaffected by the Pinus invasion. There was a mixed but open oak woodland at the foot of the slopes and on higher ground away from the lake edge. In waterlogged areas there were isolated stands of Alnus, but local site conditions were not yet suitable for expansion. This delay meant that whilst Alnus thrived on the lowlands, Pinus was dominant in the valley.

The situation at Melynllyn had been relatively stable since 8000 BP. The landscape was still open and percentages are again difficult to interpret Pinus and Quercus were the dominant trees with occasional Ulmus. Corylus was still important but decreased pollen counts suggest that perhaps shading had increased and reduced effective flowering. It is unlikely that Alnus was present.

8.5.4 6000 BP

Figure 8.6 shows there was little change in the variety of tree taxa present but proportions varied resulting in significant differences between localities. At Llyn Hendref the regional and local vegetation had changed very little suggesting that a degree of vegetational stability had been attained. Alnus still dominated the local vegetation and mixed oak woodland covered the remainder of the landscape. Corylus was an important component of the vegetation, perhaps in open areas within the woodland and as part of the carr. Woodland cover on Anglesey was at a maximum by 6000 BP

At Llyn Cororion maximum canopy cover was also reached. The invasion of Tilia distinguishes this site from other low-lying localities. Tilia largely replaced Corylus, and although it formed an important part of the local vegetation, it was not characteristic of the coastal plain. Betula increased, after initial suppression by Alnus, and formed an important component of the understorey and carr vegetation. The status of Alnus appears to have remained unchanged dominating waterlogged sites around the lake and co-existing with Betula and Salix. Quercus was still the dominant woodland type with slightly reduced Ulmus frequencies.

Nant Ffrancon is the site where the biggest changes were evident. Alnus expanded and dominated the valley with reduced Corylus and Betula. Alnus replaced Pinus, and the established Quercus-Ulmus woodland remained stable. Pinus was now virtually absent from the valley but there were occasional Tilia trees, perhaps at the break of slope on better drained soils, or in crevices and at stream-sides. Alnus was more successful at Nant Ffrancon compared with Llyn Cororion and Melynllyn.

At Melynllyn, Pinus was now relatively restricted compared with 7000 BP, and Quercus had become dominant; Ulmus was also relatively important. Increased Alnus frequencies suggest that there may have been sporadic trees but these would have been restricted in distribution.

8.5.5 5000 BP

Five thousand BP is considered the time at which the woodlands reached complete development before anthropogenic disturbance (Bennett, 1989); thereafter woodlands are increasingly disturbed by fire occurrence, forest clearance and soil degradation. A comparison of the data (table A5.1, fig. 8.7) at 5000 BP shows that at all sites there was little change in the vegetation. Woodland cover and composition remained similar to that recorded at 6000 BP suggesting that some kind of stability had been reached.

The record at Llyn Hendref for 5000 BP is disturbed and no reliable pollen data exists. However, results from Tre'r Gof suggests that at mire sites on Anglesey, Alnus and Corylus remained dominant with limited Betula and Ulmus. Quercus woodland persisted away from the mire site and probably represents the regional vegetation.

On the coastal plain, Quercus woodland (with Betula) persisted and probably formed a relatively dense canopy cover. In damper areas, around streams and lakes, Alnus declined whilst Corylus and Salix recovered, indicating subtle changes in local carr vegetation. Tilia was still present in localised areas and Ulmus persisted in favourable locations.

In Nant Ffrancon, Alnus increased slightly and the woodland was slightly more open, suggested by decreased total land pollen. Tilia persisted as isolated trees and Ulmus decreased slightly but was probably as important as Quercus. Generally there was little change in the vegetation with only subtle adjustments in relative quantities. At Melynllyn there is no discernible change in the vegetation with Quercus still prominent and smaller quantities of Ulmus and Alnus. Betula still persisted in marginal habitats and Corylus was an important shrub.

8.6 SUMMARY OF SPECIES DEVELOPMENT

This study and its comparison with published data indicates that vegetational development and succession varied both spatially and temporally within a small area of North Wales. This conclusion depends on the accuracy of the radiocarbon dates used for site correlation. There may be problems with dating at Llyn Hendref and at Melynllyn as a large number of dates are interpolated. However, the synchronous dates obtained for the Ulmus decline suggests that the dates are relatively reliable and correctly indicate the timing of important vegetational events.

Juniperus: A characteristic Juniperus peak is recorded at all four sites but the factors controlling its expansion remain uncertain. On the lowlands Juniperus was quickly suppressed by Betula, probably more as a result of shading than by direct competition for habitat. In the uplands Juniperus persisted longer and was the dominant vegetation type until the immigration of Corylus. The reduced competitive ability of Betula in the harsher upland environment meant that Juniperus continued to flourish even after the Betula invasion. Juniperus was only eliminated at higher altitudes by the arrival of Corylus and even than lingered on in marginal habitats. On the lowlands Juniperus was succeeded by Betula.

Betula: Betula was unrestricted in its invasion of the lowland areas and valleys. Its rapid expansion was facilitated by a lack of competition and its ability to survive in a range of habitats. Juniperus was suppressed and Betula dominated the landscape until the arrival of Corylus. The Betula phase is relatively short-lived where Corylus arrived early, but Betula woodland persisted where the Corylus woodland was slow to expand. In the uplands Betula was relatively restricted and co-existed with Juniperus; Betula may have been restricted by slow rates of pedogenesis (Smith, 1972). With the introduction of deciduous trees, Betula was suppressed, mainly by Quercus at Llyn Cororion and Melynllyn, and later by Alnus at mire sites. Betula was then restricted to an understorey shrub, patches of secondary woodland and to carr vegetation. At high altitudes Betula possibly formed scrub woodland with Pinus.

Corylus: Corylus expanded early in the lowland sites due to migrational factors and the mild oceanic climate. It occupied many habitats previously occupied by Betula. Later Corylus expansion occurred in the valley and uplands. In Nant Ffrancon this may have been due to migrational factors or competition with the established Betula woodland in a confined area with limited available habitats. Once established, Corylus was an important component of the vegetation except at higher altitudes where it was probably restricted by extreme temperature fluctuations and frost.

Quercus: Quercus was an important component of the regional vegetation except within the valley, where the Betula woodland was difficult to invade and where there may have been a lack of suitable habitats. Quercus was an important addition very early on at higher altitudes and persisted from 8000 BP onwards. Here there was little competition and given its northerly migration direction, Quercus was able to expand relatively rapidly. On the lowlands mixed oak woodland was the dominant vegetation type from 7000 BP onwards but with distribution varying locally.

Ulmus: Ulmus never formed a dominant forest component in North Wales but was important locally, forming populations occupying exclusive niches on deep fertile soils. Once established it was more or less undisturbed until the appearance of Tilia. It appears that Ulmus was more important at higher altitudes both in the valley and cwms, perhaps less restricted here by competition.

Pinus: Pinus was successful and persistent within the valley and at altitude. On the coastal plain it occurred sporadically where marginal habitats persisted and on Anglesey *Pinus* was absent or scarce. On fertile base-rich sites it was out-competed by other taxa and so on the lowlands it was necessary for a new ecological niche to occur before *Pinus* could become established. Its distribution appears to have b en controlled by interaction with other species, only abundant where poor soils, harsher climate and marginal habitats (eg. mire surface) persisted. *Pinus* therefore formed a fringe above the low-lying *Quercus*-*Ulmus* woodland.

Alnus: *Alnus* was very site specific and so it is difficult to make generalisations about its distribution. It was important around Llyn Hendref and in Nant Ffrancon it remained the dominant vegetation type from 6000 BP onwards. The *Corylus*-*Alnus* woodland which dominated these sites was probably associated with hydroseral development. *Alnus* was less important at Llyn Cororion, a reflection of the small lake size and restricted carr. *Alnus* was restricted at altitude possibly by climate and limited carr development.

Tilia: The status of *Tilia* in North Wales appears to be very similar to West Wales (Moore, 1972b) in that there was only local establishment. *Tilia* would have been close to its climatic limit and was unable to thrive at higher altitudes. Only at some lowland sites and in sheltered valleys did sporadic *Tilia* populations establish, locally prominent where edaphic and climatic conditions were favourable.

8.7 DISCUSSION

Bennett (1989a) showed that the forest composition across Britain varied in time and space, making it difficult to generalise about the Postglacial forest history of the British Isles. This study illustrates that even over a small geographical area, woodland variations were complex. During the early Postglacial there were the introductions of major tree taxa and the establishment of mixed deciduous forest over much of the area. Pollen curve forms are similar at all sites but there were differences in the empirical and rational limits of most trees and shrubs, resulting in distribution and dominance variations. The general chronological order of appearance is similar for the lowland sites (with the addition of *Tilia* at Llyn Cororion) but there was the apparent later arrival of *Pinus* and *Alnus* in the valley and the early arr val of *Quercus* in the upland.

A similar study in Holland (van Leeuwaarden and Janssen, 1987) compared vegetational successions of valley and upland sites and concluded that generally vegetational changes in the upland were a few hundred years later than at valley sites due to migrational factors. Over small distances it is almost impossible to trace migration routes or to suggest migration rates but in North Wales, migrational factors (ie. factors dependent on tree physiology) do not always appear to have been the major factor in varying tree distributi n. Soil type, ground wetness, aspect, exposure, rainfall, slope angle, and competition (or lack of it) were just as important in determining tree establishment and dominance.

Taxon success depended on its ability to compete, and varying 'arrival' times and lack of competition ensured the survival of some species for a longer time in some localities (eg. *Juniperus* in the valley). Vegetation changed as critical thresholds were crossed within hydrological and climatic tolerances; eg. *Alnus* did not expand until local hydrological conditions were suitable and this occurred at different times at different sites. Competition and climate appears to have excluded *Pinus* from Anglesey but local conditions were suitable for its establishment around Llyn Cororion.

Site type was important; mire sites (Llyn Hendref and Nant Ffrancon) encouraged the growth of carr vegetation where *Alnus*, *Betula* and *Corylus* could thrive on the extensive peaty waterlogged soils. Llyn Cororion (a small lake) had limited hydroseral development and drier, fertile soils resulting in extensive *Quercus*-*Ulmus* woodland.

It is probable that the vegetational differences recorded are partially a function of pollen source areas. Llyn Hendref and Nant Ffrancon had essentially regional pollen source areas but these were modified by over-representation of pollen from extensive bog vegetation and local carr, and also from inflowing streams. High pollen producers around the lake edge compound the problem and the resultant pollen record probably over-emphasises the lake-side vegetation. Alnus dominance in the valley was due to the high number of habitats available, but is also probably over-emphasised. Llyn Cororion has a smaller pollen source area and probably gives a better indication of general vegetation types.

The rate of vegetation change varied from site to site with gradual changes at high altitudes and rapid changes recorded in the lowlands; this is likely to be a function of edaphic conditions and climatic factors. Fertile, well-drained soils were characteristic of the coastal plain, ideal for the establishment of mixed oak woodland. At upland sites soils were drier, thinner and nutrient poor and only certain taxa were able to thrive. The apparent stability of the upland sites may reflect the gradual processes of change compared with the lowland; Melynllyn showed gradual change throughout the Postglacial and had only a limited number of successful taxa.

Some form of 'equilibrium' is reached at all sites. Vegetation in the valley and on the coastal plain was stable by 6000 BP, slightly later than the lower exposed site of Llyn Hendref. Here the woodland appears to be relatively stable by 7000 BP although in reality taxa distributions may have shifted. This stability indicates that soil conditions, hydrological and climatic conditions had reached a degree of stasis and that the established woodland was no longer disturbed by invading species.

Until recently Nant Ffrancon had yielded the only well dated Postglacial sequence available for North Wales. The temporal and biostratigraphic resolution of this site are good and the dates reliable, so it has often been taken as representative for North Wales. This work shows that perhaps it is not possible to cite Nant Ffrancon as 'typical' because local site factors were strongly influencing the vegetational succession; Tregaron Bog (Cardiganshire; Moore, 1972a) is a similar case.

The pollen records for Llyn Cororion and Nant Ffrancon are similar in many respects but there are significant differences in the dates of important events at both sites. Anglesey, Arfon and Snowdonia encompass an area of diverse topography and associated mesoclimates, resulting in varied vegetational successions at different sites. This produced a complex mosaic of vegetation with composition varying significantly within a few kilometres. In an area such as this it is unlikely that any one site could represent the area as a whole, and careful consideration should be made when selecting sites for comparison outside of the region or at varying altitudes.

It is difficult to elucidate causes of vegetation change when important data are absent. Concentration data provides an idea of species interaction and charcoal studies indicate periods of fire disturbance; the latter may have a significant effect on woodland but without the necessary data this cannot be evaluated. Neither Melynllyn or Nant Ffrancon have concentration or charcoal data making it difficult to assess taxa abundance, or to speculate on the role of fire in vegetational change at these sites.

This study has shown that the pollen assemblage zones constructed at the sites are similar and the pollen curves show the same essential features, but that dates for chosen events are often very different. The pollen assemblage zones have different ranges with fewer discernible LPAZ at altitude due to the persistence of some taxa (eg. Juniperus) and later arrival of others (Corylus); a phenomenon also noted in Browne's work in Ireland (Browne, 1986). The way in which this occurs is not always predictable, eg. an earlier Alnus rise at Melynllyn compared with Nant Ffrancon, and therefore it is not easy to correlate in the absence of reliable radiocarbon dates.

Bennett (1989a) compared pollen assemblage zones within the British Isles and illustrated that they were asynchronous and not necessarily comparable in composition from one site to another. He concluded that during the Postglacial there was a mosaic of woodland cover which varied continually in time and space across the British Isles. This study compliments this work by showing that this was also true on a small scale and over a distance of just a few kilometres. These differences are emphasised in areas such as North Wales where site types and topography are so varied.

8.8 RECOMMENDATIONS

Dating on the basis of similar pollen assemblage zones is unreliable in an area such as North or West Wales and correlation without dating is not recommended. Some vegetational events are less reliable than others as dating horizons, but all identified in this project, with the exception of the *Ulmus* decline, show variation from site to site. It would appear that the correlation of sites on the basis of biostratigraphy is limited and it is necessary to have reliable radiocarbon dates, with comparison done within a chronostratigraphic framework. Smith and Pilcher (1973) state 'a sequence of radiocarbon dates is an indispensable adjunct to all pollen analytical studies of the Postglacial'. Radiocarbon dating provides a framework for site comparison and correlation that is independent of biostratigraphic data, but even this is not without problems (section 5.2). Where radiocarbon dates are not available but age estimates are required, a number of recommendations can be made:

1. Correlation should be done with a site of similar type eg. compare two lake sites.

2. Site characteristics should be as closely matched as possible eg. size, geology, altitude, aspect, exposure. Where this is not possible, differences should be taken into

account.

3. Match with a site that has the same chronostratigraphic order of tree arrival and a similar vegetational history (eg. lake infilling).

4. Match potential pollen source areas.

Van Leeuwaarden and Janssen (1987) noted that comparisons using pollen curves alone can result in 'false conclusions on the fine spatial distribution of the vegetation' and they recommend that for adequate correlation the following are required:-

1. Full set of reliable radiocarbon dates for important biostratigraphical events.

2. Full information on site type and location.

An alternative method for the correlation of undated sites would be to produce a range of dates for each vegetational event within the region. These limits would help to constrain possible dates for undated sites taking site factors into account. In North Wales this would be of limited success due to the lack of sites with a good sequence of radiocarbon dates. Many sites have only one or two available dates and this is not sufficient for the interpolation of dates for vegetational events.

A comparison of the four sites along the transect illustrates some of the main differences observed but it is acknowledged that these are crude and remain to be corrected when additional data (eg. better biostratigraphic resolution, accelerator dates) become available. The observed spatial and temporal variations are general and there are more sites to be investigated that would provide an insight into the fine scale variations in the Postglacial vegetational history of North Wales.

There is a lack of work on lowland sites, perhaps partly a reflection of availability, and high altitude sites such as Llewesig could be explored for a full Postglacial sequence It still remains necessary to find a full Postglacial sequence for central Anglesey. When further sites are studied in detail and have adequate radiocarbon dates it may then be possible to construct a regional scheme to enable better comparison with other regions. Both Llyn Cororion and Nant Ffrancon have good biostratigraphic resolution and dating but neither could be described as 'typical' for the area. At least with the addition of Llyn Cororion to the data bank there is now an example of lowland vegetation development to enable comparison with other coastal sites in north-west Britain.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

9.1 CONCLUSIONS

The main aim of this chapter is to assess how far this study has fulfilled the aims defined in chapter 1 and to propose recommendations.

AIM 1: To elucidate the Postglacial palaeoecology, vegetational history and sedimentological history of lowland lake sites in Gwynedd; to study influences on the variability of vegetational succession at low altitudes and on a local scale; to use pollen accumulation rate and concentration diagrams to supplement frequency data in order to study the impact of new incoming tree species on established taxa.

Previous Quaternary palynological work in North Wales has concentrated on upland Snowdonia; this study rectifies this situation by describing the vegetational history of two lowland lake sites. Llyn Cororion provides a complete and undisturbed pollen record with excellent biostratigraphic and temporal resolution. At Llyn Hendref much of the Postglacial sequence is disturbed and the pollen record is biased by an over-representation of fen and aquatic taxa.

The Arfon Platform (Llyn Cororion) supported a relatively dense woodland for most of the Postglacial, dominated by mixed Quercus-Ulmus woodland with a Betula-Corylus understorey; Salix carr fringed the lakeside. A local but dominant Pinus population thrived between 8425 and 7900 BP, associated with the development of new, marginal habitats resulting from water level fluctuations and fire. Tilia also established around 5500 BP as an important canopy former. This is atypical for this area.

The loss-on-ignition and depth-age curve, suggest a relatively steady sedimentary regime. After a brief period of sediment focusing in the early Postglacial, sedimentation rates remained steady until the onset of permanent deforestation. Organic soils were first eroded but gradually deeper unleached substrate was exposed and mineral soils were transported to the lake basin.

The advantages of using concentration and accumulation rate data are clearly illustrated at Llyn Cororion. The steady sedimentation rates mean that pollen deposition and changes were dependent on vegetational changes and not the sedimentary regime. The interaction between incoming taxa and the established vegetation is easy to discern using the concentration data (eg. Alnus replacing Pinus, Tilia replacing Corylus). Concentration data are also useful when considering the impact of fire disturbance and the influence of anthropogenic activity.

At Llyn Hendref the woodland was generally more open and although Quercus and Ulmus were present, Corylus and Betula had a greater representation. The site type greatly influenced the dominant taxa with Alnus from 7800 BP onwards, favoured by the waterlogged soils. Pinus was absent due to competition and Tilia was restricted, perhaps a reflection of the exposed location of the site.

The sedimentological history of Llyn Hendref appears to have been complex and continually changed throughout the Postglacial. There was probably initially more than one depositional centre with some sediment focusing but sedimentation rates at the core site were generally steady until around 8650 BP. After this mire encroachment appears to have upset the internal hydrodynamics of the lake and the sedimentary regime became unstable with the foci for preferential sedimentation continually changing, resulting in variable sedimentation rates and periods of sediment redeposition. The stratigraphic sequence above 5735 BP is disturbed but the loss-on-ignition results indicate that at some point (Bronze Age?) soil erosion increased with a corresponding rise in minerogenic deposition.

At Llyn Hendref the pollen concentration and accumulation data are of limited use as most of the pollen deposition was determined by sediment accumulation. Changes in pollen concentrations therefore reflect sedimentary changes and not true vegetational changes and so the interaction between taxa is obscure. Although the results do not serve the purpose for which they were intended, they are useful in identifying serious sediment disturbance within the lake. A hiatus was identified from the frequency diagram but it would have been possible to mis-interpret the upper diagram as a complete sequence unaware that much of it was disturbed. Simultaneous changes in pollen concentration and accumulation data show that the late Postglacial sequence is unreliable; dating may have been affected and it is not possible to identify the actual sequence of vegetational change.

Vegetational variation between Anglesey and the Arfon Platform resulted mainly from local factors. Llyn Hendref was exposed to south-westerly winds which perhaps restricted _Pinus_ and _Tilia_, the latter being close to its climatic limits. The absence of deeper soils may also have limited _Tilia_ and _Ulmus_ growth and encouraged taxa such as _Betula_ and _Corylus_. Soils immediately around the lake site were waterlogged and the expansion of mire favoured taxa such as _Salix_ and _Alnus_. At Llyn Cororion the site is relatively sheltered and, with thick drift on the Arfon Platform, the soils were relatively rich and deep. This encouraged the growth of _Quercus_, _Ulmus_ and _Tilia_. _Pinus_ populations were encouraged by new habitat development provided by a chance combination of factors including water level fluctuations and fire disturbance.

Local vegetation was therefore controlled by soils, hydrology, microclimate and fire occurrence. Taxa expansion often appears to have depended on habitat availability and gaps in existing vegetation, rather than on climate which appears to have been optimal for many taxa. Inertia of existing vegetation was high and it was not until there was some form of disturbance (eg.

fire, lake level fluctuation) that many taxa were able to compete with established woodland (eg. Quercus). It was therefore often not a simple case of direct competition between taxa; Alnus replaced Pinus but only because hydrological conditions changed and Pinus was no longer able to survive. Many taxa were subordinate around the sites until the correct combination of factors enabled them to expand.

Differences in the pollen data from the two sites could also partially be explained by differences in pollen source areas as this influences the resultant pollen diagrams. Llyn Cororion registered local and extra-local vegetation compared with Llyn Hendref which had a local pollen source area with an over-representation of fen and aquatic taxa, superimposed on a regional pollen source. The former 'swamped' the regional pollen record making it difficult to discern the true regional vegetation.

Aim 1 has been achieved, although with limited success at Llyn Hendref. A complete Postglacial vegetational and sedimentological history has been presented for Llyn Cororion and the advantages of using concentration and accumulation data have been confirmed. At Llyn Hendref only the early Postglacial vegetational history has been fully described; although it is clear that the sedimentary regime was complex it is difficult to elucidate exactly what processes were occurring. Vegetational variation between the mainland and Anglesey was dependent on local site factors.

AIM 2: To present environmental data for archaeology and to assess the impact of early man on the lowland landscape.

Llyn Cororion provides a full Postglacial sequence and the biostratigraphic resolution enables a detailed reconstruction of anthropogenic activity. This is the first low altitude mainland site to provide this data and is therefore archaeologically important. Man was active in North Wales from the Mesolithic onwards. Initially activity was limited to temporary and restricted forest disturbance and much of the charcoal record is believed to be derived from small domestic fires. Activity increased in the Neolithic, but the site was temporally abandoned in the early Bronze Age. Permanent deforestation began in the late Bronze Age but secondary woodland and carr survived. Charcoal records increase in the Bronze Age and Iron Age and these are often associated with vegetational change, although the relationship between the two is not always clear. Fire was increasingly used as a tool for woodland clearance and evidence of arable farming increased from 2900 BP onwards. The Romans were responsible for much woodland clearance, and although activity decreased after their withdrawal the forest never recovered and there were increasing areas of scrub, heath and grassland. Cannabis retting occurred around the site in Medieval times and this site provides the earliest date for this activity in North wales.

Llyn Hendref was not so useful in an archaeological context as the later Postglacial record is disturbed. Tre'r Gof (northern Anglesey; Botterill, 1988) remains the only site on Anglesey recording archaeological events after the Neolithic. With the failure of Llyn Hendref to produce a full Postglacial record, there is still no complete Postglacial palynological record for central Anglesey. Llyn Hendref shows that Mesolithic man was active in the area but his effects on vegetation were not as marked as at Llyn Cororion. This may be a true reflection of anthropogenic activity, with early man avoiding inland areas and keeping to the coast. It could alternatively indicate that the forest was more open around Llyn Hendref, so that fewer trees needed to be felled and disturbance did not have such an identifiable effect on the pollen diagram. It may also reflect the pollen source areas of the two sites. Llyn Cororion records the local vegetational succession and so is ideal for recording vegetational changes on a small scale. At Llyn Hendref the pollen source area was regional and small scale changes are unlikely to be so clearly registered in the pollen diagram; subtle pollen changes would be 'swamped' by regional and fen taxa. Here relatively severe clearance would have to take place before it would be registered in the diagram.

Llyn Cororion therefore provides a clear picture of anthropogenic activity on the coastal plain from the Mesolithic onwards. The impact of early man is illustrated although interpretation is difficult due to the coincidence between anthropogenic activity, water level changes and fire occurrence. Llyn Cororion therefore goes some way to fulfilling the aim and provides important environmental data. The early record at Llyn Hendref does provide archaeological data but the remainder of the record is disappointing. Archaeological evidence suggests that there was Bronze Age activity in the vicinity of the lake but this cannot be correlated with the palynological record. Research remains to be undertaken at this site, and perhaps a full undisturbed sequence from a deeper area of the bog would provide further archaeological data. Correlations with archaeological evidence could then be attempted and it may also be possible to elucidate the effect of anthropogenic activity on mire development. There is still much potential for integrated palynological and archaeological work in the lowlands.

AIM 3: To produce pollen diagrams with high biostratigraphic and temporal resolution for comparison with published data from upland sites, thus allowing the temporal and spatial variations in Postglacial vegetational development over a small geographic area to be examined; to study the affect of altitude on the distribution of tree taxa within North Wales during the Postglacial, and enable more accurate correlation for undated diagrams in the area.

The early Postglacial data from both Llyn Cororion and Llyn Hendref have good biostratigraphic resolution and a large number of radiocarbon dates. This enables comparison with upland sites but a number of problems associated with site comparison and radiocarbon dating have been identified. Although correlation was therefore crude it has still been possible to identify major variations in taxa distribution.

All sites have similar pollen curves and order of arrival, but the timing of the main vegetational events varies considerably. This reflects irregular taxa distribution with the dominance of one taxon in the lowlands whilst another taxon thrived in the valley; mixed oak woodland was important on the coastal plateau whilst Pinus dominated in the valley. Anglesey was relatively open with Corylus-Alnus woodland whilst at high altitudes Quercus was an important taxon. Llyn Hendref and Nant Ffrancon show similarities in their vegetational histories with Corylus and then Alnus dominating much of the Postglacial. This may be a reflection of site type and pollen source area as both are lake sites that were gradually infilling.

Altitude did not always have a direct relationship with vegetational change, and differences in migration rates are thought unlikely to have produced the observed variations; it is concluded that local site factors were the most important influences on vegetational development. Vegetational change did not diffuse from the lowlands to the uplands, and did not vary in a predictable manner with altitude. Altitude affects climate which at higher sites influenced vegetation in terms of abundance, but most tree types survived. Tilia and Alnus are the exceptions and they were virtually absent at higher altitudes. Local site factors including competition, availability of habitat, fire disturbance and soil status were all significant. Taxon establishment on the lowlands may have been limited by different factors than those operating at higher altitudes. In the uplands climate was an important influence whereas in the lowlands competition was probably more important. The influence of biotic factors and climate would have varied at different altitudes and it is difficult to interpret when each is important and over what scale.

By 6000 BP it appears that at all sites some kind of stasis had been reached with little progressive change in the vegetation. The dominant taxa remained the same but it is possible that distributions changed in response to local fluctuations in hydrology, microclimate and competition. The variations in vegetational development show that it is difficult to correlate undated sites in North Wales on the basis of biostratigraphy. The complex variations in the factors influencing vegetational succession make it difficult to predict with certainty the dates of particular events (eg. Alnus rise).

It has been shown that there was considerable vegetational variation within a small area in the Postglacial. Interpretation of published work is hampered by the lack of concentration data and charcoal results and it is recommended that where possible these should be produced alongside frequency data. There still remains much detailed work to be done to further elucidate the factors controlling the success of particular taxa at different altitudes.

AIM 4: To provided detailed palynological data for lowland North Wales within a well defined chronological framework.

The Llyn Cororion data fulfils this aim and presents an excellent site for comparison with other lowland sites in Britain. The biostratigraphic resolution afforded by undisturbed sedimentation and the close sampling interval is excellent and is complemented by a series of eleven radiocarbon dates with minimal errors. Ince (1980) states that future palynological work 'may enable the investigation of one or two sites with a pollen stratigraphy representative of the region in general'. There is no such thing as a 'typical' site for this area, but at least Llyn Cororion now offers an alternative site to Nant Ffrancon for comparison with other sites in Britain. The evidence suggests that Llyn Cororion is more representative of the regional lowland vegetation and that the Nant Ffrancon site is possibly atypical of the area in that the pollen diagram is biased by over-representation of species such as Alnus and Corylus which were encouraged by mire development and steep valley sides.

Llyn Hendref provides detailed palynological data for the early Postglacial but after 5730 BP the data is of limited value. Although Llyn Hendref did not fulfil all expectations it is an excellent example of the problems faced by the palynologist when working with lake sediments. It shows the importance of critical site selection and illustrates how sediment disturbance, erosion and redistribution affect the pollen diagram.

9.1 SUMMARY AND RECOMMENDATIONS FOR FURTHER WORK

The main aims of the project have been fulfilled but there still remains much work to be done in this area. Central Anglesey still has no full Postglacial pollen profile and, as yet, there is no dated Lateglacial site from either Arfon or Anglesey. Although Llyn Cororion and Llyn Hendref do provide environmental archaeological data there is still much work to be done in integrating archaeological evidence with palynological work. Cors Bodwrog is an important potential site in this context.

Other future work of relevance to palynological studies in North Wales would be modern day studies on pollen transport at higher altitudes in an attempt to improve interpretation of sites such as Melynllyn. Research on tree-line variations would be beneficial although in the absence of macrofossils (eg. tree stumps) this may be difficult. It is also possible that research in offshore and coastal areas would be profitable with respect to elucidating lowland vegetation and the impact of early man. Offshore organic deposits, buried during Holocene sea level rise, would provide information on low-lying sites and, as early man tended to favour coastal localities, they may provide further evidence of anthropogenic activity. Data from offshore would also help to provide dates for sea-level rise although locating suitable deposits for this kind of work is difficult.

This study has shown that the integration of data from a number of different techniques can enhance interpretations. Radiocarbon dating, pollen concentration and charcoal analyses are the most important techniques for reconstructing vegetational history and loss-on-ignition and chemical analyses are important when considering the sedimentological history of the site.

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Appendix A1

Lakes visited during initial site selection

NAME	GRID REF.	REASON FOR REJECTION
Bodhunod	SH 413936	Temporary, often dries out
Llaneuddog	SH 475882	Tidal
Mynydd Bodafon 1	SH 464852	Shallow and disturbed
Mynydd Bodafon 2	SH 467851	Shallow (figure A2.3)
Llanddona	SH 565792	Disturbed, extended
Pentre Berw	SH 462725	Silted up and overgrown
Mynydd Llwydiarth	SH 547785	Poor access *
Caer-glaw	SH 369767	Small,infilled depression
Llyn Padrig	SH 365727	Section 2.2.2 (Pollen poor)
Tyn-y-felin	SH 285765	Infilled shrubby depression
Caergeiliog	SH 305784	Infilled and vegetated
Llanfflewyn	SH 359893	Poor access, very large *
Pant-yr-eglwys	SH 304923	Man made
Coferydd	SH 209825	Reserve, access restricted
Llanerchymedd	SH 425849	Man made
Llechylched	SH 769338	Infilled and dry

* Possible sites for future work.

Llyn Padrig (SH 364727)

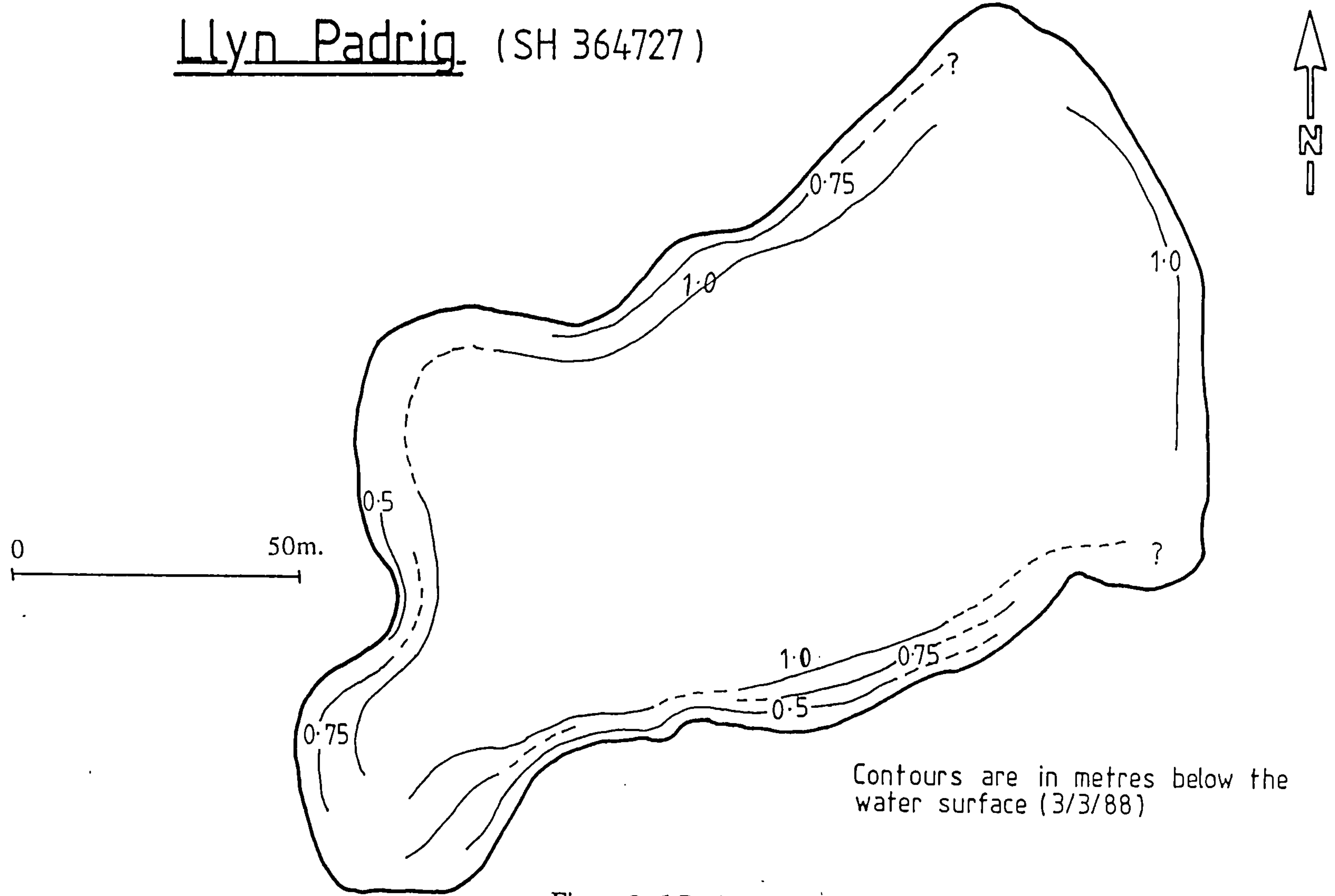


Figure 2.1 Bathymetric map of Llyn Padrig. (SH364727)

APPENDIX 2.1

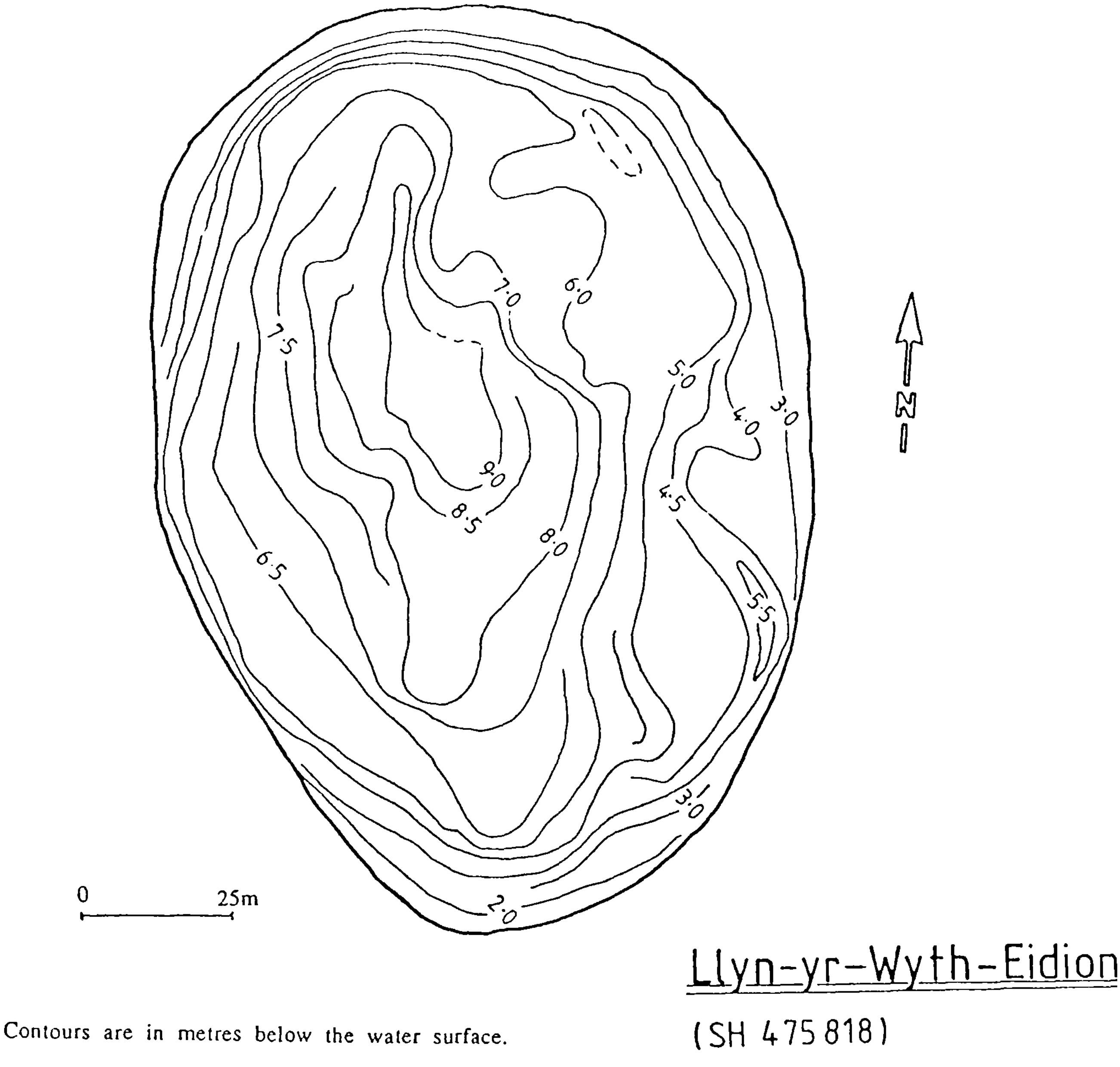
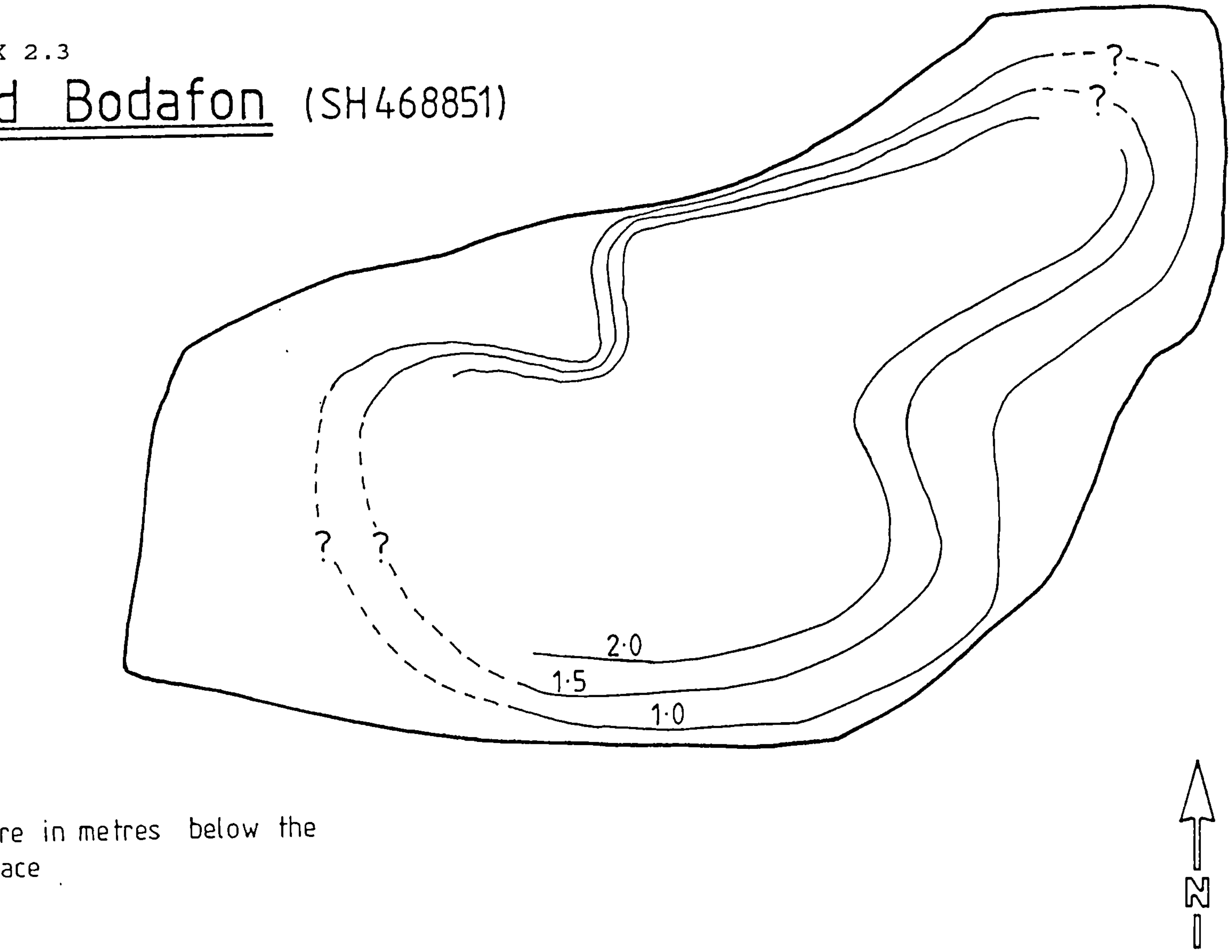


Figure 2.2 Bathymetric map of Llyn yr Wyth Eidion

APPENDIX 2.2

APPENDIX 2.3

Mynydd Bodafon (SH468851)



Contours are in metres below the water surface

Figure 2.3 Bathymetric map of Mynyyd Bodafon

Appendix 3.1

STRATIGRAPHIC DESCRIPTION OF THE LLYN-YR-WYTH-EIDION CORE

All contacts gradational unless otherwise stated

Depth cm	Comp.	Colour	Nig.	Str.	Elas.	Sicc.	Humo.	Comments
007-076	Ld3Lc1	2.5Y2/0	4	0	1	3	4	
076-100	Ld1Lc3	10YR4/1	3	0	1	3	1	+Molluscs
100-118	Ld1Lc3	10YR4/1	3	2	1	3	1	Sharp conta(
118-132	Lc4Ld+	2.5Y5.2	1	0	1	3	0	
132-139	Ld4Lc+	2.5Y2/0	4	0	1	3	4	+Molluscs
139-141	Layer of gastropods							
141-142	Ld4Lc+	2.5Y2/0	4	0	1	3	4	
142-209	As3Sh1	2.5Y3/0	3	2	1	3	3	Calcareous
209-250	As3Sh1	7.5Y4.2	1	2	1	3	3	
250-253	Micaceous sand							
253-323	As3Sh1	7.5Y4.2	1	2	1	3	3	+Mineral bar
323-328	As4Sh+	10YR5/1	1	1	0	3	0	
328-353	As4	10YR5/1	1	1	0	3	0	
353-358	As4Ag+	10 R4/3	3	3	0	3	0	Laminae 0.5-
358-400	As2Ga2	10 R4/3	3	4	0	3	0	Laminae <0.5
400-406	Lost							
406-422	As3Ag1	10YR5/1	3	3	0	3	0	Laminae <0.5
422-438	As3Ag1	5Y 4/2	3	2	0	3	0	
438-443	As4Ag+	10YR4/1	3	0	0	3	0	
457-458	As2Ga2	5Y 4/2	3	4	0	3	0	Laminae <2mm
458-500	As4Ga+	10YR5/1	3	1	0	3	0	
500-510	Lost							
510-564	As4Ga+	10YR5/1	3	1	0	3	0	
564-571	As3Ag1	5Y 5/1	2	1	0	3	0	Laminae<3mm

Appendix 3.2

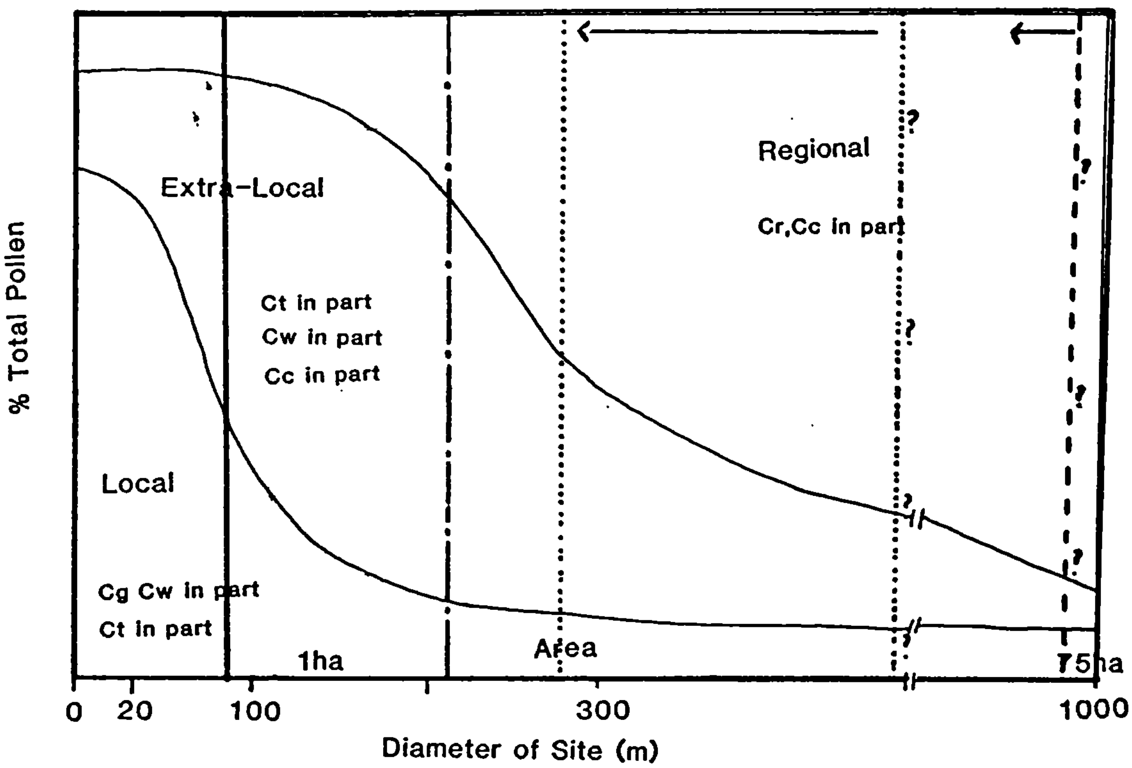
STRATIGRAPHIC DESCRIPTION OF THE LLYN PADRIG CORE

All contacts gradational unless otherwise stated

Depth cm	Comp.	Colour	Nig.	Str.	Elas.	Sicc.	Humo.	Comments
000-084	Ld3Ag1	2.5Y3/2	3	0	1	3	3	+Charcoal
084-085	Ag3Ld1	Mica rich sand and schist particles						
085-178	Ld3Ag1	2.5Y3/2	3	0	1	3	3	Sharp contact
178-250	Ld4Ag+	7.5YR3/2	3	0	1	3	3	
250-251	Dh3Ld1	Moss rich layer						
251-280	Ld4Dg+	7.5YR3/2	3	0	2	3	3	Increased macros
280-315	Ld4Ag+	7.5YR3/2	3	0	2	3	3	
315-320	Ld4Ag+	7.5YR3/2	3	0	1	3	4	Compressed Dg+
320-435	Ld4Ag+	7.5YR3/2	3	0	1	3	4	
435-440	Ld3Ag1	7.5YR3/2	3	0	1	3	4	
440-442	Cg3Ga1	7.5YR3/2	3	0	1	3	0	
442-500	As2Ag1 Dh1	10 YR5/1	2	0	0	3	0	Ga+ Hydrogen sulphide
500-550	As3Ag1	2.5Y 5/0	2	0	0	3	0	
550-558	As3Ag1	2.5Y 5/0	2	2	0	3	0	Quartz rich sand
558-561	As3Ag1	2.5Y 5/0	2	0	0	3	0	
561-583	Cg2Ag1 As1Ga+	2.5Y 5/1 5Y 5/1	2	0	0	3	0	Poorly sorted Quartz and slate

APPENDIX A4

Figure A4.1 Model to show the relationship between pollen source area and site size, (Jacobson and Bradshaw 1981).



Local — Less than 20m.
Extra-Local — 20m. to several hundred metres.
Regional — Greater than several hundred metres.
} Pollen Source Area

Cw water
Ct Through trunk space
Cc Above canopy
Cr By rainfall
Cg Gravity component
} Pollen Transport

Overlay showing the estimated pollen source areas for:

1) Llyn Cororion ————

2) Melynllyn —— . —— . ——

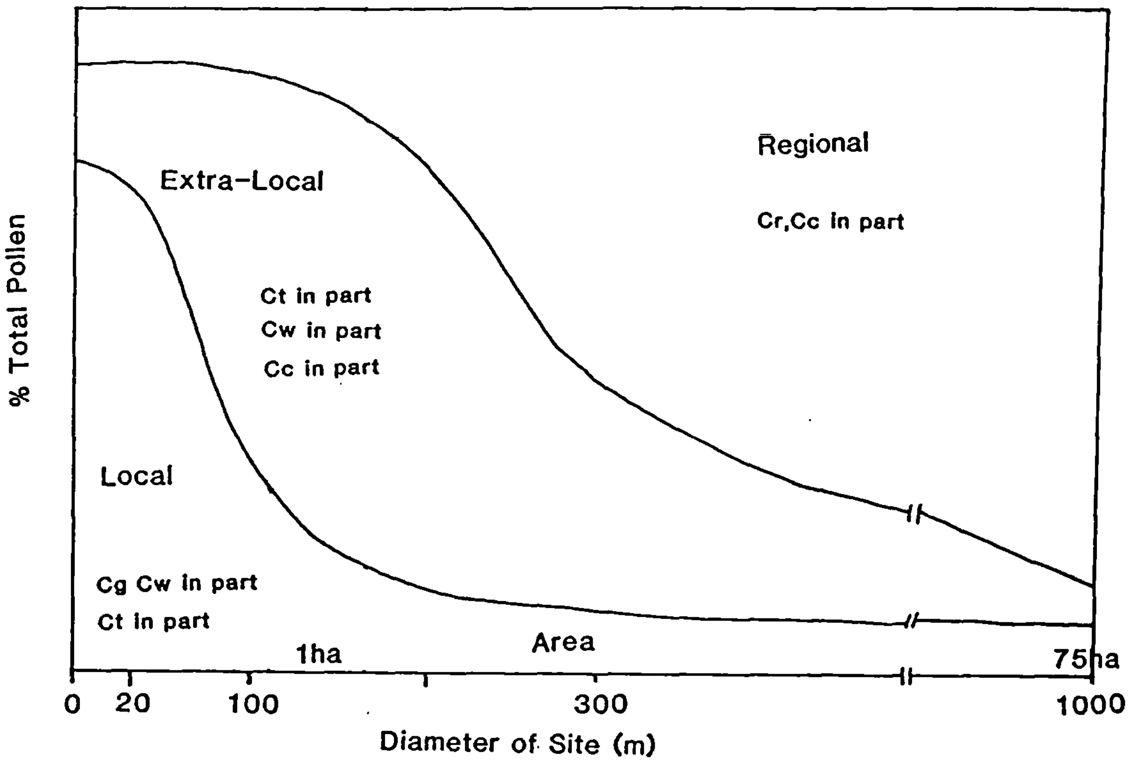
3) Llyn Hendref Pre-1960 * ....?
Present ....

4) Nant Ffrancon Early Postglacial * — —?—

←—Indicates a reduction in pollen source area over time.
*** Pollen source area uncertain as the original lake size is unknown. The pollen source area would also have been modified by inflowing streams.**

APPENDIX A4

Figure A4.1 Model to show the relationship between pollen source area and site size, (Jacobson and Bradshaw 1981).



Local Less than 20m.
Extra-Local 20m. to several hundred metres.
Regional Greater than several hundred metres.
} Pollen Source Area

Cw water
Ct Through trunk space
Cc Above canopy
Cr By rainfall
Cg Gravity component
} Pollen Transport

APPPENDIX A5

Table 5.1 Percentages used in discussion and to construct pie graphs.

Percentages calculated with Corylus included in the tree sum.

Years BP	Llyn Hendref 9	8	7	6	Llyn Cororion 9	8	7	6	5	Nant Ffrancon 9	8	7	6	5	
Betula	25	26	19	9	59	16	14	36	32	85	28	18	3	3	
Quercus	2	20	17	21		3	26	24	24	3	6	13	10	10	
Ulmus	1	2	4	4		4	4	5	1		4	5	8	5	
Pinus	2	3	6	5	1	56	9	2	+	7	12	40	8	7	1
Alnus			25	25		+	13	16	12		+	5	43	63	
Tilia								+					+	+	
Corylus	71	49	29	36	40	21	34	16	30	4	50	22	28	10	
Salix	3	2	1	1	2	1	1	2	3	10	+	+	+	+	%(Tr+Sh)
%T+Sh	88	90	93	97	87	93	92	97	97	75	95	98	87	85	%TLP

Percentages calculated with Corylus excluded from the tree sum.

Years BP	Llyn Hendref 9	8	7	6	Llyn Cororion 9	8	7	6	5	Nant Ffrancon 9	8	7	6	5	Melynllyn 9	8	7	6	7	
Betula	91	51	18	11	97	20	21	43	45	89	56	23	4	3	50	7	10	5	5	
Quercus	1	38	24	32	2	4	40	28	34	3	12	17	14	11	4	30	30	50	55	2
Ulmus	+	4	5	6		5	5	6	2		7	6	11	6		8	5	13	6	
Pinus	8	7	8	4	1	71	14	3	1	7	23	51	11	46	55	54	18	15		
Alnus			45	47			20	20	18		+	6	60	70			4	14	17	
Tilia								+					+	+				+	+	
Corylus	60	43	26	33	45	19	31	16	30	x	x	x	x	x	5	32	20	30	30	%TLP
Salix	3	2	1	1	2	1	1	1	3	x	x	x	x	x	15	<5	<5		+	
%T+Sh	88	90	93	97	87	93	92	97	97	75	95	98	87	85	70	85	90	93	90	%TLP

+ <1%

X It is not possible to calculate these frequencies from the data provided

%(Tr+Sh) Percentage calculated using (trees+shrubs) as the pollen sum.

%TLP Frequencies calculated as a percentage of total land pollen (including Corylus).

1 % Trees including Corylus

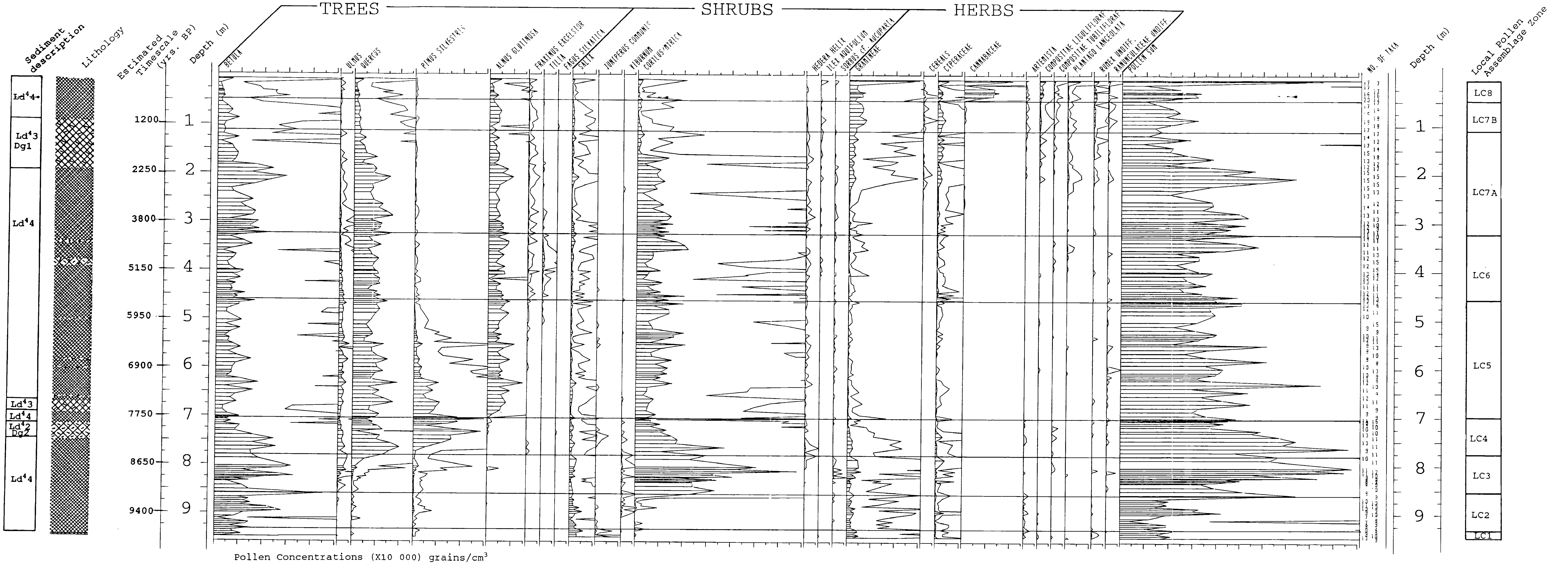
2 % Trees excluding Corylus

Figures within tables are comparable but figures between tables are not (details in section 8.2.2).

LLYN CORORION, ARFON, (SH597688). POLLEN PERCENTAGE DIAGRAM.

RUTH WATKINS 1987

LLYN CORORION, ARFON, (SH597688). POLLEN CONCENTRATION DIAGRAM. RUTH WATKINS 1987

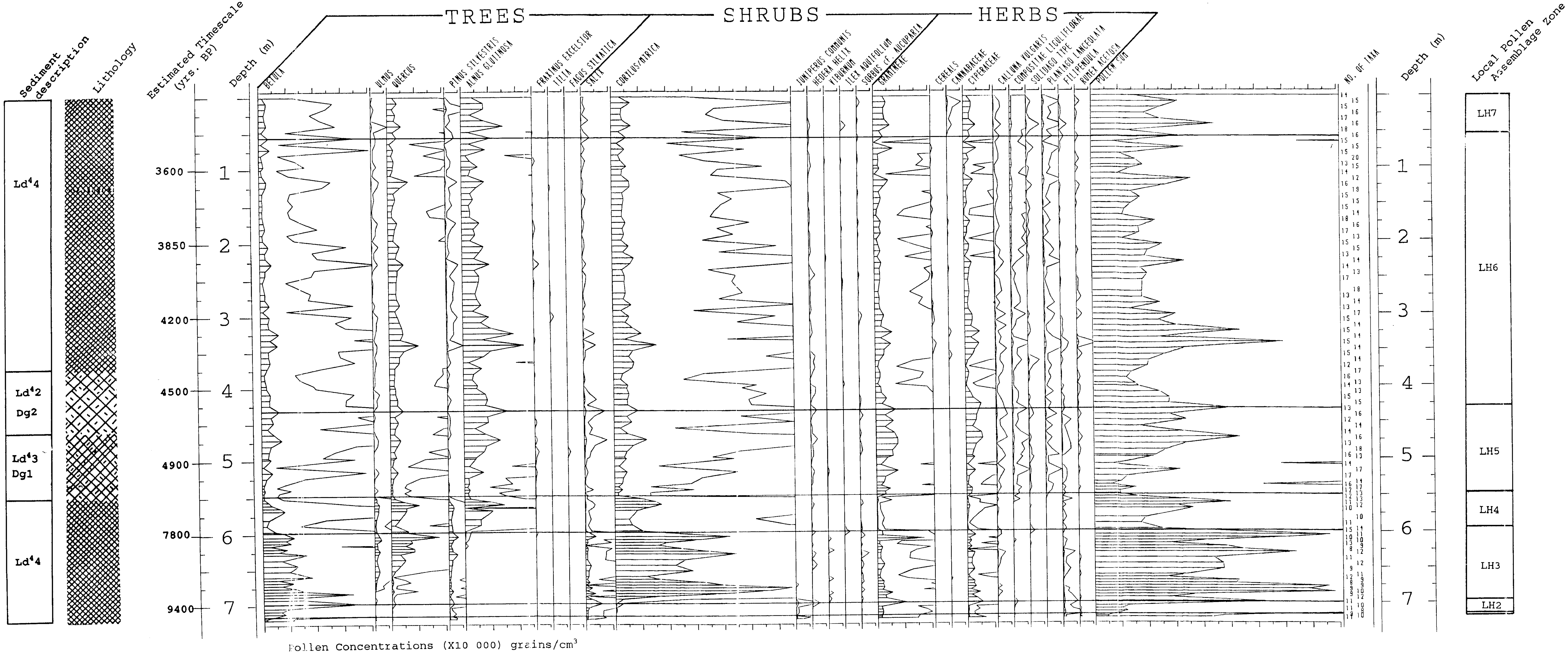


LLYN CORORION, ARFON, (SH597688). POLLEN ACCUMULATION RATE DIAGRAM RUTH WATKINS 1989

LLYN HENDREF, ANGLESEY, (SH398765). POLLEN PERCENTAGE DIAGRAM

RUTH WATKINS 1988

LLYN HENDREF, ANGLESEY, (SH398765). POLLEN CONCENTRATION DIAGRAM. RUTH WATKINS 1988



LLYN HENDREF, ANGLESEY, (SH398765). POLLEN ACCUMULATION RATE DIAGRAM RUTH WATKINS 1989

- - - - - - - Examples of levels affected by possible sediment redeposition