LATE DEVENSIAN AND EARLY FLANDRIAN VEGETATIONAL HISTORY AND DEGLACIAL CHRONOLOGY OF WESTERN ARGYLL

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DECLARATION

The data contained within this thesis represents the results of original field and laboratory investigations undertaken whilst a N.E.R.C Postgraduate Research Student, between October 1979 and January 1983.

Signed

Date 18th September 1984

ABSTRACT

The study atttempted to assess, through the analysis of critically located pollen sites, the vegetational history of a region between Loch Etive and the Cowal Peninsula during the Lateglacial and early postglacial periods, and to reconcile the varied reconstructions of Loch Lomond Readvance glaciers, proposed on geomorphic data, in the light of the palynological evidence.

Two Lateglacial biostratigraphies were examined by relative and pollen concentration techniques. These suggest that trees were not established in western Scotland during the Lateglacial Interstadial, possibly due to factors of exposure, while a climatic deterioration is recognised at both sites during the interstadial (c. 12,000 B.P.). Loch Lomond Stadial pollen spectra are sub-zoned at both sites, and it is suggested that the later part of the stadial became increasingly arid. One site was C 14 dated, but results showed errors due, perhaps, to graphite in shallow till in the catchment.

The early postglacial pollen sequence was examined in detail with regard to the consistency of representation of pollen-types, possible synchroneity and environmental determinants. This vegetational succession at six postglacial sites in the Awe valley is then employed to examine the potential of pollen data in determining the rate of deglaciation of Loch Lomond Readvance glaciers.

Two further pollen sites, located outside presently estimated Loch Lomond Readvance limits, recorded litho- and bio-stratigraphies suggesting deposition from the Loch Lomond Stadial, and their geomorphic settings suggest that each basin was dammed by Readvance ice. These findings have led to the proposal that Loch Lomond Readvance glaciation in the study area was more extensive than portrayed in recent reviews.

In addition to these results, at all sites deteriorated pollen was recorded and evaluated as to its origin and palaeo-environmental value. Experimental results suggest that there may be serious errors in certain pollen techniques as practised at present.

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CHAPTER ONE

BACKGROUND TO THE STUDY

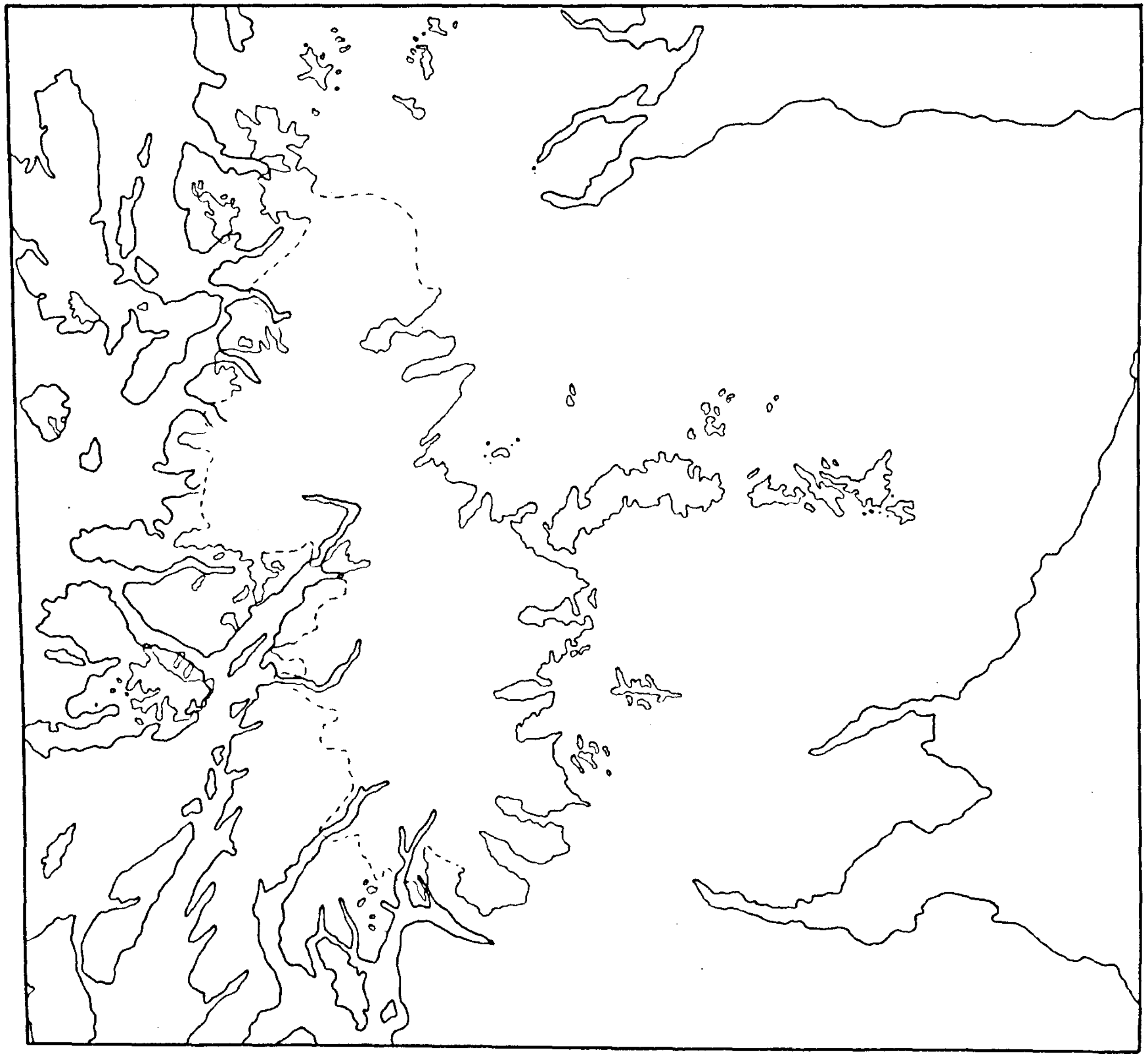
1.1 INTRODUCTION

In a recent review of the Loch Lomond Stadial in the British Isles Sissons (1979a) presented a map (fig.1.1) of the glacial limits related to that stage, distinguishing between mapped and uncertain termini. Perhaps the most conspicuous gap in our knowledge of the extent of these Loch Lomond Readvance glaciers is seen to be in the area between Loch Long, in the Clyde estuary, and Loch Etive in the south-west Scottish highlands, particularly in view of the large number of glacio-geomorphological investigations conducted in the region since the 1890's (see sect.1.5).

Many uncertainties exist concerning the age and synchroneity of the deposits mapped, and with the need for a stratigraphic framework for the area pollen analytical studies were considered the most useful approach in establishing a chrono-sequence (cf. Sissons et. al., 1973).

In addition to its proven success in relative dating palynology provides information on the vegetational changes within a region, and by implication the palaeoclimatic fluctuations that produced those changes. Radiocarbon dating of sediments can provide an understanding of their timing. Such studies had not

Fig. 1.1 Loch Lomond Readvance Limits in Scotland (after Sissons, 1979)



been made in this region prior to the present research.

1.2 THE CHOICE OF STUDY AREA

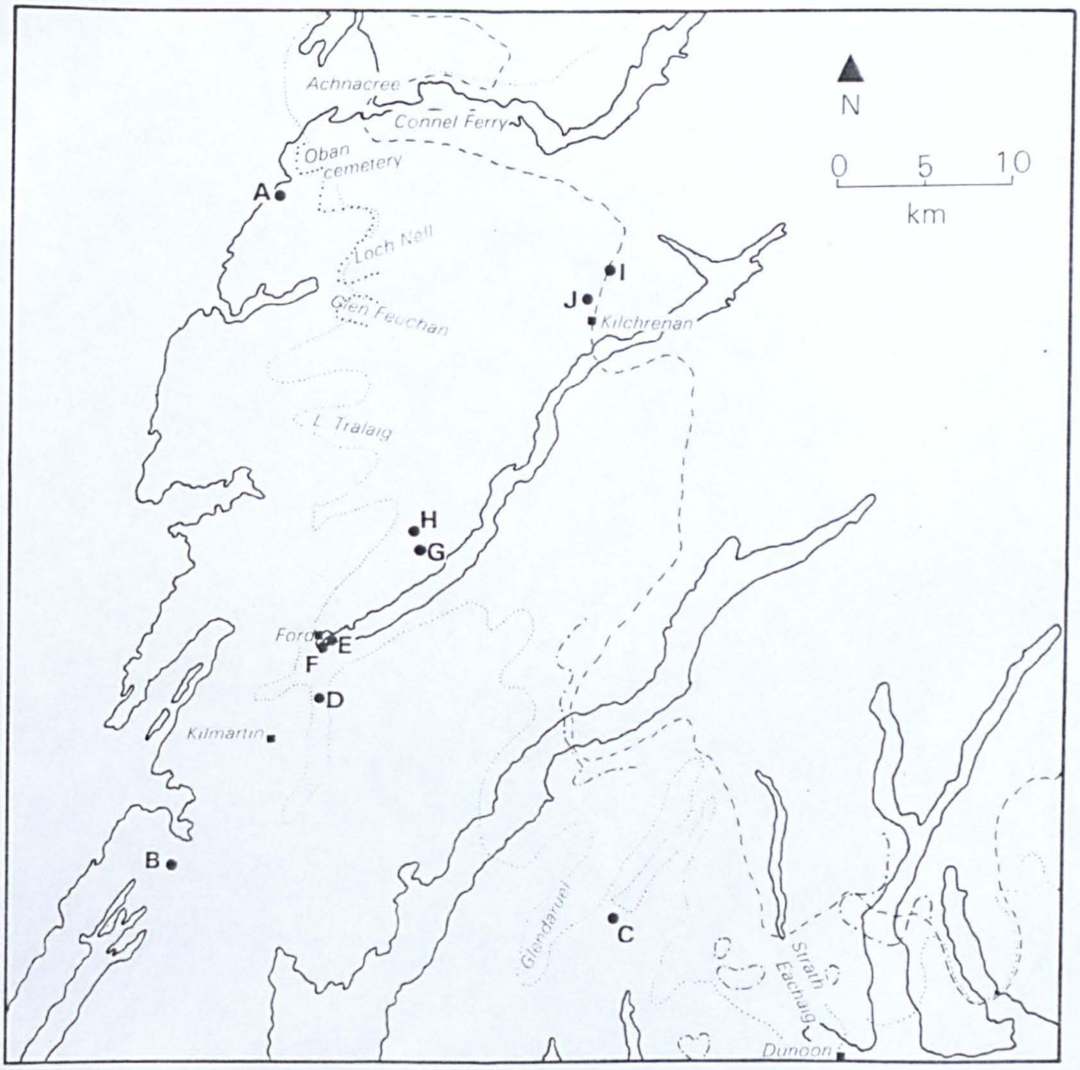
It can be seen from fig 1.2 that within the south-west Scottish highlands there is considerable consensus over the positions of Loch Lomond Readvance limits in the south-east of the region, at Row (Rhu) Point (Anderson, 1949; Charlesworth, 1955; Rose, 1981; Sutherland, 1981) and immediately north of Oban at the entrance to Loch Etive (Charlesworth, 1955; Donner, 1957; McCann, 1966; Synge and Stephens, 1966; Gray, 1975). Between these two 'fixed' points there is considerable uncertainty over the extent of these glaciers. It was decided to concentrate attention on this area in an attempt to resolve some of the conflicting reconstructions.

1.3 THE STUDY AREA

(a) Physiographic Development

The study area as defined above lies almost wholly in the 'western plateaux and lowlands' of Sissons (1976, p.13), this phrase emphasizing the relatively subdued topography between Dalmally, the head of Loch Fyne and Loch Eck in the east, and the western seaboard (fig 1.3). Nowhere in this lowland region are the hills high enough to support distinctive corrie-features (Sissons, 1967a; Robinson _et. al_, 1971), the nearest being on Ben Cruachan in the north-east,

Fig. 1.2 The study area: Pollen sites in this study and their relation to inferred glacial limits



Charlesworth (1955)		Pollen sites	•
Donner (1957)		Pulpit Hill	A
Sissons (1979)		Loch Barnluasgan	B
Sutherland (1981)		Na Lona Min	C
		Lon Glas	D
		Ford I, II	E F
		Inverliever I, II	G H
		Barachander I, II	I J

and above Loch Restil to the south-east of the study area.

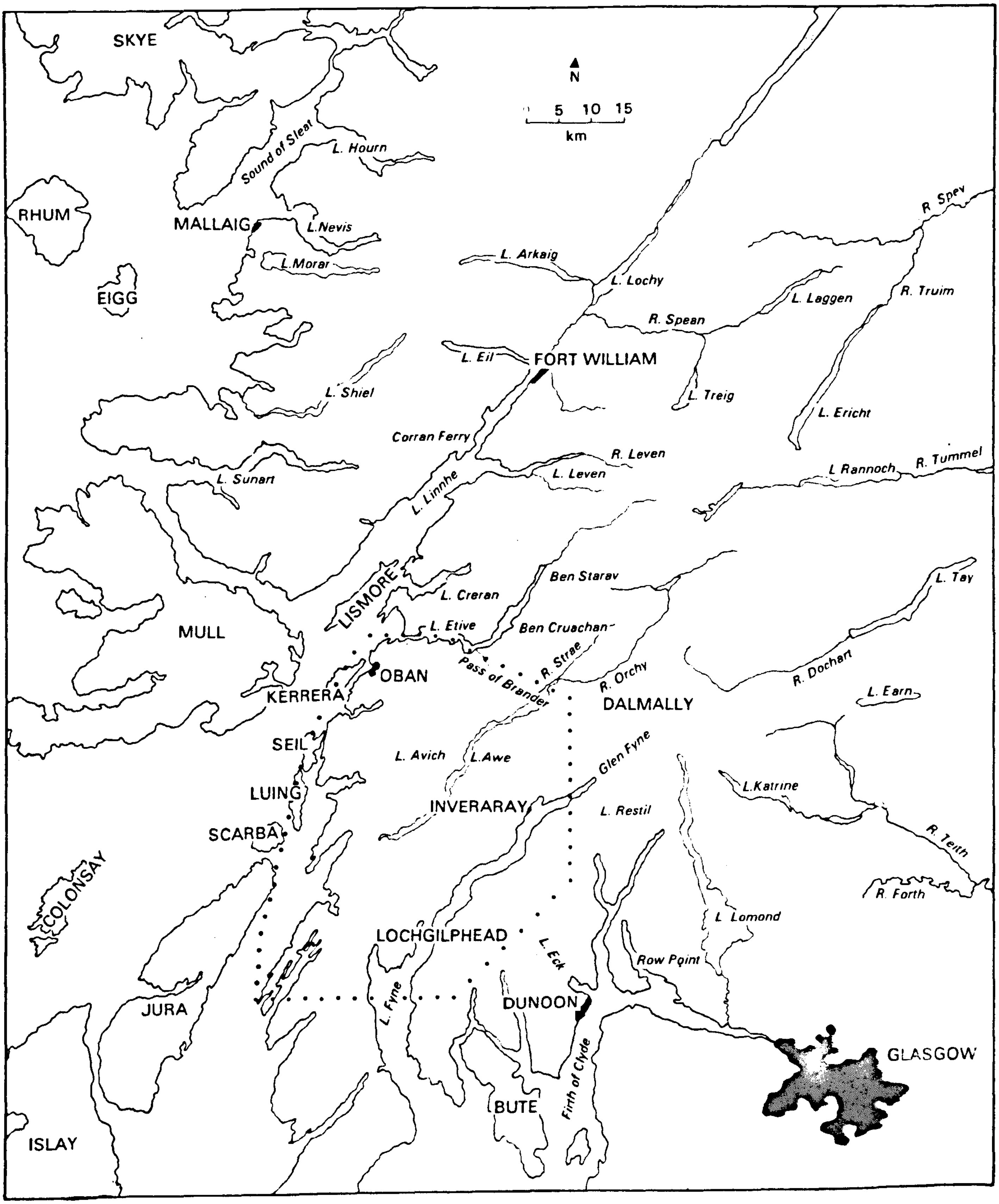
Whether the westerly draining lochs Etive, Awe and Fyne are the result of the pre-glacial drainage system (Sissons, 1967a) or are the product of later glacial erosion (Linton, 1951), the effects of intense glacial modification are clear, and demonstrate that, in common with the western highlands in general, the region was a zone of erosion during glacial maxima (Gordon, 1979). The three major lochs all show features of glacially-deepened fjords, and this pattern is continued offshore in the very deep troughs of Loch Linnhe, around Mull and other islands of the Inner Hebrides.

(b) Solid Geology

Fig 1.4 illustrates the considerable complexity of the region's geology. The greater part of the region is occupied by rocks of the Dalradian assemblage, with a plutonic complex around Ben Cruachan and an associated sequence of lavas and related sediments on the Lorne plateau.

The Dalradian rocks are highly complex structurally, being dominated by several very large nappe structures of early Caledonoid age, further folded in late Caledonoid times and subjected to thermal and non-thermal polyphase metamorphism (Johnstone, 1966). Sedimentologically the

Fig. 1.3 The study area in Western Scotland



majority of the sediments are of shallow shelf-sea origin, probably of Cambrian age; current bedded quartzites, limestones and pelites, superseded by shales, schistose grits and coarse sandstones typical of subsiding geosynclinal trough deposition by turbidity currents.

Eruptive pillow-lavas and intrusive soda-rich 'greenstones' of Upper Dalradian age are common around Loch Awe and Tayvallich (fig 1.4), but the major igneous sequence is of post-Caledonoid/pre-middle Old Red Sandstone age. On the Lorne plateau between Lochs Avich and Etive (fig 1.4) are over 2000' (615 m) of subaerial andesites, felsites, tuffs and agglomerates which overlie Lower Old Red Sandstone breccias, conglomerates, grits , sandstones, shales and limestones, themselves unconformable on the Dalradian.

In the north-east of the region, separated from the Lorne lavas by a fault through the Pass of Brander is the large cauldron -subsidence controlled Etive ring-complex of Ben Cruachan - Ben Starav, which may represent one of the magma chambers feeding the lavas of the Lorne plateau (Johnstone,1966).

Dykes related to the Tertiary volcanic centre of Mull cut all the rocks of the area in a north-west - south-east trending swarm. The major fault-lines, probably of Armorican times, control the location of the major lochs, Etive, Awe and Glen Fyne.

(c) Climate.

At the present day the south-west Scottish highlands have a cool oceanic climate. Temperatures at Oban range from -4°C (January) to 24°C (June/July: average monthly means). The influence of the Gulf Stream is most marked in winter months, maintaining the western seaboard and Knapdale several degrees Centigrade above areas immediately inland. Rainfall is notably seasonal; the lowlands are much drier, due to orographic influences, than the Highlands and the major interfluves within the region. The area is, however, wetter than the east of Scotland. The region has a similar amount of sunshine to the east coast, though more than the cloudier Highlands. The subdued topography means that north -south slope temperature differences are less than in the highly dissected uplands, and related to this is the observation that only in the Ben Cruachan massif can snow be expected to lie for more than 30 days. Snow-lie on the plateaux is seldom for more than a day or two. The most characteristic climatic factor is the strong westerly wind, which "most certainly controls the distribution and development of trees and woodland" (Jermy, 1978; p.6.1) in the western highlands and islands.

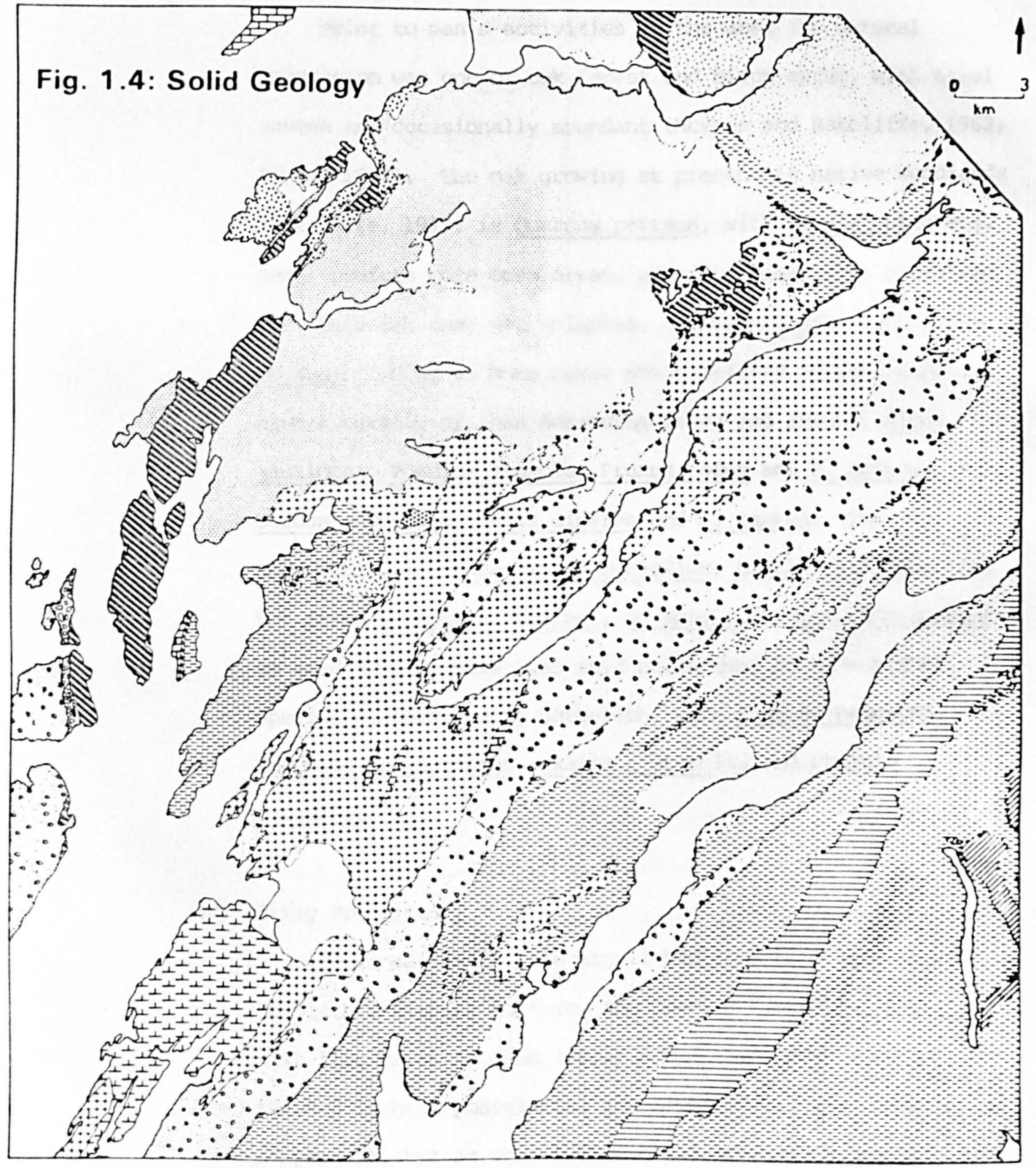


Fig. 1.4: Solid Geology

(a) Symbols employed in Fig. 1.4

- Recent

Devonian

- Lower O.R.S. conglomerate ssts
- Lower O.R.S. tuffs and agglomerates
- Lower O.R.S. lavas
- Intrusive Felsite
- Granite

Dalradian

- 'Green Beds'
- Dalradian Limestone
- Undiff. & micaceous schists, phyllites and slates
- Black Slates
- Schistose grits & greywackes
- Epidioritic, Hornblendic & Quartzitic schists
- Epidioritic & Hornblendic schists
- Quartzite & quartzitic schists
- 'Boulder bed': Tillite

(Dalradian strata not necessarily in stratigraphic sequence)

(b) Symbols employed in following chapters

Site location maps

- Open water
- Marsh/Bog
- Outline of Inset maps
- 200 Contour (m)
- Sampling point
- River
- Buildings
- Road/Track
- Fence

Lithostratigraphies

- Sand
- Silt
- Clay
- Gyttja
- Coarse detritus mud
- Fen Peat
- Sedge peat (undiff.)
- Sedge peat (poorly humified)
- *Eriophorum* peat
- Moss remains
- Birch wood peat
- Contamination
- Micro-laminations (horizontal)
- Micro-laminations Contorted
- Coarse colour laminations
- Faint micro-laminations
- Clay patches

Lithostratigraphic boundaries

- Horizontal, sharp
- transitional
- wavy, irregular

(d) Native Vegetation

Prior to man's activities in the area the natural vegetation was one of oak forest and birch scrub, with hazel common and occasionally abundant (McVean and Ratcliffe, 1962; Birks, 1977). The oak growing at present in native woodlands (Ratcliffe, 1979) is *Quercus petraea*, with *Betula pubescens*. Hazel prefers more open areas, and is present with birch and ash where oak does not colonize. *Ulmus glabra* and *Fraxinus excelsior* occur on more basic soils related to lava flows, with a variety of less demanding trees and shrubs; *Alnus glutinosa*, *Populus tremula*, *Prunus padus* and *P. spinosa*, *Sorbus aucuparia*, *Salix cinerea* and *S. caprea*. The understorey is of *Vaccinium myrtillus*, *Luzula sylvatica* plus the ferns *Dryopteris borreri*, *D. aemula* and *Blechnum spicant* on acid soils, while less acid soils tend to have higher species numbers, being herb-rich, with *Anemone nemorosa*, *Endymion non-scriptus*, *Oxalis acetosella* and *Primula vulgaris*.

(e) Early Pre-history

The coastline of mid Argyll has long been known for its Mesolithic fishing culture, the Obanian (Lacaille, 1954), with five caves in Oban itself and others further south, related to high postglacial sea-levels. On Jura the Obanian is present, but is only the youngest of three Mesolithic cultures excavated by Mercer (1970, 1974, 1979). The earliest may be Upper Palaeolithic, as Mercer (1979) argues for a lateglacial origin for a few rolled and derived stone tools. The earliest post-glacial industry has been dated at 8194 +/- 350 B.P. which is the earliest date yet obtained for Mesolithic occupation sites in Scotland. Phase 2 correlates with the maximum post-glacial sea-level, while Phase 3 (contiguous with the Obanian industry) is dated at 4620 +/- 140 B.P., quite late, for the earliest Neolithic settlement commences at 4200 +/- 100 B.P..

1.4 STRATIGRAPHIC TERMINOLOGY

It is considered important at this early stage to clarify the usage of stratigraphic terms in the following pages.

The term 'Lateglacial' is used as a condensed form of the more correct 'Devensian late-glacial.' The beginning of the Lateglacial is in some dispute. Mangerud *et. al*. (1974) proposed that the Middle/Late Weichselian boundary be placed at 13,000 B.P., but in 1978 Mangerud and Berglund revised this decision, placing the boundary at 25,000 B.P., close to the date of 26,000 B.P. suggested by Mitchell *et. al*. (1973). Viewed as part of the Late Devensian the commencement of the Lateglacial period is marked by a climatic amelioraton, which appears to have occurred somewhere around 14,000 B.P. (Lowe and Gray, 1980). Whilst not entirely agreeing with the recommendations of Mitchell _et_. _al_. (1973), the author conforms to the current usage of the terminology.

The most valid stratigraphic approach in the Quaternary has been climatostratigraphy (Mitchell _et_. _al_.,1973), and this has been the basis of two schemes for the Lateglacial proposed by Gray and Lowe (1977; Lowe and Gray, 1980). In addition they have demonstrated that Mangerud _et_. _al_'s (1974) zonation is also in principle climatostratigraphic, though thought chronostratigraphic by these authors (1974; p.114). Chronostratigraphy is regarded by Hedberg (1976) as the "ultimate goal of stratigraphy" (p.96), but it s use in the Lateglacial has been heavily criticized (Lowe and Gray, 1980; Watson and Wright, 1980) on grounds of lack of precision in the techniques, and loss of information by imposing a false synchroneity on what are in reality diachronous boundaries. It appears too adventurous at the present time to establish an absolute chronology for the Lateglacial.

Climatostratigraphic boundaries need bear no relation to isotopically dated sequences, and need not be synchronous (Watson and Wright, 1980). This is acknowledged in Lowe and Gray's (1980) scheme which incorporates transition zones between formal units to accomodate time-transgressive climatic responses. These transition zones are, however, often of equal duration to the formal units, which would appear to lessen the usefulness of the scheme, and are in any case strictly unnecessary in a climatostratigraphic system. This study will adopt the more orthodox scheme proposed by Gray and Lowe (1977), which was emphasized to be a 'temporary working definition' (p.179), and this approach is preferred to more rigid constructions (e.g., Mangerud et. al., 1974).

The term 'Loch Lomond Stadial' is retained as it has established itself as the most widely used term for the post-interstadial period in Britain (Sissons, 1979a; Walker,1980). The Loch Lomond Readvance represents the recrudescence of glaciers and is in essence a litho- and morpho-stratigraphic unit. The term 'readvance' is adopted as no proof has yet been presented of the total disappearance of ice from Britain during the Lateglacial interstadial.

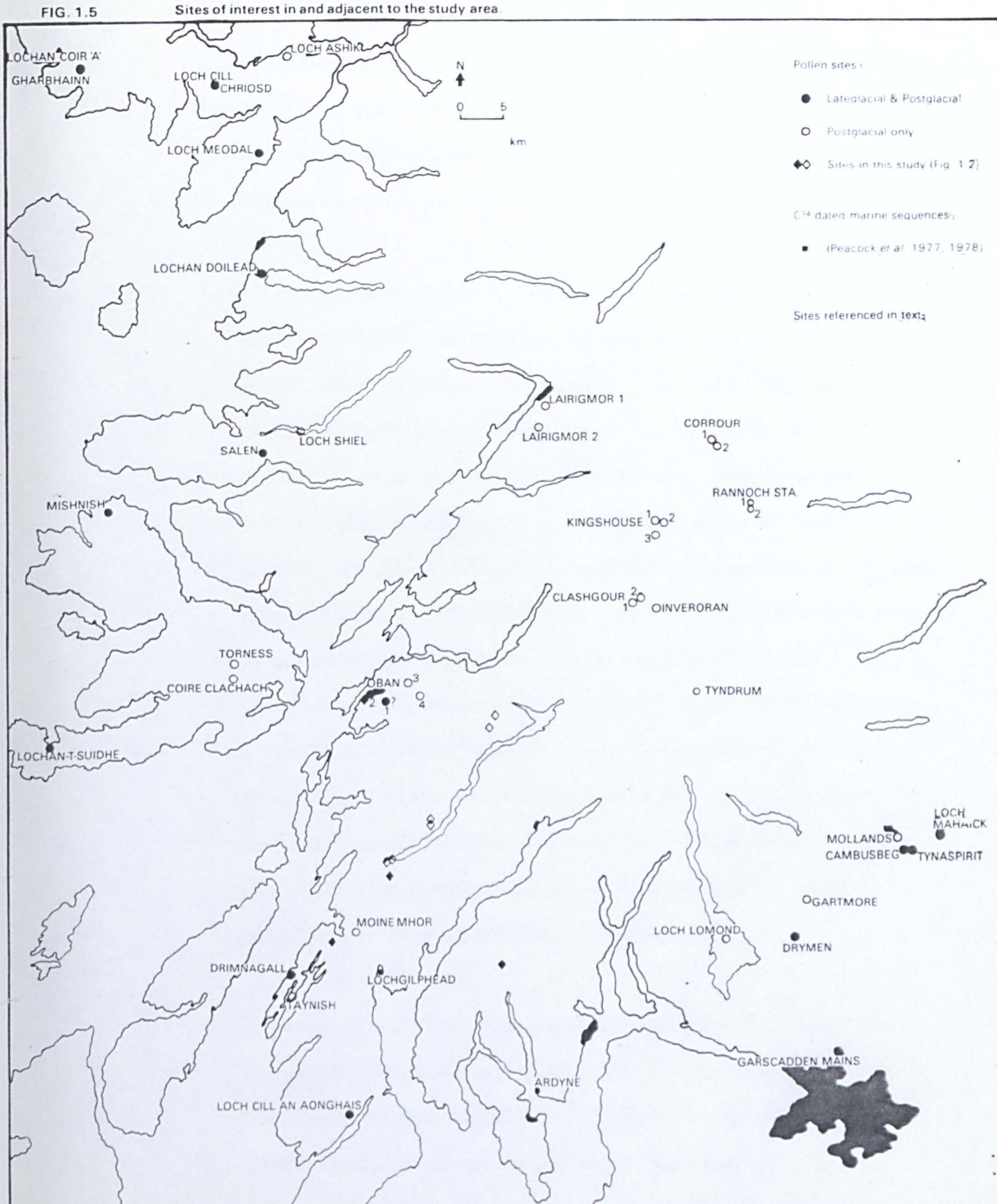
The end of the Lateglacial has been the subject of much debate in recent years. Most European researchers have accepted a boundary at 10,000 B.P. (Mangerud et. al., 1974; Mitchell et. al., 1973), and overseas workers appear also to agree (Morrison, 1969; Nelson and Locke, 1981). The reasons for adopting this date on climatostratigraphic grounds are unsound, and C14 dates show a large spread, contrary to the assumption of synchroneity proposed by Nilsson (1961), so that Hopkins (1975) may be close to the truth in commenting that the choice of this date was "simply because that's a nice round number" (p.10). Shotton (1977;p.109) concedes that Mitchell et. al's adoption of the date of 10,000 B.P. was largely one of "convenience", simply coinciding with the base of the Holocene. Yet the Holocene is clearly chronostratigraphically defined, while the Flandrian is based on climatostratigraphic criteria, and the two are not synonymous, contrary to the usage of Mangerud and Berglund (1978). They are different ranks, and should not be interchanged as these authors propose. The retention of the term "Holocene" appears to be as much a matter of philosophy as of geology, and Godwin (1975) and West (1977), among others, have argued for the abandonment of the rank in view of the essential similarity of the present interglacial with others, a viewpoint this writer supports. The term "Flandrian" is used throughout this study. The end of the stadial may be several hundred years prior to the start of the Flandrian, however (Walker and Lowe,1982), and until this problem is resolved, reference to this important period, not part of the Loch Lomond Stadial nor of the Flandrian, is referred to informally as "postglacial".

1.5 REVIEW OF PAST RESEARCH

i Palynological Investigations and Related Radiocarbon Dates

Fig 1.5 locates the pollen sites in and adjacent to the study area. Within the study area only two palynological studies have been undertaken. Erdtman contributed pollen

FIG. 1.5 Sites of interest in and adjacent to the study area.



analyses to Chester's (1931) study of the Flandrian peats of the Moine Mhor (NR 8294). Erdtman's own investigations of Scottish peats (1924, 1928) included only one Argyll site, at Inveroran (app. NN 2741).

The recognition of distinctive Lateglacial tripartite sequences at Whitrig Bog and Garscadden Mains (Mitchell, 1948, 1952) led Donner to apply a relative dating approach developed by him in Finland (1951) to Scotland (1957), based on the presence of Lateglacial sequences outside moraines, and postglacial and Flandrian sediments only within these termini, establishing the age of the ice readvance as of Loch Lomond Stadial age (pollen zone III). In the Oban area some doubts concerning Donner's conclusions remain. His Lateglacial lithostratigraphies, Oban 1 (NM 872276) and Oban 2 (NM 851292) did not show tripartite sequences, but only thick clays, which can be of postglacial age (this study, chap. 6; Lowe and Walker, 1976,1981). Donner's sites within the study area consequently do not demonstrate a maximal position for Stadial glaciers (Gray, 1975).

Donner's (1957) discussion of postglacial vegetational changes in Scotland come partly from his sites, Oban 3 and Oban 4 (NM 901028; NM 918279). Although retaining Godwin's (1940) zonation scheme he expressed doubts as to its application in Scotland, which eventually led to the rejection of this terminology by Birks, H.H. (1970), and the adoption instead of local pollen assemblage zones.

No Lateglacial pollen diagrams were known in the area prior to this study. The nearest diagram to the study area is from Drimnagall, north Knapdale (NR 714848), analysed by Rymer (1974, 1977). No radiocarbon dates were obtained due to the low carbon content of the sediment, (Rymer; pers. comm.). Rymer's work was part of a network of sites designed to assess the Flandrian forest history of Scotland (Birks, 1977). South of Rymer's site, at Loch Cill an Aonghais (NR 776617) Peglar (unpub.)analysed a lake profile with Lateglacial sediments which revealed a similar sequence to that at Drimnagall, with low Betula percentages and prominent Juniperus peaks in the interstadial. Once again, however, no C14 dates were obtained on sediments older than c. 10,000 yrs B.P. As part of the same programme Donner's (1957) Oban 1 site was resampled by Birks (H.J.B.,pers. comm. 1980) using a Mackereth corer (Donner had sampled from the basin-edge) and recovered over 3.0 m of clay, as had Gray (1975) with a Hiller corer from the lake-edge. This may belatedly support Donner's suggestion of Lateglacial deposition, but no organic interstadial muds were recorded (Birks.,pers. comm.,1980). No analyses of these minerogenic sediments were made, however, only the Flandrian sequence being recounted and C14 dated. The basal organic contact was dated at c.7000 B.P., which must be in serious error given the date for the Ulmus rise of 7505 +/- 75 B.P., some 110 cm above (Birks,1980).

Loch Salen, on the Ardnamurchan peninsula (NM 6865; fig 1.5) was analysed by Wain-Hobson (1981), who obtained dates of 10643 +/- 75 B.P. (SRR 1212) for the interstadial/stadial boundary, and 9796 +/- 75 B.P. (SRR 1211) for the start of the Flandrian. Williams (unpub.) produced a C14 dated postglacial pollen diagram for this site, and also for sites on Skye and the Morar peninsula (Williams, 1977). The Lateglacial sequence of Lochan Doilead (NM 677946; fig 1.5) was pollen-analysed, and a date of 11990 +/- 135 B.P. (SRR 775) was obtained for the earliest organic sediments, and one of 10280 +/- 120 B.P. (SRR 774) for the Lateglacial - Flandrian boundary, comparable with a date of 10090 +/- 100 B.P. (SRR 1186) for the same boundary at Salen (Birks, 1980; Harkness and Wilson, 1979). A postglacial diagram for Loch Shiel (NM 8072; Thompson and Wain-Hobson, 1979) has been published but the lack of detailed analysis invalidates attempts at palaeoecological interpretation.

To the east of the study area the glacial limits in the Teith valley (fig 1.5; Thompson, 1972; Smith et. al., 1978) have been shown to be of Loch Lomond Readvance age by Lowe (1978). Correlation of his Tynaspirit site (NN 667047) with others in the south-east Grampians (Walker, 1975 a,b.; Lowe,1978; Walker and Lowe, 1977) made a reconstruction of that region's Lateglacial vegetation possible, with sufficient uniformity between local pollen assemblage zones to produce a regional zonation scheme (Sissons et. al., 1973). Correlation by absolute dating was, however, problematic due to several suspected erroneous dates.

Uncertainty over radiocarbon dating of basal postglacial deposits in Scotland (Walker and Lowe, 1980; Sutherland, 1980) has led to a closer appraisal of the uses of the early postglacial pollen zonation in relative dating. Walker and Lowe (1980) have shown the vegetational succession at this time on Rannoch Moor to be sufficiently uniform to construct regional "R (Rannoch) - zones" for twelve sites on and near the Moor (fig 1.5). A fuller discussion of this work is found in chap. 5.

Since the present study commenced Walker and Lowe (1982) have published radiocarbon dates from four pollen sites on Mull (fig 1.5); Loch an t-Suidhe (NM 370215), Mishnish (NM 455565), both Lateglacial, while Coire Clachach (NM 613304) and Torness (NM 643333) lie within stadial limits. These dated profiles are the closest to the study area, and are discussed in chap. 3.

Detailed consideration of the above-mentioned sites and others in the British Isles will be made in later chapters. In particular, data from 42 published and unpublished Scottish Lateglacial diagrams are examined in a series of analyses of major taxa to illustrate the regional vegetational differentiation through the Lateglacial period (chap. 3). In chap. 5 the early postglacial vegetational succession is analysed in some depth.

ii Glacio-geomorphic Investigations

A brief resumé of the history of research in the study area is given below, together with details of the conclusions of the principal workers as related to glacial stages post-dating the Main Devensian ice-sheet, which extended beyond the western seaboard of Argyll, though its maximal extent is in dispute (Sissons, 1982b). Figure 1.2 provides the information in graphic form, while details of particular localities related to the pollen sites analysed in this study (fig.1.2), will be given in the sections on "geomorphic setting" in chaps.3, 4, and 6. The geomorphological evidence is fully reconsidered in chap.8.

The Geological Survey (various authors, 1897, 1905, 1908, 1911, and 1924) established the view, at least in part, that deposits of two stages of glaciation can be recognized, an ice-sheet phase and a less significant stage subsequent to that. It is clear from the checking of evidence in the field that their descriptions of "fresh drift", generally associated with the latter phase, can in most cases be regarded as "hummocky moraine" of Sissons (1967a), or Peacock's (1970) "morainic drift". The limit on fig 1.2 relating to Charlesworth's (1955) study can generally be applied to the Geological Survey's composite reconstruction (see below) e.g., Gunn et. al., 1897; Hill et. al., 1905; Kynaston et. al., 1908; Peach et. al., 1911; and Bailey et. al., 1924. While the concept of a second readvance of ice was familiar to Anderson (1888) and Bailey et. al. (1924), other workers (Kynaston et. al., 1908) regarded the "fresh drift" as representing only a small halt in ice-sheet retreat. The second glacial phase (halt or readvance), was related by Kynaston et. al. (1908) to the fluvioglacial terraces mapped at Loch Nell, Oban cemetery and Connel Ferry (fig 1.2), (Kynaston et. al., 1908), and at Ford (Hill et. al., 1905), which were in turn related to the "100' raised beach," a correlation which has influenced many reconstructions since that time.

Correlation was an important aspect of the work of Charlesworth (1955). He regarded the readvance he described as that of piedmont glaciers with lobes extending down individual glens. His reconstructions can be seen to be very poor in detail, and he frequently makes uncritical use of the Geological Survey's observations. His reconstructions (fig

1.2) are in many cases, therefore, similar to theirs. In fact his limit can only be approximate as the scale of the original maps (Charlesworth, 1955; figs. 9 and 10; 1" = 6 miles) and his highly schematic diagrams render accuracy impossible. The major weakness of the research is not the spatial distribution of the readvance, however (for Charlesworth admitted the maps to be generalizations), but his method of relative dating. The western highland moraines are related to Charlesworth's "Stage M" on the grounds that they are "contemporaneous with the 100' beach sea;" (p.912), despite some termini, i.e. Lochs Shiel and Morar, being related to sea-levels well below 100' (McCann, 1966). This geomorphic "marker horizon" is known to be invalid in that the altitudes of many raised beaches do not accord with this simple pattern, and those beaches which do approximate to that altitude are not everywhere of the same age (Sissons, 1962,1967a).

In his study Donner (1957) chose not to use relative sea-level changes in dating the moraines, but employed pollen analytical techniques (section i above). Although retaining the term "readvance" (he accepted the "Stage M" glaciation but renamed it the Highland Readvance) he regarded it principally as a retreat stage of the last glaciation (1957; p.222). Despite some inconsistencies in mapping his terminal limit east of Oban is regarded as accurate (Gray, 1975), although he failed to establish this palynologically (section i).

In the light of the criticisms of Charlesworth's methods by Sissons (1962), McCann (1961, 1966) re-investigated Charlesworth's (1955) "Stage M" limit in the western highlands, re-interpreting gravel spreads at Corran Ferry, on Loch Linnhe (fig 1.3) and the Moss of Achnacree on Loch Etive, thought to be the 100' beach, (Kynaston et. al., 1908), (fig 1.2) as fluvio-glacial outwash (McCann, 1961) and correlating these with similar spreads in Lochs Creran, Leven, Shiel and Morar, (fig 1.3). Although showing that none of these deposits lies on the "100' raised beach" no further evidence of their synchroneity is provided. McCann later (1966) considered these sediments to represent the termini of valley glaciers of the Loch Lomond Readvance, yet they could equally well represent retreat stages of that readvance.

This latter view is implicit in Peacock's (1971) paper, in which he extends the Loch Lomond Readvance limit further south and west than McCann's (1966) by a few kilometres. In that paper (Peacock, 1971), a Loch Lomond Readvance age for the deposits at the mouth of Loch Creran (fig 1.3) had been established by C14 dating shells of <u>Chlamys islandica</u> from glacially disturbed marine clay, which yielded dates of 11300 +/- 300 B.P. (St. 3262; outer part of shell) and 11530 +/- 210 B.P. (St. 3332; inner part). More recently Wain-Hobson (1981) has demonstrated a Loch Lomond Readvance age for the Loch Shiel deposits from the analysis of pollen sites "inside" and "outside" the limit (fig 1.5).

Synge (1966) and Synge and Stephens (1966) turned their attention to the fluvioglacial terraces and marine platforms between Lochs Awe and Etive, mapped initially by Hill et. al. (1905). The glacial limits used were those of the Geological Survey (fig 1.2; Charlesworth's (1955) limit). Synge and Stephens (1966) believed they recognized two major glacial episodes following the retreat of the Main Devensian ice-sheet, one associated with high sea-levels between 130' - 140' (40 - 43 m) O.D., which they termed the Oban-Ford moraine, and a later period related to sea-levels below that of the postglacial maximum, which they correlated with McCann's (1966) Loch Lomond Readvance. The emphasis in Synge's (1966) work was in demonstrating that the outwash terraces were all graded to a consistent altitude, thus implying synchroneity of deposition.

Such a consistent relationship has been doubted by Gray and Sutherland (1977), who re-mapped Synge's (1966) localities following strong criticism of Synge and Stephens' approach to mapping by Sissons (1967 b). At several localities Gray and Sutherland (1977) showed that the outwash terraces were graded to lower altitudes than Synge (1966) had thought. At other places the glacial limits of the Geological Survey and Synge and Stephens (1966) were rejected, e.g. at Loch Tralaig (fig 1.2), where an alleged moraine (Hill et. al., 1905) was re-interpreted (Gray and Sutherland, 1977; p.40) as an epidiorite ridge. Gray and Sutherland (1977) concluded that a major phase of glaciation graded to high sea-levels in this region must be doubted (but see below: Otter Ferry stage of Sutherland (1981)).

With regard to the outwash terraces graded to low (9 - 10m) sea-levels, a Loch Lomond Stadial age is accepted by Gray and Sutherland (1977). Thus at Ford in the Awe valley these authors tentatively accept, on the absence of evidence to the contrary, that Loch Lomond Readvance ice occupied Loch Awe and deposited outwash terraces from Ford to Kilmartin (fig 1.2).

Recently, however, Sutherland (pers. comm.) has identified what he regards as a possible terminal moraine at the north-east end of Loch Awe, near the village of

Kilchrenan (fig. 1.2). This region is the subject of detailed discussion in chapter 6.

Sutherland (1981) has studied the late- and post-glacial shoreline sequence in Cowal, south of Loch Fyne (fig. 1.2). He identified two principal glacial stages. The earlier is the Otter Ferry stage, considered to be a halt phase or readvance during the Main Devensian glacial retreat, tentatively dated at 12900 +/- 200 B.P. and associated with high sea-levels (38m O.D.). Correlations with the high sea-level evidence on the Argyll seaboard (Synge, 1966) are tentatively suggested, but no major readvance need be invoked for this stage.

The Loch Lomond Readvance limits were mapped by Sutherland in the sea-lochs of Cowal (fig. 1.2), and their age established by C14 dates on transported marine shells. Their extent was assessed primarily on the termination of "hummocky moraine", and so can only be an approximation. Around Dunoon he reports five independent corrie and valley glaciers (although more glaciers have been mapped in Cowal than are reported: Sutherland, 1981; p.239; fig. 1.2). Interestingly, four of these glaciers coincide with local accumulations of "well defined (hummocky) moraines" on plate 9 of Gunn et. al. (1897). Also significant are ice-contact deposits in the

Glendaruel valley and Strath Eachaig (fig 1.2), south of Loch Eck, which cannot be directly related to contemporaneous sea-levels, but which Sutherland considers must be below the uppermost Flandrian shoreline. Possibly related also is the distinctive moraine at Na Lona Min (Gunn et. al., 1897), not discussed by Sutherland (1981). A Loch Lomond Readvance for these deposits is briefly considered by Sutherland, but at least for the Glendaruel valley "would pose a considerable problem as to the origin of the glaciers," (p.247). In conclusion to this section, which illustrates the considerable uncertainty persisting in the extent and magnitude of the Loch Lomond Readvance in this region, it is noted that a similar dilemma to Sutherland's (1981; p.247) was indicated by Gray (1972; p.128) in the north of the area, who, on arguing for a Loch Lomond Readvance age for the deposits at Glen Feochan, recognized that "however, a problem arises as to the source of this ice."

1.6 AIMS OF THE STUDY

These can be defined as thus:

(a) the location of palynological sites containing sediments of lateglacial age to establish (a) a detailed account of the vegetational changes in the region during the Late Devensian, and (b) the maximal possible limit of Loch Lomond Readvance glaciers.

(b) to obtain from such sites material suitable for radiocarbon-dating to attempt to produce a firm absolute chronology for the vegetational changes.

(c) to compare these sequences with others in a regional context, and to sites in other regions of the British Isles.

(d) to locate sites in strategic positions adjacent to or on features believed to be the terminal limits of glacial stages, and to establish a relative chronology for these stages.

(e) to relate the sequence of glaciation thus deduced to the environmental changes apparent in the C14-dated pollen record, and thus produce an absolute chronology for the glacial stages.

(f) to generate and test an hypothesis for determining a relative chronology for the deglaciation of the region in post-Loch Lomond Readvance times.

1.7 LAYOUT OF THE THESIS

Figure 1.2 features the locations of the ten pollen sites to be discussed at length in the following chapters. Problems of site selection and sampling are dealt with in chapter 2, together with a careful consideration of the techniques employed in the study.

The two Lateglacial diagrams of Pulpit Hill and Loch Barnluasgan are discussed in chapter 3. The Pulpit Hill site was sampled for radiocarbon dating (chap. 3).

Chapter four is concerned with the implications of the sites of Na Lona Min and Lon Glas for ice movement following ice-sheet retreat. Lon Glas lies near Ford in the Awe valley, and that valley is considered in detail in chapters 5 and 6. An hypothesis whereby postglacial biostratigraphies can demonstrate occupation of a region by Loch Lomond Readvance ice is proposed (chap. 5) and tested (chap. 6).

Chapter 7 considers the environmental significance of deteriorated pollen grains, and discusses the possible errors and uncertainties in this work.

In conclusion, chapter 8 considers the reconstruction of aspects of the Lateglacial environment in the study area.

CHAPTER TWO

METHODOLOGY

2.1 INTRODUCTION

Before discussing the results of the pollen analyses certain prerequisites for palynological study need to be discussed, and specific assumptions tested. These include site selection, sampling and laboratory techniques, pollen counting and identification, the choice of pollen sum, the advantages and disadvantages of adopting pollen concentration techniques, and the construction and zonation of the pollen diagrams.

2.2 SITE SELECTION

Sites were identified from a variety of sources:
O.S. 1:25,000 and 1:10,000 maps: stereo-photograph coverage of the region at a scale of 1:50,000; reference to earlier literature and discussions with researchers with an extensive knowledge of the region, namely Dr. J. M. Gray, Dr. D. G. Sutherland and Mr. P. W. Thorp.

In recent years considerable attention has been paid to the importance of site selection. Since Tauber's (1965) work in illustrating the effects of source area and dispersal ranges on the pollen content of different-sized lakes in woodland regions many workers have extended his theoretical approach (Janssen, 1966, 1973; Andersen, S. Th., 1973; Peck, 1973; West, 1973; Bonny, 1976, 1978). This work has produced an awareness of differing pollen sources, with Janssen (1966) defining three such sources; local, extra-local and regional. The present study takes the definitions of these as proposed by Jacobsen and Bradshaw (1981): local pollen originates from plants growing within 20 m of the basin, extra-local pollen derives from plants present between 20 and a few hundred metres of the basin-edge, and regional components from vegetation greater than a few hundred metres from the site. The relative importance of these components in sediments from lake-basins and small hollows has been examined by Bradshaw (1981), but representation factors have not been calculated for tundra environments, such as pertain to the time-period under study.

Berglund (1979) suggested that in treeless areas lakes of radius 50-150 m should be of sufficient size to attract pollen from a dominantly regional source (up to 80% of the pollen sum). All the sites in this study satisfy this criterion, and it is considered that the pollen counts are representative of regional vegetation.

2.3 SAMPLING

After the provisional location of a site, depths from surface to impenetrable substrate were assessed by systematic probing at 10.0 m intervals, closing to 5.0 and 2.0 m spacings to ensure maximum resolution in locating the deepest point of a basin. All the basins are infilled peat-bogs, with the exception of Loch Barnluasgan (chap.3), and inaccessibility was not a limiting factor in choosing the eventual sampling position. The importance of sampling the deepest sediments in relation to post-glacial sites in the region will be enlarged upon in the discussion of a de-glacial chronology in chap. 5.

The selection of bedrock basins meant depths could be reliably ascertained from the probing. At Ford I & II (chap. 6), kettle-holes on kame sands, difficulties were encountered with the rods gradually seizing rather than convincingly "bottoming" on bedrock, a problem mentioned by Livingstone et. al. (1958) in arctic lakes on drift geology. Similar problems were met with at Na Lona Min, where it is thought that post-glacial fluvial deposition left spreads of impenetrable sand under the blanket-peat development (chap.4).

The deepest point in the basin was selected for sampling on the assumptions that here would be found the oldest sediments, the greatest sediment thickness, the clearest temporal resolution and the lowest probability of hiatuses induced by wind/wave activity. Lehman (1975) has developed models of sediment focussing which support these assumptions. Most of the sites are simple basins, and although Barachander II (chap. 6) proved to be a complex basin, with a rock bar approaching the surface in the centre of the basin, the samples were taken from the deeper of the basins, as Lehman suggests that the above assumptions hold true even for complex morphometries (1975: p. 541).

Sites were sampled with either a Russian sampler (1.0 m or 0.5 m length and 5 cm internal diameter), or a modified Abbey-type piston corer (Lowe & Walker, 1976) of 0.6 m length and 5 cm internal diameter. The use of the 1.0 m Russian sampler reduced the number of cores needed considerably,and full sequences could be obtained from only a few cores. Sediment was sampled from adjacent holes with 20 cm overlaps and the cores were matched litho - and bio-stratigraphically. In particularly thick sequences requiring several samples depths were controlled by levelling with a surveyor's level and staff. The success of this method can be seen in the detailed correlation of cores from Na Lona Min (chap. 4: fig. 4.2).

For post-glacial sites where sampling of the basal sediments is crucial the piston corer was used (the Russian sampler with its 10 cm long point protruding below the sampling chamber cannot sample the basal material). Berglund (1979) recommends the use of a piston corer, and West (1977) describes it as collecting undisturbed cores, but in the fieldwork it was noted that in semi-liquid clay considerable mixing of the sediments disrupted the original stratigraphy, also reported by Lowe and Walker (1981). Basal sediments could be sampled with care, but core-matching was problematic, and several sites had to be re-sampled with a Russian corer. More cohesive sediment did not behave in this way.

Cores were extruded in the field, placed in clean plastic "guttering", covered with adhesive film and labelled. Sampling was normally undertaken out of the flowering season, and contamination from modern pollen "fall-out" is considered unlikely. Contamination along one edge of the Russian sampler is possible if the flange does not seal the sediment successfully, but as this is derived from above the depth sampled, the contaminant is invariably peaty, contrasting with the lacustrine muds, and it can usually be removed. However, as is discussed in the site description chapters (3, 4 and 6), contamination is nevertheless apparent in the pollen diagrams.

In the laboratory cores were stored at c.5°C until sub-sampled for pollen analysis. Once unwrapped the cores were carefully cleaned and sampled, usually at 2 cm intervals, but at closer spacing for certain sites, using a small sharp-edged spatula.

2.4 CHEMICAL PREPARATION TECHNIQUES

The preparation techniques followed were essentially those described by Moore & Webb (1978, pp 23-25) and so will not be documented in detail here. Certain modifications regarded as advances on their methods are however discussed in the following section.

(a) Fine Sieving

It was apparent when counting the Pulpit Hill 1 diagram that the HF acid treatment was ineffective in removing the minerogenic sediments typical of Lateglacial deposition. Up to nine slides were required to obtain the pollen sum despite intensive use of cold HF acid for up to three days.

There are several supplements to the HF acid treatment: density separation methods such as the use of $CHBr_3$, $ZnBr_2$ (Kummel and Raup, 1965), $ZnCl_2$ (Bjorck _et_. _al_., 1978) or alcohol on water (Hansen & Gudmundssen,1979): the disaggregation of clay-bonds by chemical attack by, for instance, sodium pyrophosphate ($Na_4P_2O_7$) (Bates _et_. _al_., 1978): and by sieving the clay through meshes of a smaller size than the pollen grains themselves (Cwynar _et_. _al_., 1979).

The $Na_4P_2O_7$ technique was originally adopted, but was found to be excessively time-consuming, prone to increase problems of pollen loss due to the increased number of centrifugations necessary (important in pollen concentration techniques; discussed later) and was relatively ineffective unless the pH of the sediment was corrected to neutral (Lowe, S.; *pers. comm.*).

Cwynar *et. al.* (1979) detail the construction and use of fine nylon mesh sieves, and describe the results from comparing sieves of 5, 7, 10 and 15 μm mesh sieves. The coarsest mesh size was prone to selective loss of small grains, while the 5 μm sieve tends to clog with clay particles. Both the 7 and 10 μm sieves were considered extremely effective, and reduced counting times significantly(Cwynar *et. al.*, 1979).

Sieves were constructed in a similar way to the method described by Cwynar *et. al.* (1979) using mesh material of 10 μm size* and sawn drain-pipe of dimensions 10 x 7.5 cm. Trial samples were sieved, and the washings retained to check losses. Very few grains were found (Lowe, S.; *pers. comm.*) and losses can be regarded as minimal.

* Mesh material of 10 μm size was obtained from Henry Simon Ltd., Stockport, Cheshire, England.

Contrary to Cwynar _et_. _al's_ usage the sieves are introduced prior to the HF acid stage, allowing the acid to attack silt-size material (which is retained on the sieve) more effectively. A second sieving may be required after the HF acid stage.

The 10 μm sieves fitted under the 180 μm sieves, used to remove coarser grade material, and this reduced the need for further centrifugation and the risk of further pollen loss.

Results confirm Cwynar _et_. _al_'s (1979) findings of the effectiveness of the method. Not only was counting time greatly reduced but the clarity of individual grains made identification much easier, and the number of obscured and indeterminable grains was reduced. The use of the sieves also meant that samples originally deemed non-polleniferous were rendered countable to a high pollen sum, but as will be apparent in later chapters, considerable care is required in interpreting these spectra.

Also contrary to Cwynar _et_. _al_. (1979), the mesh was re-used several times with no apparent detrimental effects, and was simply cleaned by washing under a fast-flowing tap before mixing with distilled H_2O. No sediment was seen to remain on the mesh, and no contaminants were noted in samples prepared using the same sieve.

(b) Auto-stirring

When counts of deteriorated grains are to be made (chap. 7) it seems important to eliminate all sources of artificially induced mechanical collapse. Perhaps a significant factor here is the violent agitation of the sediment by glass rods, and to avoid such effects an automatic stirrer was employed. Time was not available to undertake specific checks on the effect of this agitation, but a small-scale attempt was made in observing any effects on the exotic pollen used in the pollen concentration diagram of Pulpit Hill (Pulpit Hill II), Ailanthus altissima. The results are reported in chap. 7 (sect. 7a). When counting the Pulpit Hill II diagram the Ailanthus grains recorded were also evaluated as to deterioration class. The results are shown in Table 2.1. Encouragingly, the figures show that no increases in deterioration occurred during the chemical preparation, although the samples were not agitated by glass rods. In fact, the "fresh" grains were more damaged, with 34% of the grains being split compared to 15% from the Pulpit Hill II diagram. Whether the glycerol had any adverse effect on the grains is difficult to gauge, although such deterioration is known in glycerol jelly

(Andersen, S. Th., 1960) (see chap. 7.7A).

Marked differences are known in the susceptibility of deterioration of pollen types (Cushing, 1967; Havinga, 1967, 1971; Anderson, S. Th., 1978; Hall, 1981) and a correlation between deterioration liability and exine thickness and grain size seems well established (Praglowski, 1970). Ailanthus grains have exines of average thickness 1.6 μm (n=30) and a diameter of 25.4 μm : range 23.8 - 27.0 μm (in glycerol). It can be argued that other taxa would show signs of mechanical deterioration absent in the exotic pollen. Problems of this kind may be more noticeable in material stirred by glass rods, and experimental data on this problem are needed.

(c) The Mounting Medium

Silicone oil was preferred to glycerol jelly due to the well-known disadvantages of the latter medium: the tendency for grains to swell (Faegri & Deuse, 1960) deterioration of grains if stored for longer than five years (Andersen, S. Th., 1960), the problems of pollen recognition in a solid medium, and the tendency for grains to crumple more easily in glycerol jelly (Praglowski, 1970).

Silicone oil is superior in all these respects

TABLE 2.1

Comparison of 'Fresh' and 'Prepared' *Ailanthus* Grains

WELL PRESERVED		CRUMPLED		SPLIT	
(a) 'FRESH' GRAINS					
COUNT	%	*COUNT*	%	*COUNT*	%
52	52	14	14	34	34
(b) PULPIT HILL 2 (28 spectra)					
% *AILANTHUS* GRAINS					
79.6 ± 3.4		5.0 ± 1.8		15.4 ± 2.3	
(c) LOCH BARNLUASGAN (20 spectra)					
% *AILANTHUS* GRAINS					
87.0 ± 5.1		3.6 ± 1.6		9.4 ± 3.7	

(Andersen, 1960; Praglowski, 1970), but being a fluid medium its major disadvantage is that grains intended for reference at a later date are frequently no longer at or near the recorded graticule co-ordinates, and unknown or problematic grains remain unidentified.

The greater viscosity of glycerol jelly means that the emplaced cover-slip remains higher above the slide than in silicone oil, and thus compresses the grains less, contrary to the views of Cushing (1961). This may be important as it was observed that large grains, e.g., Pinus, can appear split in a manner which suggests cover-slip pressure rather than natural deterioration (see fuller discussion in chap. 7.7A).

2.5 POLLEN CONCENTRATION STUDIES

Three principal approaches to the problem of obtaining absolute pollen deposition rates have been described since the first such diagram from Rogers Lake, Connecticut, was presented (Davis & Deevey, 1964); volumetric methods (Davis, M.B., 1965, 1966); weighing methods (Jorgensen, 1967, modified by Peck, 1974) and the use of exotic marker grains (Benninghoff, 1962; Matthews, 1969; Bonny, 1972; Maher, 1972, 1981). The advantages and disadvantages of each method have been amply assessed by Peck (1974). She concluded that, although the reliability of the estimate of pollen concentration is less for the Matthews method (addition of a known quantity of exotic pollen), "As a measure of reproducibility of results, there is little to choose between the preparation methods tested", (p. 580). One major advantage of the Matthews method is in the relative unimportance of sediment/pollen loss (termed "bias" by Peck) during the preparation, provided that the exotic "spike" (Maher, 1972) is added at the beginning of the procedure, and assuming that losses during, for instance, decanting are proportionally equal for both fossil and exotic pollen. With the necessity in both the Davis and Jorgensen methods of retaining all sediment, the extreme care required in these techniques adds considerable time to a preparation, a decided drawback when many samples are to be treated, and makes these methods more prone to operator error (Peck, 1974, p. 583) than the exotic marker technique. It is considered that the inevitable losses in the preparation, despite the rigorous checks suggested by Peck militate against the use of methods other than that of marker grains in the routine treatment of samples, and that the error inherent in the determination of exotic pollen (Bonny, 1972; Peck, 1974) is more than counter balanced by pollen losses, a view supported by Maher (1972).

It was decided to adopt the preparation technique detailed by Bonny (1972), with one major difference. This method is, as has been pointed out, principally advantageous in rendering sediment loss less significant, by adding the exotic marker grains at the earliest stage, differing from the methodology in Bonny's (1972) paper, although Matthews (1969), Maher (1972) and Peck (1974) consider it critical. Sediment loss can be as high as 40.5% (Peck, 1974; p. 582), varying with sediment type. Bonny (1972; p. 399) suggests total losses did not exceed 1%, and were usually 0.1-0.3%, although it would appear that these remarkably low figures were a result of special centrifugation procedures not used in routine analysis (p. 398). Bonny's reason for adding the exotic pollen, Ailanthus glandulosa, at the end of the preparation was related to the failure of one exotic species, Liquidambur spyraciflua, to settle out during centrifugation in 10% KOH, reported by Matthews (1969). Bonny does not demonstrate a similar problem with Ailanthus, and Matthews (1969) suggests that a related species, Ailanthus elegantissima does not behave in this way. Secondly, Bonny recommended counting the distinctive unstained grains. The choice of marker should, however, be made with clear recognition in mind and should not depend on such obvious contrasts. Sediment loss is thus not accounted for in Bonny's method, and this must be considered a severe disadvantage.

It was concluded that a method of early addition of exotic pollen was essential, but before describing the technique finally employed, certain other assumptions of the Matthews method have to be considered.

(a) Homogenization of the exotic pollen suspension.

Bonny points out (p. 394) that, "A considerable source of error can lie in the possible non-homogeneity of the exotic pollen suspension". In this study fresh, defatted Ailanthus altissima pollen was used as the "spike"*. To produce a reasonable concentration for counting amounts were added to pure glycerol (S.G = 1.26) in a 250 ml flask to produce a concentration of 2.0 mg of exotic pollen to 1.0 ml of glycerol (Bonny, 1972: p. 396). Two "flea" magnets were added to the suspension to prevent a vortex forming in the suspension and inducing unequal mixing; the flask was stoppered and placed on a magnetic stirrer running at a constant speed throughout homogenization. For counting the exotic suspension a modified Fuchs-Rosenthal haemocytometer of chamber depth 0.2 mm and volume 1.8 μl was used, being prepared and filled in the manner described by Bonny (1972; p. 394). 2.0 ml bore disposable pipettes were used to sample the glycerol suspension, and as Matthews (1969; p. 162) shows that the exotic pollen sinks in the suspension quite quickly after cessation of stirring the glycerol-pollen mixture was sampled during stirring, approximately 1.0 cm below the glycerol surface. * Obtained from Greer Laboratories Inc., Lenoir, N. Carolina, U.S.A.

The entire graticule constituted one count, and pairs of counts could be made from one filling of the haemocytometer, after the defining of criteria to avoid counting twice grains which bisected a ruled line. Fifty such counts (25 pairs) were made; designated "Batch 1". Clean pipettes were used throughout to avoid contamination, and with a 2.0 ml bore selective sampling of the suspension (Davis, M.B.,1965) was eliminated. The haemocytometer was rigorously cleaned with acetone between samples.

Estimates of the time needed for successful homogenization range from 45 minutes (Matthews, 1969, supported by Bonny, 1972) to one hour (Peck, 1974). There are suggestions in the data presented here that these estimates may seriously underestimate the time needed for homogenization. The data set can be found in Table 2.2.

(1) Initially it was decided to test the validity of the data by examining whether there were differences between counts of the upper and lower graticules of the haemocytometer induced, perhaps, by differential drag and friction effects impeding flow between the two:

TABLE 2.2

BATCH ONE: Haemocytometer counts

TIME ELAPSED (HRS) SINCE STIRRING COMMENCED	PAIRS OF COUNTS (Upper grat. first)		MEAN
2	248	284	266
17	283	262	272.5
17.5	279	*_	279
18	310	*_	310
18.5	298	258	278
19	265	318	291.5
19.5	296	304	300
20	257	277	267
20.5	279	280	279.5
21	310	286	298
21.5	332	263	248.5
22	316	261	289
22.5	263	309	286
23	264	265	264.5
23.5	256	267	261.5
24	277	273	275
24.5	291	255	273
25	227	264	245.5
25.5	282	278	280
26	263	259	261
26.5	277	288	282.5
27	281	263	272
27.5	259	263	261
40	288	273	280.5
40.5	267	249	258
50	277	285	281

* =lower graticule not counted due to bubbling under haemocytometer

No. OF GRATICULES (n) = 50

$\sum n = 13{,}829$ grains

$\bar{x} = 276.\dot{5}8$

$\sigma = 20.43$

TEST: Mann-Whitney U-test.

HYP_1: Significant differences will be observed between the two data sets C_1 (upper graticule counts) and C_2 (lower): Table 2.2.

HYP_0: no significant differences will be observed.

REJECTION LEVEL: $\alpha = 0.05$

C_1: N = 24; $\bar{x} = 277.33$; $\sigma = 23.0$; median = 277.0

C_2: N = 24; $\bar{x} = 274,33$; $\sigma = 17.5$; median = 270.0

U : 0.543; ≥ 0.05 $\therefore$ Hyp_0 is accepted.

This result confirms Bonny's (1972) qualitative observation that grains in suspension conform with the flow of the glycerol, and no significant differences exist between counts from upper and lower graticules.

(2) The effect of continous stirring for long periods on the homogeneity of the glycerol-pollen suspension was examined next.

Table 2.2 and Fig. 2.1.1a show that counting continued for a longer period (50 hours) than that proposed in the literature (refs. above), and in addition did not commence until 2 hours after the commencement of stirring. Visual estimation of

Fig. 2.1: Estimates of exotic pollen suspension

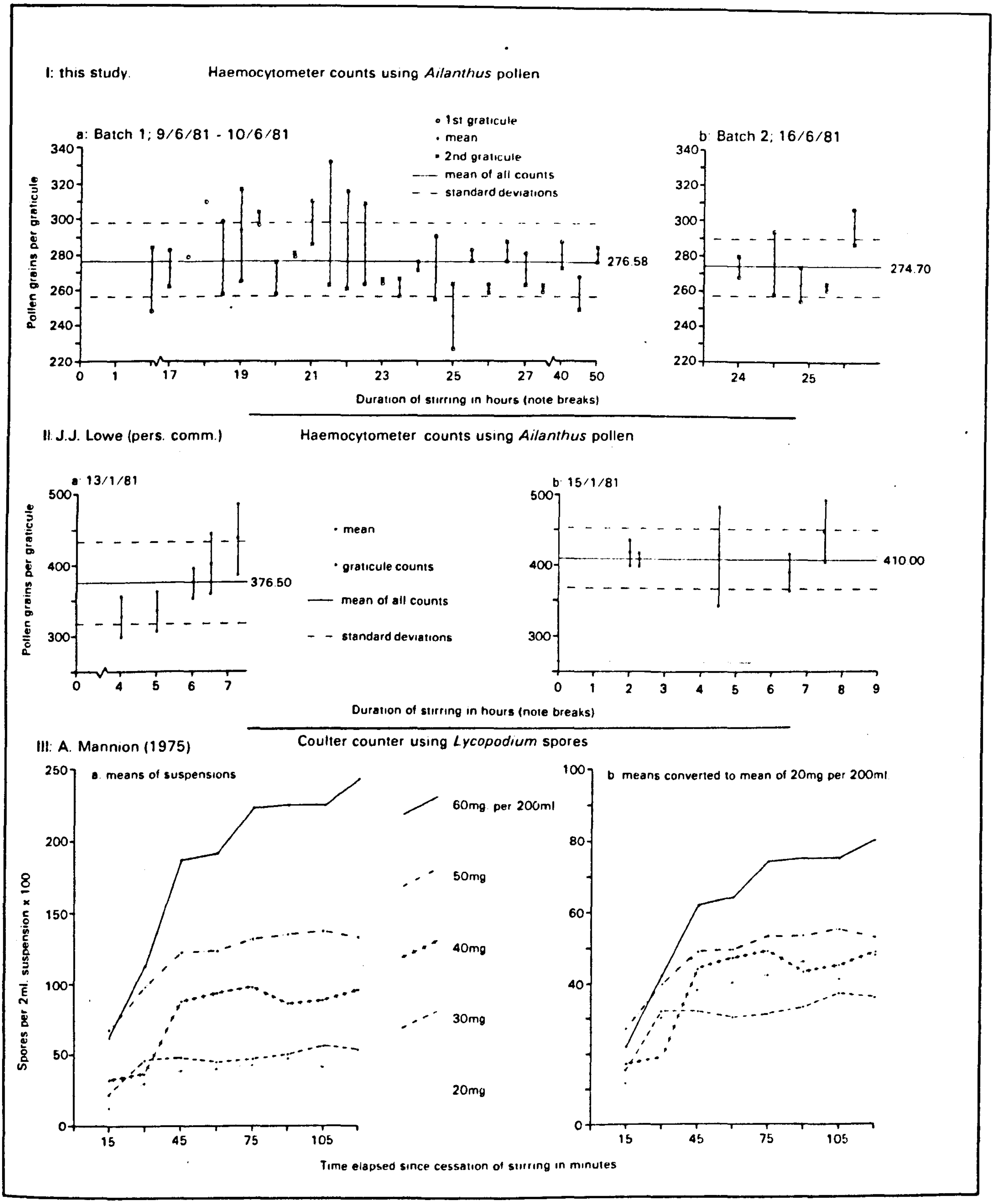


Fig. 2.1.1a suggested that counts made after c.23 hours had smaller ranges between the two counts of a pair (smaller variance about the mean), and more closely grouped means than counts made prior to c.23 hours. Accordingly the total population (n = 50) was sub-sampled:

	n	x	$\bar{x}$	σ
POP'N A (<23 hours)	24*	6838	284.92	23.08
POP'N B (>23 hours)	26	6997	269.11	14.17

* minus lower graticule counts at 17.5 and 18 hours: see Table 2.2.

The means of the sub-sampled populations were examined.

HYP_1 = Pop'n A will have significantly different means than pop'n B.

HYP_0 = No significant differences will be observed.

TEST= Mann-Whitney U-test.

REJECTION LEVEL = α = 0.05

$U = 0.0413 = < 0.05$

$\therefore$ HYP_0 is rejected.

The means of the populations A and B are significantly different.

The implications of these results will be discussed in the conclusion to this section; 5.

(3) Further work

The suspension was left to settle out for one week, then re-stirred for 24 hours before being sampled for a total of ten counts (5 pairs), designated Batch Two (fig. 2.1.1b), wherein the counts are plotted against time as in Fig. 2.1.1a. As 24 hours had elapsed since stirring began it was considered that the most useful test would be to compare Batch Two with Pop'n B Batch One (e.g., post-23 hours).

HYP_1 = Batch Two will show significantly different estimates in terms of means.

HYP_0 = No significant differences will be observed.

(B) Mann-Whitney U-test.

REJECTION LEVEL = α = 0.05

$U = 0.3075$; $p > 0.05$

$\therefore$ Hyp_o is not rejected.

It is concluded that a very good agreement is demonstrated between the independent sampling sequences of Batch Two and those counts made post-23 hours from Batch One (e.g. pop'n B). In addition, a Mann-Whitney U-test was applied to the data of Batch Two and Batch One (pop'n A), and the resultant Z-score of 2.1 signifies that these two populations are significantly different.

Thus it seems likely that these consistent results are giving a true measure of the exotic pollen suspension, in which case the significantly different values for Batch One (pop'n A) need to be explained. First, however, other workers' results are examined to test the consistency of the pattern reported above.

(4) Other Results

Table 2.3 provides the data (ranked) of 50 counts made by S. Lowe (pers. comm.) using the same glycerol-pollen suspension as in the author's data.

TABLE 2.3

Haemocytometer counts: S.Lowe.

243		259		268		272		282	
249		259		268		272		283	
250		260		269		273		287	
251		260		269		273		288	$n = 50$
251		261		270		276		289	$\sum n = 13{,}493$
252		261		270		276		290	$\bar{x} = 269.89$ grains
254		263		271		278		291	$\sigma = 13.41$
254		263		271		281		293	
255		264		272		281		294	
258		265		272		281		298	

Although records were not kept of the time each pair of counts was made the sequence commenced after 48 hours of continuous stirring (Lowe,S: pers. comm.). The mean (Table 2.3) of 269.86 grains per ml is remarkably close to the author's value for Batch One: pop'n B of 269.11 grains per ml , and that of 274.7 grains per ml of Batch Two. This strongly supports the suggestion that the pop'n B mean is a more accurate representation of the exotic pollen concentration than is pop'n A's.

J. J. Lowe (pers. comm.) ran five series of haemocytometer counts on two occasions (Fig. 2.1.11) separated by c.24 hours when the suspension was not stirred. It seems likely that this period was sufficient to return the suspension to its original, unstirred state, as simple extrapolation of Matthew's figures (1969; p. 162) of the settling rate of Nyssa sylvatica grains in glycerine indicates: the slope of the regression line of Y (no. of grains in haemocytometer counts) = 430.5465 +/- 22.1981x, (time in hours since cessation of stirring), has a correlation coefficient (R) of - 0.9099, and can explain 82.7% of the variation: extrapolation of the regression line of Y for X = 24 hours produces a value for Y of -102.2077 grains. The first set of counts (13/1/81; fig. 2.1.11a), although commencing well after the one hour established in the literature shows a very large standard deviation; $\bar{x}$ = 376.5: σ = 52.74, and a clear positive trend is suggested (fig. 2.1.11a).Linear regression was not attempted as n = 5 only. The second set of counts, made on 15/1/81 shows no trend but still shows a large standard deviation; σ = 49.82, and a mean; $\bar{x}$ = 410.0, at variance with that of set 1, and it must be assumed that even after 7 hours homogenization was incomplete.

Mannion (1975), using a Coulter counter in place of a haemocytometer, made up 5 concentrations of Lycopodium spores (Fig. 2.1.111) i.e., 20, 30, 40, 50 and 60 mg per 25 ml of glycerol. Samples of each concentration were taken every 15 mins , commencing 15 mins after stirring had begun. Each point on Fig. 2.1.111a represents the mean obtained for 16-26 independent counts; counts ceased after 120 mins. For statistical purposes the results were re-calculated by this author to represent a concentration of 20 mg per 25 ml of glycerol (by simple division: 60 ÷ 3 etc.) and plotted on Fig.2.1.111b. It is apparent from this that in terms of narrowing ranges four of the concentrations approach the mean of 43,336 grains per ml after approximately 120 mins , but it is equally clear that the 60 mg concentration shows no sign of homogenizing at or close to that value. Mannion (1975; p.80) accepts Matthews (1969) suggestion that 45 mins. is adequate for even mixing. Such a period may be acceptable for some concentrations, although it is likely that extending the time would reduce the variance about the mean even more, but it does not appear sufficient to judge from the variation apparent in the 60 mg concentration.

(5) Conclusions

It has been demonstrated that changes occur within the glycerol-pollen suspension which alter the exotic pollen concentration therein well beyond the 45-60 mins. suggested in key papers (Matthews,1969; Bonny, 1972; Peck, 1974). That one hour is not adequate seems clear from the data of J. J. Lowe and A. Mannion, and that significantly longer periods, exceeding one day provide better estimates is indicated from the author's data and, in particular, the close agreement between his counts after 23 hours and the independent counts of S. Lowe on the same material.

The trends seem to show that significant changes occur in the glycerol suspension over time. Matthews (1969) indicates that transfer of heat from the magnetic stirrer to the flask changed the temperature of the suspension from approximately 20°C to 32°C over 2 hours. The temperature generation of stirrers will vary with the manufacturer, and the r.p.m. at which the machine is maintained. Neither Matthews, Bonny or Peck indicate the speed at which their stirrers operated. The ambient temperature of each laboratory also differs, which will also affect the viscosity of the suspension. It is not possible to predict when successful homogenization will occur. For individual researchers in different laboratories the period may well differ noticeably, and it would seem dangerous to generalize as workers in the past have done.

Taking the two populations A and B of Fig. 2.1.1a one can calculate the exotic pollen concentration using Bonny's equation (1972; p.395):

POPULATION A = 158290.15 +/- 3677.8 grains per ml.
upper c.l. = 161967.85
lower c.l. = 154612.35

POPULATION B = 149506.75 +/- 3574.7 grains per ml.
upper c.l. = 153081.45
lower c.l. = 145932.05

Confidence limits (c.l.)

The two distributions do not overlap, yet both are derived from the same suspension. Pollen concentration diagrams calculated separately on these sums would appear radically different in terms of pollen influx estimates, and comparison between sites would be anomalous if the "wrong" value were chosen.

For the pollen concentration analyses in this study the estimate obtained for population B (above) was considered more accurate.

(b) Addition of the marker grains to the sediment

Following Bonny (1972) the volume of sediment was initially measured by displacement in distilled water (this was later modified, see below) in a class A (B.S 604) 10 ml measuring cylinder. The sample was then transferred to a centrifuge tube: as this stage is prior to the addition of the exotic pollen it would seem to be the most crucial in terms of sediment loss. Lacustrine clays often require copious amounts of distilled H_2O to dislodge all the sediment from the measuring cylinder, which in turn increases the number of centrifugations needed and the possibilities of loss through decanting.

Pollen concentration will vary through a sediment core, and it makes little sense to add a uniform weight of glycerol to each sample. Maher (1981) discusses the balance between "work" involved and "precision" gained, and knowing the average number of grains per drop, one can with a little experience approach Maher's balance of 2 fossil grains to one exotic marker. In this way overabundances of exotic pollen in sediments of low fossil pollen concentration can be avoided.

(c) Successful mixing of sediment and glycerol suspension.

Although Peck (1974) advises adding the glycerol suspension as early in the preparation as possible she in fact adds it prior to the HF acid stage, and after the KOH treatment (Moore & Webb, 1978) in which several centrifugations may be necessary. She reported (p. 570) that "the glycerol suspension had broken down under the acid". Matthews (1969) appears to add the suspension prior to the KOH stage and makes no comment on the effectiveness of the mixing. Bonny (1972), adding glycerol to molten glycerine jelly at the end of the preparation found no problems of this nature.

Observation of glycerol in distilled H_2O suggested that release of exotic pollen during auto-stirring of up to 10 minutes duration was only partial. It is difficult to measure this, but on a qualitative level glycerol appeared as an immiscible phase after settling. Discussions with chemists from both B.D.H. and May & Baker on this problem indicated that glycerol is extremely resistant to chemical breakdown, and it would seem in hindsight that glycerol poses many problems that other agents, e.g., Tertiary Butyl Alcohol (Maher, 1972) might avoid.

Trials were performed with HF acid and an Erdtman's acetolysis mixture of acetic anhydride: H_2SO_4 in a ratio of 9:1 (chemicals used in a normal preparation were chosen due to the unknown effect others may have on pollen preservation). Due to the hazardous nature of these chemicals the assessment could only be qualitative, and no attempts were made to check supernatants. Results from the use of HF acid were inconclusive. Heating in a water bath for 2 mins. at 95°C with the Erdtman's acetolysis mixture appeared to release the *Ailanthus* grains successfully, and no immiscible phase could be recognized on centrifugation. Accordingly this treatment was adopted prior to the KOH stage, and as a consequence the volumetric displacement of the sediment was made in glacial acetic acid, not distilled H_2O.

(d) Preparation techniques

The preparation from the stage above is essentially as for "relative" counts. The sediments thus underwent two acetolysis stages. Moore & Webb (1978) consider that prolonged acetolysis affects certain grains but other laboratories (Berglund, 1979) acetolyze material for up to 5 minutes with, presumably, no damage being done. In addition, several of Peck's (1974) suggestions for improved recovery of sediment were incorporated, notably the prolonging of centrifugation at higher speeds.

In later pollen concentration counts the method of Stockmarr's (1971), of adding Lycopodium tablets* with a mean concentration per tablet of 11,300 +/- 400 grains was used. This technique successfully circumvents many, if not all the problems described above. Addition of the tablets was at the earliest stage of preparation, e.g., coincident with the sample being placed in the test tube, and as the tablets dissolve and release the exotic spores on contact with distilled H_2O, no additional preparation is necessary.

2.6 POLLEN COUNTING

A Gillet and Sibert Conference binocular microscope was used, and routine counting was made at a magnification of x 400, with problematic grains being resolved at x 1000, under immersion oil, and under phase contrast if necessary. Levels with low pollen concentration were scanned initially at x 200. Non-polleniferous sediment was defined as material which, having undergone the most stringent preparation (i.e. 10 μm mesh sieving plus boiling in HF acid for up to 3 hours) produced fewer than c.30 grains per slide.

The pollen sum used throughout was that of "Total Land Pollen" (T.L.P.), accepting the arguments of Faegri & Iversen (1975), Wright and Patten (1963) and Birks (1973). Information loss through the exclusion of aquatics and spores from the sum, despite certain genera having both terrestrial and aquatic

* obtained from B. E. Berglund, Dept. of Quaternary Geology, Lund, Sweden.

members is unavoidable. This choice also allows for comparison with the vast majority of other Lateglacial diagrams.

Counting of "relative" pollen diagrams was to a total of 300 T.L.P. grains, and 500 grains for "absolute" counts. For the latter this sum did not include exotic pollen, for in spectra of low fossil pollen concentrations the total can be dominated by marker grains almost to the exclusion of fossil taxa (Robinson, 1977), which greatly reduces the statistical validity of those spectra. Table 2.4 summarizes the additional sums for the estimation of taxa outside the sum, and also for deteriorated grains.

2.7 COUNTING STRATEGY

Brookes & Thomas (1967) indicated the need for palynologists to adopt a pre-determined counting strategy when counting pollen slides. They detected significant departures from the expected random distribution of pollen on slides embedded in glycerine jelly. Their results lead to a choice for the analyst as to one of three options: 1) to count the entire slide to eliminate bias (too time-consuming): 2) to adopt a strategy to correct for this problem, such as Peglar's (1979) solution of counting from the centre of the slide outwards, or 3) to ensure that each slide does show a random distribution of grains.

TABLE 2.4

CALCULATIONS FOR TAXA OUTSIDE SUM + DETERIORATED GRAINS

1) AQUATICS AND SPORES AS % T.L.P. = TAXON ÷ ΣT.L.P.+ AQUATICS (ΣSPORES)

2) DETERIORATED GRAINS

a) TOTAL DETERMINABLE GRAINS AS % T.L.P. = total determinable grains ÷ Σ T.L.P.
(grains are within the sum).

b). DETERMINABLE GRAINS BY DETERIORATION CLASS AS % T.L.P. = class ÷ Σ T.L.P.

c) TOTAL INDETERMINABLE GRAINS AS % T.L.P. = total indeterminable grains ÷ Σ T.L.P.
+ indeterminable grains

d) INDETERMINABLE GRAINS BY DETERIORATION CLASS AS % T.L.P. = class ÷ Σ T.L.P.
+ Σ indeterminable grains

e) INDETERMINABLE GRAINS BY DETERIORATION CLASS AS % TOTAL DETERMINABLE GRAINS = class ÷ Σ DETERMINABLE GRAINS

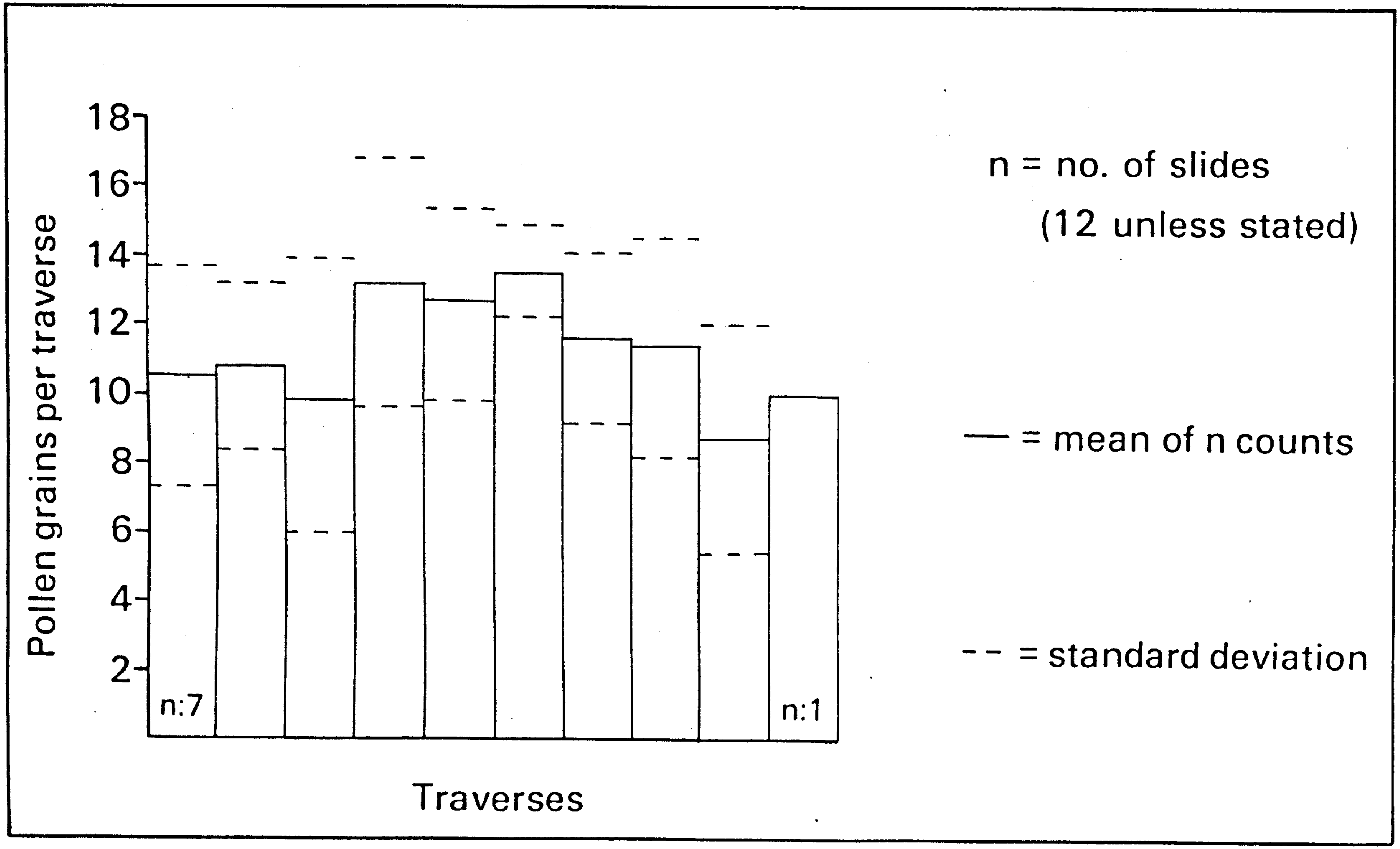
f) INDETERMINABLE GRAINS BY DETERIORATION CLASS AS % TOTAL INDETERMINABLE GRAINS = class ÷ Σ INDETERMINABLE GRAINS

g) TOTAL DETERMINABLE AND INDETERMINABLE GRAINS AS % T.L.P. = total determinable +indeterminable grains ÷ Σ T.L.P. + Σ indeterminable grains

Flow-lines within the fluid medium on emplacement of the cover-slip will control grain distribution, so initially uniform cover-slip placing must be assured. The rectangular glass slips (40 x20 mm) were lowered from one end, not dropped vertically as in Brookes & Thomas' investigations, so the flow-lines and grain distributions might be expected to differ. Having ensured consistent slide production a check on non-random distribution, as Peck (1974) proposed was made on several slides. For the Pulpit Hill I diagram regularly spaced (2.5 mm) traverses were made across the entire cover-slip, 8 - 10 traverses per slide, and total pollen per traverse recorded (Fig. 2.2). Following Peck's (1974) arguments the distribution can be checked using the X^2 test, assessing the significance of X^2 for n - 1 degrees of freedom. Slides failing at the rejection level $\alpha = 0.05$ would not be counted, and instead a second slide prepared. Slides with pollen concentrations such that over half the slide had to be counted were not checked in this way. Of the slides assessed, covering a range of sediment types, none was rejected, which strongly upholds Peck's conclusion that distribution is random in silicone oil. On this basis other sites were not tested and randomness was assumed, meaning that only portions of slides were counted at closer-spaced intervals.

Whether this assumption applies to the distribution of deteriorated grains is unknown. Pollen counts per traverse were

Fig 2.2: Pollen grain distribution across slides



too low for statistical tests of this nature. Cushing (1961) noted that slides were often thinner at the edges than the centre, and bearing in mind what has been suggested in relation to cover-slip pressure on grains, the totals of deteriorated pollen may be over-estimated in this and other studies.

POLLEN IDENTIFICATION

Notes on specific taxa can be found in the appendix. The identifications were verified by reference to type material in the City of London Polytechnic and the Dept. of Plant Sciences, King's College, University of London, discussions with Dr. J. Ince and S. Lowe and by the use of several keys, including Moore & Webb (1978), Erdtman et. al. (1961, 1963), Faegri & Iversen (1975) and Andrew (1980).

The recognition of deteriorated grains will be discussed in chap. 7.

2.8 OTHER TECHNIQUES

(a) Sampling for C14 Dates.

Multiple sampling (Deevey & Potzger, 1951; Lowe and Walker, 1976) was employed using a 60 cm chamber piston corer of 5 cm diameter. The sediments were predominantly tough, and little mixing (see earlier) was observed in the field extrusion of samples. In the laboratory all the cores for each date were matched biostratigraphically by constructing skeletal (100 T.L.P.) pollen diagrams and cross-correlating. Core-matching by lithostratigraphy was considered somewhat suspect (a fuller discussion of the laboratory techniques is presented in chap. 3.2.ix.). Appropriate 1.0 cm thick slices were taken from each core (see chap. 3.2) bulked, weighed and packed in clean plastic boxes (Harkness, 1975) and sent by post to the S. U. R. R. C. C14 dating laboratory at East Kilbride, where all the C 14 dates were obtained using a liquid scintillation counter. The results are discussed in detail in chap. 3.2.ix.

(b) Carbon/Nitrogen Content

Total carbon and nitrogen curves were produced for some sites using a Carlo Erba 1106 CHN+O Analyser (Carlo Erba Strumentazione; unpub.) by Mr. B. Saunderson of the Chemistry Dept., City of London Polytechnic. Samples 0.5 cm thick were oven dried overnight at 105°C , ground to powder, and material fewer than 100 μm collected for analysis. 4 mg sub-samples were placed in silver-foil capsules and decarbonated in moist concentrated HCL acid in a desiccator. The analyser is fully automated, based on the principle of gas chromatography, and results are supplied via a PET micro-computer. This method is considered much superior to other methods such as loss-on-ignition (Ball, 1964), which have errors in water loss from sediments during ignition.

(c) Macrofossil Analysis

No systematic attempt was made to construct macrofossil diagrams. Instead, residual material retained on the 180 μm sieve during the chemical preparation was washed into a Petri dish and examined under a Griffin binocular microscope under x 10 mag. in reflected light. A sheet of mm squared graph paper facilitated the estimation of relative proportions of the different sediment types. Results were expressed in the following terms, with very approximate percentages:
Present = $<$2 %; Rare = 2-5 %; Occasional = 5-10 %;
Frequent = 10-50 %; Abundant = $>$50 %. The following categories were defined:-

mineral matter (a) Coarse; size, shape and lithology were recorded.

(b) fine; fine sand $<$180 μm.

organic matter (a) coarse; leaves, stems, seeds etc., usually recognizable.

(b) fine; amorphous material.

(c) moss filaments.

(d) carbonized fragments.

(e) woody fragments.

The procedure resembles a modified form of the "Strukturanalyse" of Lundquist (1926, Berglund in Aaby, 1979) although the amount of sediment examined was very small.

Coarse organic matter was isolated and identified where possible by Dr. B. Giles, Biology Dept., City of London Polytechnic and this author. Moss filaments were examined under a Vickers M15 C stereo microscope with transmitted light under x 200 mag. Keys used were those of Smith, A.J.E. (1978) and Watson (1968), and the state of preservation was recorded according to Dickson, J.H. (1973; p.218).

(d) Sediment Stratigraphy

Lithostratigraphies were described in the laboratory, and followed the genetic system of Faegri & Iversen (1975). Cores were examined immediately on return from the field, and after the removal of the outer layers of cores to reveal fresh material. Munsell colors were determined on moist sediment under artificial light.

2.9 (a) POLLEN DIAGRAM CONSTRUCTION

For ease of interpretation the pollen diagrams presented in the following chapters conform to a uniform lay-out. From left to right the diagrams present the following information:

(1) the stratigraphical position and sample thickness of C14 dates, if appropriate.

(2) the sediment - stratigraphical column.

(3) a representation of the cores used in the compilation of the diagram, indicating the extent of overlap between cores. Sample positions for the pollen spectra are indicated, and the cores they came from so that core-matching can be assessed.

(4) depths in cm from the bog-surface.

(5) the taxa recognized, with the level of identification shown in the manner proposed by Birks (1973), in the following order:

trees - small dots next to the *Betula* curve indicate the presence of *B.nana* (see appendix).

shrubs - Duffey *et.al.* (1974) regard *Corylus* as a shrub in grassland communities, the likeliest ecological setting for the genus in this study (Godwin, 1975; Faegri,1966).

dwarf shrubs.

herbs.

T.L.P.

aquatics

spores.

Σ TAXA

(b) POLLEN ZONATION

Early workers subdivided Lateglacial pollen diagrams on lithostratigraphic criteria (e.g. Jessen, 1949). The change to biostratigraphic criteria (Smith, 1961; Watts, 1963) tended to lead to the suggestion of synchroneity between similar zones (e.g., Godwin, 1956). This assumption has been criticized (Smith & Pilcher, 1973) and following Cushing (1967) the concept of the local pollen assemblage zone, where no synchroneity between areas is assumed, has been encouraged (West, 1970; Birks, 1973). This approach has been adopted in this study, using the definition of a bio-assemblage zone as expressed by Hedberg (1976; p.50).

Visual consideration of each diagram was considered valid, particularly in the light of Gordon & Birks' (1974) investigations, which concluded that these subjective methods compared well with more objective methods of computer-zonation. It seemed best in the choice of a T.L.P. pollen sum to consider all taxa representing >5% of the sum in the zonation. Boundaries are defined on changes in one or more major taxa, and to promote consistency in comparison, are throughout assessed on the percentage-based diagrams.

Such bio-assemblage zones relate to one site alone. Regional pollen assemblage zones can be defined on the correlation of local pollen assemblage zones; some discretion is required and a certain flexibility is important in this if pollen assemblage zones are "to have any usefulness beyond the limits of a single lake". (Livingstone, 1968; p. 95).

CHAPTER THREE

THE LATEGLACIAL POLLEN SUCCESSION IN THE SOUTH-WEST SCOTTISH HIGHLANDS

3.1 INTRODUCTION

Two pollen sites, Pulpit Hill and Loch Barnluasgan (fig 1.2) were located and established on palynological grounds to be of Lateglacial age. This chapter is concerned explicitly with the evidence for environmental changes during this period obtained from these and other British pollen diagrams. Other environmental factors, e.g. sea-level changes, glaciological reconstructions, will be elaborated on in chapter 8.

3.2 PULPIT HILL (g.r. NM 85192919; lat. 56°24′35″N; long. 5°29′W)

i Site Location and Description

The site is a small basin near the land mark of Pulpit Hill, at the western edge of Oban, Argyllshire (figs 1.2; 3.1a). Lying at 60m O.D., the catchment is restricted (c 500 sq. m) and well-sheltered (fig 3.1a), in a fault-controlled basin between the Lower O.R.S basaltic and andesitic lavas of Druim Mor and the overlying Lower O.R.S. conglomeratic sandstones. Till in any substantial thickness appears to be absent from the catchment. Inflowing streams are not present, though a small stream exits to the N.E. through a concrete dam (in 1982 the site was artificially flooded to accommodate a new curling pond).

Fig 3.1b, the subsurface contours, is obtained from information supplied by J.M. Gray (pers. comm.), augmented by work in the present study, and clearly establishes the enclosed nature of the basin. These imply a simple basin extending below 7.0 m, but Donner's (1957) stratigraphic record from this site (see section 3.2.ii) extends to 6.50m (fig 3.4) "at the dam which divides the pond in two halves" (p.245), which must be close to the point located on figs 3.1b and c. This does not accord with other depth-determinations, but subsurface contours are drawn to conform with Donner (1955, 1957).

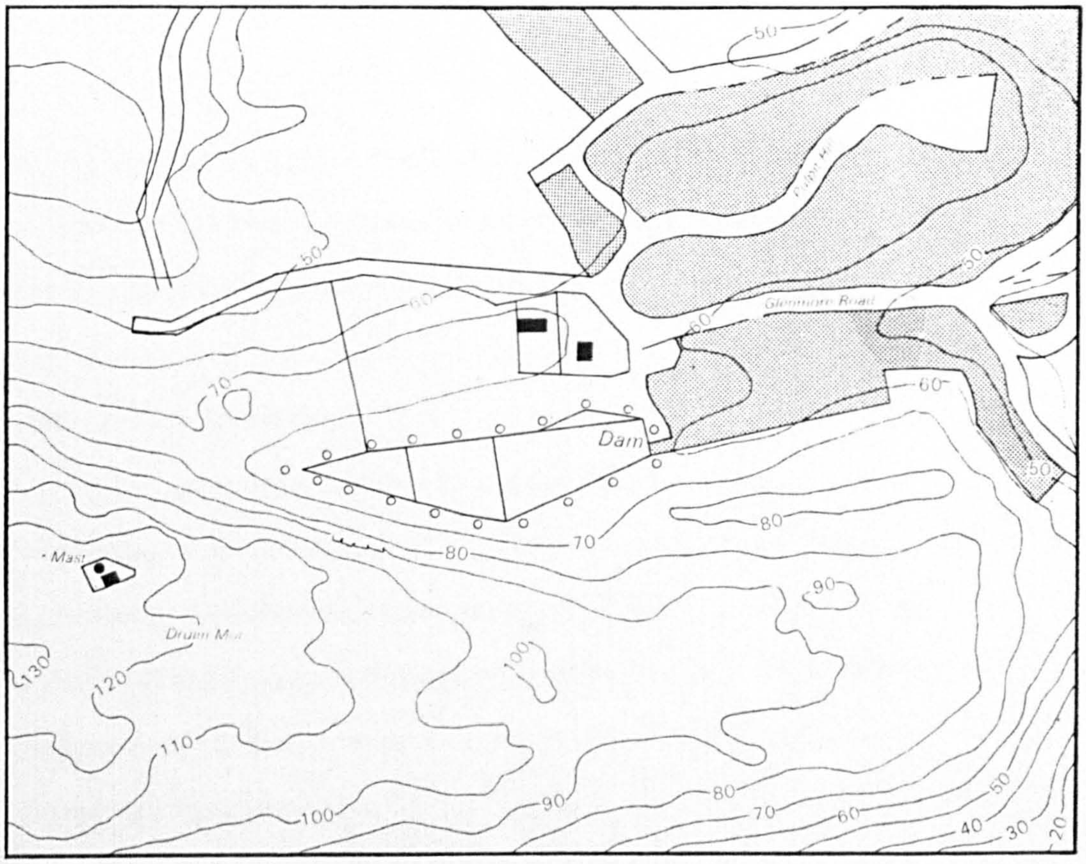
The basal 1.0m of sediment was also recorded at points a and b (fig 3.1b), where bedrock was struck at 2.50m and 3.96m respectively. No minerogenic clay was recorded in either sample, and it is likely that the Lateglacial sediments (sect. 3.2 v) are confined to a restricted region below 4.0m depth.

ii Previous Work

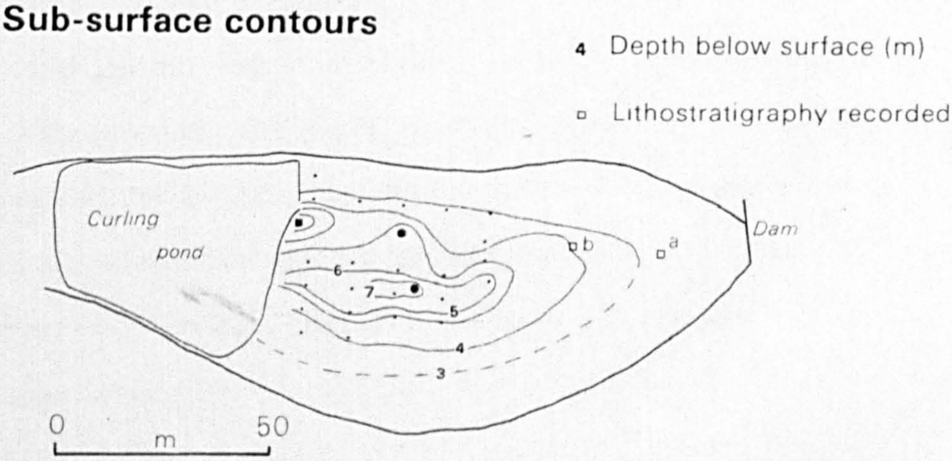
The site was identified by Donner (1955, 1957) who sampled near the point in figs 3.1b and c. This site, "Oban 2", shows a sequence of sands and silty clays 80cm thick above 650cm which he considered "probably represents Zone III" (1957; p.245). There is no palynological support for

Fig. 3.1: Pulpit Hill

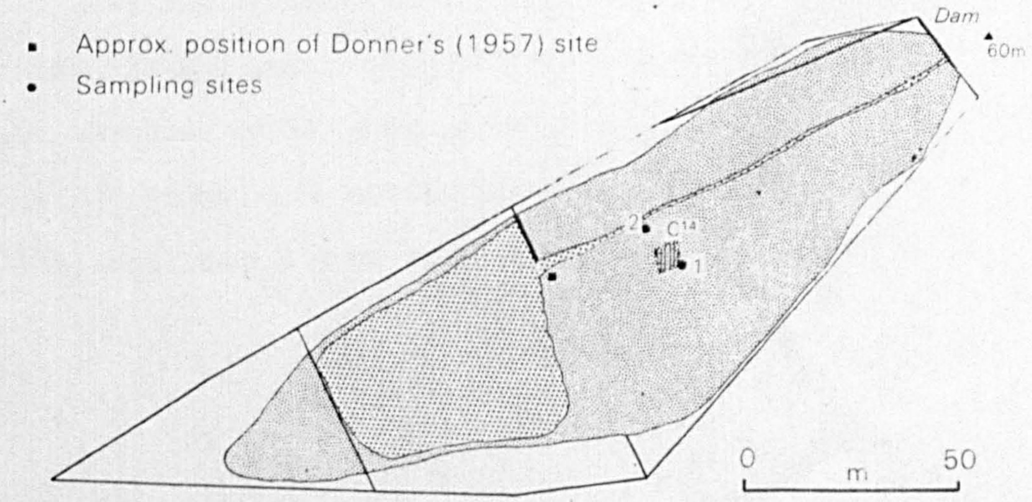
(a) Location



(b) Sub-surface contours



(c) Sampling sites



this, however, and his sampling failed to locate interstadial sediments. There is thus no evidence from his study to consider this as a Lateglacial site (cf. Gray, 1975).

iii Geomorphic Setting

The site lies within the postulated limits of Main Devensian ice (Sissons, 1981), and outside the limits of the Loch Lomond Readvance (Charlesworth, 1955; Donner, 1957; Synge, 1966; Synge and Stephens, 1966; Gray, 1972, 1975). Discussion of the ice-limits inferred by these authors is found in chapter 8.

iv Sampling

The initial sampling site (1 on fig 3.1c) was located in the deepest area of the peat-bog (the upper basin, being underwater, could not be examined) where five of 17 x 50cm Russian cores were used for pollen analysis; the lithostratigraphic correlations (fig 3.2) of cores 13 - 17 proved satisfactory.

With the intention of C14 dating the biostratigraphy, 32 x 60cm chamber piston-cores (fig 3.8a: series A,B,C, 3.9) were obtained in 1981 from the area of the bog marked in fig 3.1c. A second 1.0m Russian core was taken from site 2 (fig 3.1c) with the intention of carrying out pollen concentration analyses, tying these into the diagram constructed from site 1 (fig 3.3b), but the condensed lithostratigraphy (fig 3.5) made this difficult, and the diagrams are presented separately; PH 1 and PH2. This was not simply a duplication of results, but was felt valid in the interpretation of certain features.

v Generalized Lithostratigraphy

The lateral persistence of the major litho-units is demonstrated in the large number of cores sampled (figs 3.2, 3.5, 3.8 and 3.9). The litho-units are described from fig 3.2, and observations are augmented where necessary from other cores, also from the residue on 180μm sieves used in the preparation technique (chap. 2; fig 3.3).

LITHOSTRATIGRAPHIC UNIT A : 720 - 707 cm.

dark gray (2.5 Y 4/0) semi-liquid clay with few stones, mostly slate plus c leaved mudstone, basalt and rare red ssts.; C/N values very low: transitional boundary to

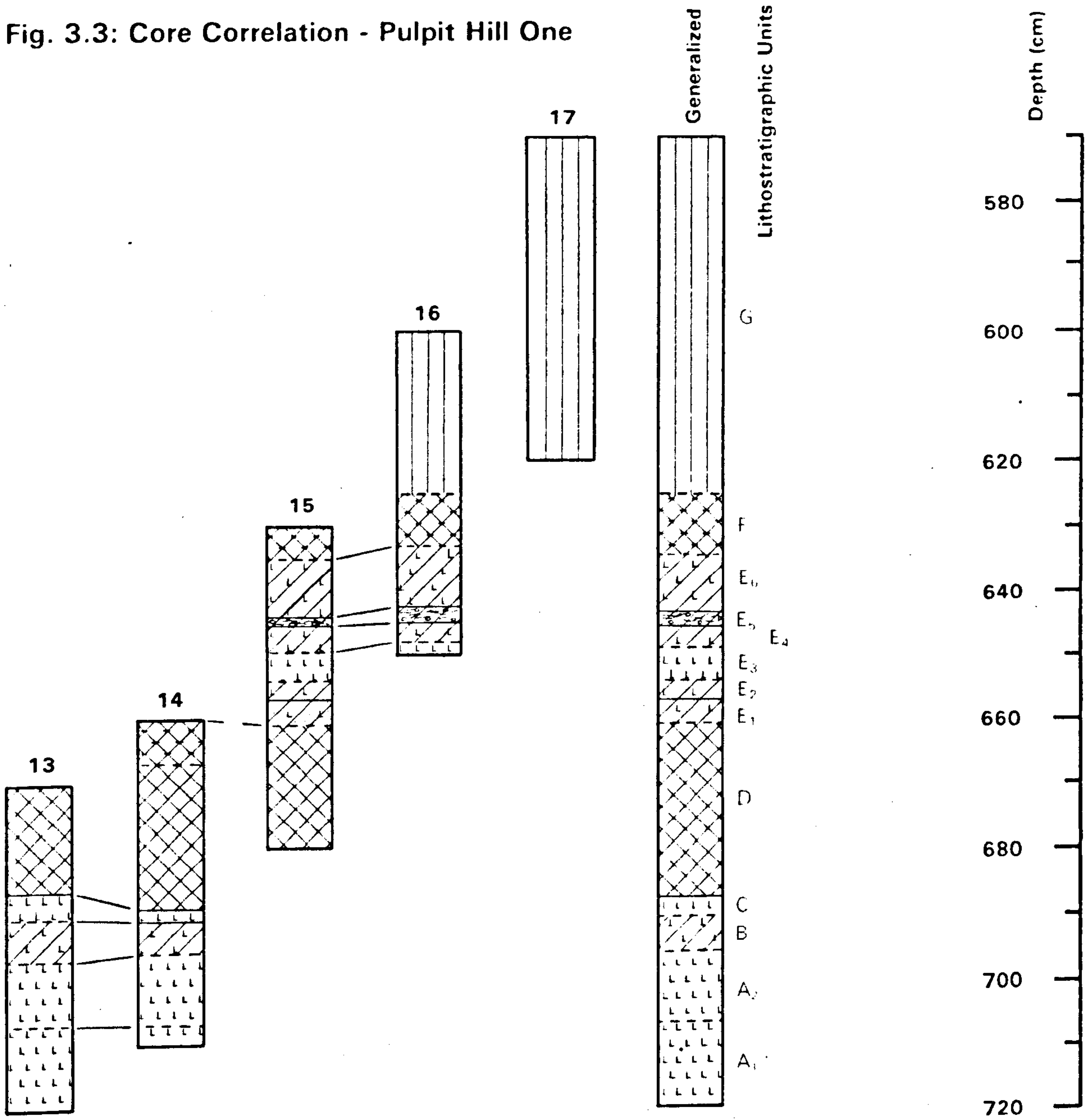
LITHOSTRATIGRAPHIC UNIT A : 707 - 697 cm.

very dark gray (2.57 Y 3/0) stiff pure clay, subrounded igneous plutonic pebble retained; C/N values rise, N more markedly: transitional boundary to

LITHOSTRATIGRAPHIC UNIT B : 697 - 691 cm.

very dark gray (2.5 Y 3/0) clay-gyttja, very

Fig. 3.3: Core Correlation - Pulpit Hill One



infrequently laminated, with few stones (as above) and mica flakes, occasional badly deteriorated seed husks, and two stems of very well preserved Rhacomitrium lanuginosum; C/N values rise markedly and decline again within this unit: transitional (generally) boundary to

LITHOSTRATIGRAPHIC UNIT C : 691 - 687.5 cm.

very dark gray (2.5 Y 3/0) silty clay, with low gyttja content; low C/N values : sharp boundary to

LITHOSTRATIGRAPHIC UNIT D : 687.5 - 661 cm.

very dark gray (10 YR 3/1) fine detrital gyttja, low clay content but occasional stones (as above) and mosses R.lanuginosum and at 664 cm several well-preserved stems of Drepanocladus vernicosus: in core 16 the sediment coarsened to include distinct black (5 YR 2.5/1) peaty gyttja; C/N values are high: transitional boundary to

LITHOSTRATIGRAPHIC UNIT E_1 : 661 - 657 cm.

dark olive gray (5 Y 3/2) gyttja/clay with abundant quartz and muscovite grains but few macrofossils; C/N values decline : variable (sharp or transitional) boundary to

LITHOSTRATIGRAPHIC UNIT E_2 : 657 - 654 cm.

very dark gray (2.5 Y 3/0) clay gyttja, moss stems prominent, exclusively Drepanocladus fluitans, usually abundant but poorly preserved and indeterminable seeds: transitional boundary to

LITHOSTRATIGRAPHIC UNIT E_3: 654 - 649 cm.

very dark gray (2.5 Y 3/0) pure clay with few stones but abundant D. fluitans (in many cores this unit is absent or represented by discrete moss bands overlying litho-unit E); C/N values continue to decline: transitional boundary to

LITHOSTRATIGRAPHIC UNIT E_4: 649 - 645.5 cm.

as unit E_2, with well-preserved stems of D. fluitans: C/N values rise; sharp boundary to

LITHOSTRATIGRAPHIC UNIT E_5: 645.5 - 643.5 cm.

very dark gray (2.5 Y 3/0) clay gyttja with abundant, tightly packed moss fragments (D. fluitans only recognized) giving a fibrous, peaty appearance, and abundant rounded to sub-angular quartz pebbles plus muscovite grains; C/N values are pronounced and high in unit. This is the most variable unit in thickness, found as thin moss-rich bands (cores 10, 13, 25, 27; fig 3.8), as thick horizons (cores 14, 22, 23; fig 3.8) or as two separate units seperated by litho-units E_3 or E_4. There is usually a sharp boundary to

LITHOSTRATIGRAPHIC UNIT E_6: 643.5 - 634 cm.

as unit E_2 but more stoney (as above, plus schistose grains, gabbro and olivine-rich dolerites), few macrofossils, poorly preserved and indeterminable mosses, twigs and one Coleopteran fragment: C/N values return to those of litho-unit E_3: transitional boundary to

LITHOSTRATIGRAPHIC UNIT F : 634 - 625 cm.

dark brown (7.5 YR 3/2) coarse detrital gyttja, stoneless, increasingly peaty and less humified upward (proportions of peat to gyttja vary in cores): C/N values rapidly exceed any previously recorded: transitional boundary to

LITHOSTRATIGRAPHIC UNIT G : 625 - 560 cm.

sedge-peat (5 YR 3/3 dark reddish brown turning black (5 YR 2.5/1) on exposure) with abundant but poorly preserved organic residue. Samples seen in fig 3.9a suggest this unit is divisible into a lower, finer sedge-peat and an overlying denser, less humified, sedge-peat (litho-unit G_1): sharp boundary to

LITHOSTRATIGRAPHIC UNIT H : 391 - 382 cm.

(seen only in fig 3.9a)

well preserved, poorly humified fibrous birch-wood layer.

vi Biostratigraphy

Using strictly the concept of local pollen zonation, PH1 and PH2 are described separately before their comparability is assessed.

(A) PULPIT HILL ONE (fig 3.2)

720 - 702 cm : Non-polleniferous.

702 - 683 cm : local p.a.z. PH 1 A

Rumex - Salix - Juniperus - Artemisia

the local p.a. zone has 3 sub-zones, thus:

(a) 702 - 691 cm.

Arboreal pollen equals 5 - 7% T.L.P., with birch exceeding 90% of this, Betula nana not being recorded. Juniperus rises to 6% T.L.P., as does Salix, while Empetrum peaks at 5% T.L.P. at the upper sub-zone boundary.

Gramineae values exceed those of the sedges, and Artemisia, Cruciferae and Galium are well-represented. Filipendula is prominent, up to 4% T.L.P., but dominating all is Rumex, reaching 43% T.L.P. towards the sub-zone boundary.

Aquatics are absent, and spores poorly represented. Deterioration varies little throughout the entire zone.

(b) 691 - 687 cm.

Herb pollen now exceeds 90% T.L.P., reflected in reduced percentages for trees and shrubs; B. nana is recorded in all three spectra. Cyperaceae values are unchanged, although grass representation fluctuates, and the Caryophyllaceae, Chenopodiaceae, Compositae Liguliflorae, Thalictrum, and Crataegus-type taxa are recorded in contiguous spectra for the first time or in increased frequencies. Artemisia in particular reverses a declining trend by expanding to 3 - 4% T.L.P. Other taxa are unchanged.

(c) 687 - 683 cm.

Values for Betula and Juniperus return to those of subzone (a), while Empetrum is more strongly represented at 8% T.L.P. The important herb-taxa of subzone (b) are not recorded, and Artemisia is much reduced. Rumex now begins to decline.

683 - 664 cm : local p.a.z. PH 1 B
Gramineae - Plantago maritima.

N.A.P. totals exceed 80% T.L.P., dominated by the grasses (>40% T.L.P.). With Rumex subdued, the Plantaginaceae are characteristic, with P. maritima (4% T.L.P.), P. undiff. and P. lanceolata present at every level. Galium and Ranunculaceae are equally consistent.

Myriophyllum, Dryopteris and Polypodiaceae rise slightly as do total deterioration values.

664 - 645 cm : local p.a.z. PH 1 C

Cyperaceae - Artemisia

A notable drop in Juniperus and Empetrum, and an increase in Pinus to 8% T.L.P. mark this zone, and N.A.P. values still exceed 80% T.L.P., with the grasses declining to leave Cyperaceae dominant at c. 30% T.L.P. Artemisia expands eventually to 7 - 8% T.L.P., and Cruciferae, Filipendula, Rumex, Chenopodiaceae and Caryophyllaceae re-establish themselves, while Thalictrum and Ranunculaceae undiff. expand, and the saxifrages occur consistently for the first time.

Selaginella and Lycopodium selago become more abundant. Deterioration values change little.

645 - 637 cm : local p.a.z. PH 1 D

Betula - Artemisia

The zone is distinguished by distinctive peaks in Betula, Pinus and Artemisia, the latter also showing a more consistent expansion, as do Thalictrum and Filipendula. Umbelliferae, Plantago major/media and Poterium sanguisorba appear consistently here. Cyperaceae and spore values show a decline from the underlying zone.

637 - 629 cm : local p.a.z. PH 1 E

Gramineae - Ranunculaceae undiff.

Gramineae expand steadily, as do *Epilobium* and Ranunculaceae undiff., and the Plantaginaceae (*P. major/media)* are well-represented, with *Filipendula*. Caryophyllaceae are absent, and *Artemisia*, Cruciferae, Chenopodiaceae and *Thalictrum* decline markedly.

Myriophyllum alterniflorum rises to 60% T.L.P. + aquatics, and Typhaceae are encountered for the first time. Similar but less dramatic increases are seen in *Dryopteris*, Polypodiaceae undiff., *Athyrium filix-femina*, *Polypodium vulgare* and *Thelypteris*-type, plus *Equisetum*.

629 - 620 cm : local p.a.z. PH 1 F

Gramineae - *Empetrum* - *Juniperus*

Although the grasses again dominate, N.A.P. values decline to < 70% T.L.P., with increases in *Empetrum* and *Juniperus*. *Filipendula* expands again, but many herbs are poorly represented or are absent from the counts.

Myriophyllum is still prominent though reduced in numbers of grains, but ferns persist strongly.

620 - 580 cm : local p.a.z. PH 1 G

Betula - Juniperus - Filipendula

the local p.a. zone has two sub-zones, thus:

(a) 620 - 602 cm :

Gramineae declines initially, while Salix rises to 7% T.L.P., and Filipendula is very well-represented. Crucifer values are maintained in this sub-zone, but birch is dominant, and Juniperus important. Taxa outside the pollen sum show reduced percentages.

(b) 602 - 580 cm :

With Betula again dominant ($>$ 60% T.L.P.), the sedges show increases, together with the Saxifragaceae (5% T.L.P.).

580 - 562 cm : local p.a.z. PH 1 H

Coryloid - Betula

The pronounced increase in coryloid grains typifies this zone, but Betula declines only slightly: B. nana is recorded only below 574 cm. Salix persists, but other shrubs are not present in the upper part, although the Ericaceae undiff. are also recorded throughout, with Calluna vulgaris at two levels. A few herbs, Plantago maritima, Filipendula, Rumex and Saxifragaceae are present in reduced percentages.

Menyanthes is noted sporadically in this and the lower zone, and Potamogeton is recognized, at one point 4% T.L.P. + aquatics.

(B) PULPIT HILL TWO (fig 3.5)

655 - 640 cm : Non-polleniferous.

640 - 630 cm : local p.a.z. PH 2 A

Gramineae - Rumex - Compositae

With N.A.P. values at 90% plus, Betula and Pinus dominate the low arboreal component, and Alnus and Tilia are recorded. Salix is the most abundant shrub pollen, but Juniperus expands towards 640 cm.

Of the herbs, Gramineae values exceed all others, though Rumex attains 43% T.L.P. at the top of the zone, rising throughout, and there are high values for Compositae Liguliflorae, Bidens type and Artemisia. Plantago maritima, Chenopodiaceae and Caryophyllaceae are also distinctive.

Myriophyllum alterniflorum rises throughout, and the Polypodiaceae undiff. are the most important spore-producers. Deterioration is uniform at 41 - 42% T.L.P. and indeterminable grains.

630 - 618 cm : local p.a.z PH 2 B

Gramineae - Rumex

This local p.a. zone has three sub-zones, thus:

(a) 630 - 626 cm.

Although Betula nana is recorded consistently, birch percentages decline to 4% T.L.P., but both Juniperus and Empetrum continue to expand, as do the grasses and aquatics and spores. Conversely, many herbs are no longer recorded.

(b) 626 - 622.5 cm.

Betula values are very subdued, as are those of juniper and Empetrum (< 2% T.L.P.), while Salix expands.

Herb changes are seen in the expanding Rumex curve, and reappearance of Caryophyllaceae, Chenopodiaceae, Compositae (Liguliflorae and Artemisia are distinctive), Cruciferae, Crataegus-type and Saxifraga granulata.

Armeria maritima and *Ononis*-type are restricted to this sub-zone, while *Epilobium*, *Galium* and Ranunculaceae are reduced. The aquatics and spores of subzone (a) decline abruptly in percentage terms.

(c) 622.5 - 618 cm.

Empetrum regains its values of subzone (a), although *Juniperus*, *Salix* and *Betula* show only a limited recovery.

The sedges briefly exceed Gramineae percentages, and most herbs continue into this zone, though at declining values (*Artemisia*, *Thalictrum*, *Rumex*). Aquatics and spores show only modest expansions.

618 - 604 cm : local p.a.z. PH 2 C

Gramineae - *Plantago maritima*

Major changes occur in the herbs, with the grasses expanding, as does *Plantago maritima* (12% T.L.P.). *Rumex* is poorly represented, and many herbs are not recorded.

604 - 576 cm : local p.a.z. PH 2 D.

Cyperaceae - *Artemisia* - Chenopodiaceae

this local p.a. zone has two sub-zones, thus:

(a) 604 - 584 cm.

As grass values decline, Cyperaceae are again dominant. Pine and willow increase, but Juniperus and Empetrum are noticeably less common. Chenopodiaceae and Artemisia rise to sustained prominence, but characteristic only of this sub-zone are the crucifers, Helianthemum, Dryas, and to a lesser extent, Thalictrum and Filipendula. Likewise, Polypodiaceae undiff. and Selaginella are abundant only in this sub-zone.

(b) 584 - 576 cm.

Ranunculaceae undiff. are characteristic, and the grasses also expand. Pinus and Salix values decline.

576 - 555 cm : local p.a.z PH 2 E.

Gramineae - Empetrum - Rumex

the local p.a. zone has two sub-zones, thus:

(a) 576 - 568 cm.

The principal taxon is Rumex, which rises as Artemisia, Chenopodiaceae and Ranunculaceae decline sharply. The grasses continue to expand, though little response is seen in tree pollen, or in shrubs except Empetrum towards the upper sub-zone boundary. Myriophyllum alterniflorum rises dramatically at the base of the sub-zone, but declines as abruptly within the sub-zone.

(b) 568 - 555 cm.

Prominent in this subzone are the rising curves for Juniperus, Betula and Salix. With the grasses still prominent at 50% T.L.P., Plantago maritima is characteristic, as are Epilobium and Filipendula.

Myriophyllum once more expands, with similar increases in Dryopteris and Polypodiaceae undiff.

(C) COMPARABILITY OF PH 1 AND PH 2.

The biostratigraphical correlations are shown in fig 3.7. Not all zones can be correlated, and indicator taxa are often different between zones that are correlated. The uppermost two zones of PH 1 are both younger than the top zone at PH 2 (PH 2 E).

It is clear that the majority of zones and subzones can be correlated, and often indicator taxa are comparable. In view of this close correlation it is proposed to discuss the combined information from the two sites in the following section. Prior to this, however, some anomalies between the diagrams need to be discussed briefly. No attempt has been made to compare the diagrams quantitatively using, for instance, the

SLOTSEQ computer program of Birks (1979).

It cannot be expected that taxa represented by single grains or very low percentages will show a close correspondence between cores, and the lack of agreement between p.a. zones PH 1 C/D and PH 2 Da concerning the occurrence of Betula nana may reflect the paucity of this pollen type in the sediments. The close agreement of this grain's distribution in zones PH 1 A and PH 2 B is interesting in view of the element of subjectivity in its recognition (see Appendix), and may show the importance of the dwarf birches at this time.

The major tree, shrub, dwarf shrub and herb taxa all show strong similarities, and trends are consistent. Ranunculaceae and Dryas pollen seem better represented at PH 2, while the reverse is true for Thalictrum, but there is little reason to suggest the shallower site (PH 2), presumably nearer the lake-edge, had pollen depositional mechanisms dissimilar to the centre of the basin in general.

Marked contrasts do exist between the aquatic and spore records, the scale of which is unlikely to be due to statistical artefacts (cf. Davis and Deevey, 1964).

The expansion of ferns and Myriophyllum in zone PH 2 Ba is not seen at PH 1. It is difficult to envisage pollen dispersal mechanisms or, in the case of the aquatic Myriophyllum, distribution within the lake of the plant itself (Spence, 1967) affecting this pattern, the ferns being anemophilous and the water-milfoil increasing in abundance off-shore. This anomaly remains unexplained, but in the discussion (section vii) the sequence at PH 2 is taken as valid for reasons mentioned therein. The synchronous rise of the same three taxa, Myriophyllum, Dryopteris and Polypodiaceae undiff. in zones PH 1 E/PH 2 Eb suggests that the same feature at this depth is not a statistical artefact.

Sediment types are uniform between zones PH 2 Ba and PH 1 Aa, no erosion surface is apparent at PH 1, and other factors, such as deterioration or redeposition, would affect both cores equally. It is unlikely that this period of prominence among aquatics is contained within "non-polleniferous" sediment at PH 1 in view of the lithostratigraphic correlation with PH 2 and the presence of countable spectra at PH 1 in clays apparently earlier in the biostratigraphy.

Despite these problems, the sequences are sufficiently correlatable that interpretations can be made from combining the two diagrams, plus the pollen concentration diagram constructed from PH 2 (fig 3.5).

vii Interpretations

ZONE PH 2 A

As implied in fig 3.7 this basal zone is considered to have no correlative at PH 1 in view of the already high values in *Rumex* and low representation of Compositae at that site.

Total land pollen concentration is very low initially but rises smoothly to 15,000 grains per cm^3 of wet sediment. Few taxa besides *Rumex* and Gramineae respond to this increase, and at the top of the zone *Rumex* exceeds the contribution of the grasses by a factor of 2. This is not reflected in the percentage diagram, clearly an example of over-representation: Markgraf (1980) reports the pollen productivity of grasses as 10 x that of other herbs including *Rumex*, itself a prolific pollen producer. Where impoverished, local grassland pollen productivity can be swamped by regional contributions (Markgraf, 1980), and this might be the situation at the base of this zone, with its low pollen concentrations, but by zone PH 2 B grasslands probably existed around the site.

The more rapid and larger influx of Rumex pollen is interesting in the light of the well-known problems of over-representation associated with the docks. Here the percentage values mirror the concentration increases, contrary to the pattern exhibited by the Gramineae, and given the relative pollen dispersal rates for the two taxa it seems likely that these levels of pollen concentration for Rumex must imply considerable importance of this herb in the local and regional vegetation. From modern population studies concerning the effect of competition on Rumex (Putwain and Harper, 1970) it would seem that R. acetosa is more tolerant of competition than R. acetosella, and although it cannot be concluded on this evidence which species was growing at Pulpit Hill, it seems very likely that the genus was thriving on bare ground, not within grassland communities.

Pennington (1977 b) describes modern surface samples registering high percentages of Rumex comparable with those at Pulpit Hill, from "pioneer" communities rich in Rumex acetosa and Oxyria digyna. There must, however, be some uncertainty over the relevance of this observation to the initial immigration sequence in view of the relative maturity of the substrate she investigated, it having been exposed for "the last two centuries" (Pennington, 1977b; p.129), and the absence of both Lycopodium selago and Salix herbacea in her vegetational analyses (Pennington, 1977b), both indicator taxa of the earliest pollen assemblages in northern Scotland (Pennington, 1977a). Rumex' expansion is seen to follow the appearance of typical pioneer plants such as Chenopodiaceae, Epilobium (Persson, 1964; Matthews, 1978) and Artemisia, but occurs with the rise of plants able to withstand increased competition from the grasses, e.g., Cruciferae, Compositae Tubuliflorae, Galium-type, Plantago maritima, Filipendula and Urtica-type. Bare areas persisted, however, and the grassland must have remained very open if the high Rumex concentration values reflect the dominance of the plant. Savile (1972) describes a relationship between Taraxacum (Comp. Lig.) and Oxyria (Rumex) on light, well-drained arctic soils which warm up rapidly in the spring, and this may be reflected in part of this zone. Pennington (1980) reports that in Greenland Taraxacum is apomictic and absent from the pollen rain, though it is known to be a high pollen producer at the present day in Scotland (Birks, 1973).

It is possible that its abundance at this stage at Pulpit Hill reflects some form of ecotypic differentiation controlled by ameliorating climate.

The low pollen concentration values of Betula and Juniperus do not suggest local growth. Likewise, the values for Empetrum can be similarly interpreted, although it is not usually considered of non-local origin in pollen diagrams. Salix, on the other hand, rises more conspicuously within this zone, and Fredskild (1973) states "it can only exceptionally be capable of long-distance dispersal" (p.83), having sticky grains which often clump together. In addition, Pennington (1980) reports influx of Salix pollen to lakes to be only half that of terrestrial polsters, suggesting under-representation in aquatic environments.

Two pollen types of Salix were distinguished in the counts, but lack of type slides meant identification to below generic level was impossible. Reference to Andrew (1980) suggested that one type (with typically a coarse reticulum and muri as thick as the lumina), could be S. herbacea, but this remains unclear. This species is recorded in macrofossil form from Garral Hill (Donner, 1957), Ireland (Jessen, 1949) and in the study area at

Lochgilphead (fig 1.3), from the marine Clyde Beds (Dickson, 1977). More than one type is recorded at Pulpit Hill. Jessen (1949) proposes S. cf. phyllicifolia to have been important in Ireland. Iversen (1954) suggests S. polaris and S. reticulata were also important, but their alkaline preferences contrast with that of S. herbacea (Kirk and Godwin, 1963). It is unlikely that tall-shrub willows were present in this basal zone. A role in the open-ground Rumex communities seems likely, as Viereck (1966) notes that increases in the ground cover of Elymus (Gramineae) inhibits Salix growth. The peak in Salix concentration in zone PH 2 A occurs immediately prior to the major expansion of the Gramineae.

Such open vegetation would not have inhibited solifluction. The carbon content of these sediments is very low, and the C:N ratio is the lowest in the lithostratigraphy (fig 3.3). Mackereth (1966) published curves from Esthwaite and Buttermere with very similar characteristics to Pulpit Hill in their high N contents at the base of the profiles, to which he attributed the release of ammonium ($NH^{+}4$) from the clays. This may be the case at Pulpit Hill also, despite the low occurrence of nitrogen in most rocks (Raleigh, 1939), and rainwater probably adds a proportion also.

Stable vegetation systems retain nutrients more efficiently than disturbed types, and the C:N ratio possibly reflects the inherent stability of the vegetation at any one time. Following nitrification, (the dominant pedological process where C:N ratios are <10: Bolt and Bruggenwert, 1978), and the conversion of ammonium to nitrate (via nitrite), the nitrate ions are more easily leached than in other forms, but will be easily assimilated given sufficient biomass. The varying proportions of carbon and nitrogen can thus be viewed as measures of plant abundance. Values for nitrogen of 0.1 - 0.2% are typical of moderately fertile loams (Townsend, 1973), so that the potential to support a considerable biomass is clear, as indicated by the developing grasslands.

ZONES PH 1 A / PH 2 B

The change to organic sediments at the zone boundary, with increasing carbon and nitrogen curves, probably reflects rapidly colonizing vegetation in the catchment. The still rising nitrogen curve probably indicates a change to organically bound forms. Mackereth (1966) describes how the C:N ratio in organic sediments mirrors those for agricultural soils (8.5 - 11.4), representing the stable end-product of humification (Bolt and Bruggenwert, 1978). This would seem to allow certain inferences to be drawn on the rate of soil development.

The C:N ratio in agricultural soils (c.10) is determined principally by the conversion of carbon to CO_2 or by its incorporation into the biomass, so that in well-mixed soils a steady state in chemical processes exists. This ratio is attained very rapidly in this pollen assemblage zone. In arctic soils (chernozems) leaching is limited (Limbrey, 1975) and precipitation is lost in evaporation. Under alpine soils (brunizems) leaching is prominent and conversion of plant matter to humus complete (Rietzer, 1974), so that the inferred pedological changes at Pulpit Hill at this time can be seen to represent a change from arctic to alpine conditions, and some form of climatic amelioration.

Such inferences depend on the chemical components analysed being derived from terrestrial soils. Given the high numbers of Myriophyllum grains part at least of the gyttja must derive from the lake itself, but at many lake-basins sedimentological (Holmes, 1968) and geochemical (Mackereth, 1966; Pennington and Lishman, 1971; Cranwell, 1974) analyses suggest a predominant terrestric input. Towards the top of subzone a *Juniperus* and *Empetrum* expand slightly. Berglund and Malmer (1971) describe *Empetrum* as developing when soil humus accumulates.

Andrew (1980) defines two broad types of *Ranunculus*, on whether the verrucae have ringed dimorphic columellae, or are unringed. The type recognized at Pulpit Hill was exclusively unringed, a type which includes *R. fluitans*, *R. trichophyllos*, *R. aquatilis*, *R. peltatus*, *R. bandottii*, *R. tripartitum* and *R. hederaceous*, in short, all aquatic species, plus spp. of *Anemone*, of which *A. nemorosa*, the only native, is not likely at this time, its habit being within deciduous woodland (Clapham *et. al.*, 1962). It seems likely, therefore, that the *Ranunculus* is of aquatic type, and has no role in the developing grassland communities (cf. Appendix One).

This increase in Ranunculaceae is not seen at PH 1, and it might be that the shallow-water habit of aquatic buttercups implies pollen deposition very close to the shore, i.e. at PH 2. *Galium* shows a similar pattern, and the pollen may relate to *G. palustre*, a shallow-water/

fen plant. Such suggestions would mean that sediment movement in lakes is not as uniform as Davis (1973) and Lehman (1975) have argued, but from the remains of mosses, minerogenic material and woody fragments in the gyttja it may be that slope-wash and basin-edge collapsed material contained entrapped pollen of these fen plants, and their concentration at PH 2 is not typical.

Clear climatic indicators are few. Pennington (1975) describes Myriophyllum alterniflorum as "comparatively warmth-demanding" (p.162), but Berglund (1966) considers its increased growth in Scandinavian lakes to be the result of lack of competition: certainly aquatic pollen is sparse until this point. The water-milfoil's expansion at the onset of organic sedimentation might suggest that nutrient supply was a further consideration. Although found in nutrient-poor waters (Spence, 1967) it can be expected to grow more vigorously when nutrient levels are high.

Dryopteris may be associated with the willow scrub communities, as McVean and Ratcliffe (1962) relate their Salix lapponum - Luzula sylvatica nodum to a Dryopteris-rich community in Norway (Nordhagen, in McVean and

Ratcliffe, 1962), also related to Dahl's (1956) Rumiceto - Salicetum lapponae sociation (Rumex-rich willow scrub) described as comprising "tall herb and broad leaved grass meadows of the Low-alpine and Sub-alpine zones. Willow and birch scrub with tall herb components and fern meadows are included", (McVean and Ratcliffe, 1962; p.140). This is probably an apt description of the vegetation at this period, with the plantains and Thalictrum being typical of neutral-to-alkaline grasslands, and open-ground taxa, Chenopodiaceae and Compositae Liguliflorae declining.

The biostratigraphically defined boundary between subzones a and b lies close to but prior to the change to litho-unit C. In addition, carbon and nitrogen changes are seen to be independent of sedimentological variation, declining in subzone a.

In both diagrams in subzone b the herbaceous elements expand at the expense of woody plants, Juniperus and Empetrum. Salix remains well-represented. Betula suffers significant reduction, but all three spectra from subzone PH 1 Ab show Betula nana, probably growing around the site. This close correlation is not seen at PH 2, however.

The expanding pollen-types are the open or disturbed ground plants such as Armeria maritima, recorded for the first time, Potentilla-type (PH 2), Caryophyllaceae, Cruciferae and Crataegus-type (only taxa represented in more than one level are mentioned). Taxa seen to expand from their subzone a values include Artemisia, Chenopodiaceae and Rumex (PH 2). The aquatics and spore-producing plants all decline, and the fen-communities containing Ranunculus and Galium appear to have been markedly affected. Gramineae concentration values decline in this zone.

There are several alternative explanations for this trend:

(a) variations in pollen curves can be induced by statistical artefacts, or alternatively, in the closer sampling of this interval one is identifying natural fluctuations in the pollen production of plants under environmental and competitive stresses.

These suggestions cannot explain the chemical and sedimentological changes apparent at this time, nor the seemingly ecological distinctiveness of the expansion in bare-ground taxa. These changes are recorded at two sites within the same basin, in samples counted to a consistently high pollen sum, with pollen concentration techniques endorsing the percentage results. It seems clear that the palynological changes are significant.

(b) basin-edge collapse of sediment can account for changes in litho- and biostratigraphy.

Basin-edge collapse is generally sudden, with the clay being deposited <u>en masse</u>. Although contacts between litho-units are occasionally sharp (cores 1, 2, 3, 19; fig 3.8) the majority of cores (71%) show transitional boundaries. From such rapidly deposited clay pollen concentration values might be expected to remain constant, being derived from the same source and having been well-mixed before settling on the basin floor. Yet Chenopodiaceae and <u>Rumex</u> in particular show variations through the clay band (fig 3.6). One can instead infer that vegetational changes occurred during deposition of the clay, in turn implying a slow rate of sedimentation.

Reworked pollen commonly has a different pattern of deterioration to contemporaneously deposited pollen, in corrosion, for instance (Birks, 1970). No firm conclusions from the remarkably uniform deterioration curves (fig 3.3a; 3.5) can be made. Such additions to the pollen rain might be expected to increase the T.L P. concentration, but the mean values drop, although these are obviously dependent on sedimentation rates. The principal difficulty with this suggestion lies in its inability to account for the declining values for carbon and nitrogen prior to the sedimentological change.

(c) climatic deterioration is reflected in the palynological and physical changes.

Taking the chemical evidence first, the declining curves can perhaps most easily be interpreted as reflecting a period of reduced organic matter production in the catchment soils. That the change is gradual is seen in the unchanging C:N ratio, implying a period of pedological adjustment to the new, lower levels of organic productivity. Decreasing amounts of organic matter would eventually lead to the deposition of minerogenic material.

Biotic changes are few when the chemical effects are first noted in subzone a. It could be argued that existing assemblages would be maintained initially, so that a time-lag occurred between the initiation of climatic deterioration and vegetational response .

These effects are not dramatic, and the revertence to pioneer communities was by no means complete, with the Plantaginaceae, Bidens-type Compositae, Thalictrum and Filipendula, and concentration values for Gramineae, at levels close to those in the latter half of zone PH 2 A, suggesting that expanses of open grassland with willow scrub were maintained.

The temporary nature of the revertence is seen by the rising carbon and nitrogen values before the end of clay sedimentation, the resumption of gyttja sedimentation, and palynological changes in subzone c. Lithostratigraphical boundaries are again usually transitional.

In subzone c a return to the Rumex - Taraxacum open-ground, shade intolerant communities of zone PH 2 A, with the persistence of many open-ground taxa from subzone b is indicated, and Gramineae values do not rise until the overlying zone. The vegetational succession is seen to recommence, and the rapid establishment of areas of Empetrum may mean that the soils still contained some acid humus, and did not become entirely lithomorphic, perhaps indicated by the carbon and nitrogen values being higher in subzone b than in zone PH 2 A, and the C:N ratio of c.8 suggesting moderate fertility. The response of Juniperus is less clear-cut, being distinctive (7 - 9% T.L.P.) at PH 1, but not seen at PH 2, although one concentration spectrum shows values approaching the maximum production of subzone a (fig 3.6). Total land pollen concentration is much higher than in zone PH 2 A. Without influx data comparisons are difficult, but it seems reasonable to propose that although qualitatively the vegetational assemblages equate with those of zone PH 2 A/subzone PH 1 Aa: PH 2 Ba, the biomass was considerably more abundant.

Watts (1970) described several tests to be applied in establishing an oscillation as being primarily climatic in origin. He proposed that at any one site;

> "the sediments which define the oscillation must contain a pollen flora studied to a good modern standard which is clearly distinct from the pollen flora contained in the underlying and overlying sediments." (p.144).

This point is believed supported by the selective increases in characteristic open-ground and pioneer taxa at the expense of newly-established shrub, dwarf-shrub and grassland communities, and by the re-establishment of these assemblages in subzone C and zone PH 1 B/PH 2 C.

"Distinctive single pollen spectra do not provide a sufficient basis for a firm identification of an oscillation." (p.144).

At Pulpit Hill two separate pollen sequences are zoned independently and each counted to a statistically significant pollen sum. Each subzone contains more than one spectrum, and in addition the above discussion deliberately excludes taxa present in single spectra.

"clear evidence of climatic reversion is essential. 'Revertence' is what distinguishes an oscillation from a long slowly developing plant succession." (p.144).

The establishment of grassland with Juniperus and Empetrum heath in subzone a is in successional terms an advance on the pioneer and open grassland assemblages of subzone b (Cooper, 1939; Persson, 1964; Viereck, 1966), so that the sequence is best described as a vegetational revertence.

The pollen evidence is strengthened when "associated with distinctive sediments and/or macrofossils which may reflect a physical change on the upland." (p.144).

The clay band (litho-unit C) is considered indicative of increasing soil impoverishment, and additional evidence comes from the chemical analyses.

> "Ideally, the beginning and end of the oscillation are dated by radiocarbon." (p.144).

This last point is not critical, but is obviously important in correlation (see sections 3.4; 3.5B).

The exact nature of the postulated climatic fluctuation is uncertain. Its effect is noted in both terrestrial and aquatic ecosystems. It is doubtful if increased rainfall would reduce the fen-communities by affecting regional water-tables, while a reduction in precipitation might explain the patterns. Yet the only limited extent of the Lateglacial lake at Pulpit Hill has been mentioned (section 3.2i), and it is to be expected that a lowering of the water level would introduce coarser sediment to the basin. PH 2 is critical in this, being the shallower site, and here the sediments of litho-unit C are fine clays. Declining temperatures could also generate the necessary vegetational revertence, but little evidence is available to define thermal fluctuations at this time. It is felt, however, that the site was not subject to the same harshness of climate apparent in zones PH 1 C, D/PH 2 D,E (see later).

ZONES PH 1 B / PH 2 C

The succession continues with the establishment and dominance of closed-turf grasslands and secondary Empetrum-heath. Trees and other shrubs are not thought present around the site. Betula has low percentage and concentration values, the latter well below the 8 - 10,000 grains per cm^3 Pennington (1977a) considered indicative of local growth. The concentration values of Juniperus do not suggest local growth when compared to its major expansion in zone PH 2 Eb, unless it existed in the dwarf form with much reduced pollen productivity (Iversen, 1954; Birks, 1973). The persistence of willows until this zone could have been encouraged by the suggested climatic reversion in subzones PH 1 Ab/PH 2 Bb, and with the expansion of grasses the Salix shrubs might not have survived (Viereck, 1966). The concentration values for Empetrum suggest that, despite falling percentages, once established crowberry sustains itself quite successfully. Ericaceae grains are only intermittently recorded at PH 1, but occur at the base of zone PH 2 C, rising through the underlying subzone. The species could not be determined, but heath of this kind requires acid soils with, generally, a high humus content. In this zone the C:N ratio rises to 10, the optimum for organic matter breakdown by saprophytic bacteria (Bolt and Bruggenwert, 1978).

The closure of the grasslands was not complete, although the competition - intolerant docks and sorrels decline. The Plantaginaceae are most common on bare or disturbed (i.e., trampled) ground, and Sagar and Harper (1960) suggest that establishment and regeneration of P. major, P. media and P. lanceolata does not occur in tall or closed grasslands, and their presence is thought indicative of open grasslands. All three species avoid acid ericaceous heaths, P. lanceolata being scarce on soils below pH 4.5 (Grime and Lloyd, 1973). The pollen of P. lanceolata is common when the plant itself is not (Birks, 1973), but its persistence in the pollen counts with other plantains is taken as implying local growth. Plantago media is a sub-arctic climatic indicator (Iversen, 1954), and Sagar and Harper (1960) provide quantitative data in defining successful germination only above $20^{o}C$, $25^{o}C$ for P. major.

The most important plantain at Pulpit Hill, P. maritima, is undoubtedly present in the vegetation, Markgraf (1980) reporting high values only when the plant is growing on site. The Umbelliferae, also open-grassland plants, are also thought to be local as Hagerup (1951) has reported only restricted pollen dispersal.

Problems of specific determination or ecological variability limit the significance of other taxa. Filipendula is found with Rumex (acetosa), Compositae (Anthemis type) and Valeriana in the Dwarf Herb nodum of McVean and Ratcliffe (1962), but also with Galium, Epilobium, Carex (Cyperaceae), Drepanocladus and Sphagnum in fen communities (Birks, 1972). Drepanocladus vernicosus, to which species a poorly-preserved stem was keyed, is reported from the Lateglacial deposits at Colney Heath, and is common in sub-alpine bogs, avoiding the highest latitudes (Dickson, 1973), and a fen or small eutrophic valley-bog may have been established. The aquatics are seen not to recover from the climatic deterioration of the preceding zone.

Although total pollen concentration increases distinctly, without influx data the high value, 54,000 grains per cm^3, is of uncertain significance. The carbon and nitrogen values reach their highest levels so far, however, and it is thought that this zone represents the period of maximum biological productivity prior to local p.a. zones PH 1 F/ PH 2 E. Climatic indicators are again limited and of uncertain value. Empetrum hermaphroditum is restricted to maximum summer temperatures below 23°C (Conolly and Dahl, 1970), but the pollen taxon includes E. nigrum, for which figures are unavailable. Likewise, Thalictrum alpinum has a similar restrictive temperature control, but T. minus grows much further south (Fitter, 1978), and is reported in Lateglacial deposits from limestone-rich areas of Ireland (Watts, 1977). The presence of the plantains and Drepanocladus vernicosus suggest sub-alpine temperatures.

ZONES PH 1 C / PH 2 Da

The carbon and nitrogen values decline above 663 cm , although the C:N ratios remain stable, and this pattern is sustained through the zone. They do not approach the low values seen in subzone PH 1 Ab/PH 2 Bb, due to the continuing supply of organic mud to the sediments of the more minerogenic litho-unit E. The lowest C and N contents appear to coincide with the purest minerogenic layers (litho-unit E_3). The cores in fig 3.8 show that these subdivisions of litho-unit E are not consistent, being occasionally absent or out of sequence, and no major environmental significance is placed on the majority of sedimentological changes in the p.a. zone. Litho-unit E_5 has already been mentioned (section 3.2v), and will be discussed later in this section.

There appears to be no time-lag between chemical and palynological changes here, but the increased minerogenic input in the sediments occurs above the pollen zone boundaries (figs 3.3b; 3.5), and as in litho-unit C it is likely that clay deposition depended on the break-up of the existing plant communities.

Total land pollen concentration is only half that of the underlying zone, and shows little variation despite the changes in lithology, perhaps emphasizing that these are of little importance. As with Juniperus in the preceding zone, Empetrum and ericaceous heath do not appear to be maintained given their sharply declining values, both genera being sensitive to solifluction processes (Dahl, 1956). Pinus values rise significantly, the pollen almost certainly derived from a long-distance source, pine not growing in Scotland at this time (Godwin, 1975). The increases could be due to either a reduction in the sedimentation rate or, more likely, declining pollen influx from local and regional sources. Betula values (concentration) also decline, which is perhaps anomalous if a long-range source is suspected; birch was not thought locally present in zones PH 1 B/PH 2 C. Grains of B. nana are recorded at PH 2 (their absence from PH 1 may be due to the relative inexperience of the analyst at that time), but it is not thought this type contributed all the birch grains. The likeliest explanation is that the extra-regional source of the tree pollen, probably eastern Scotland in zones PH 1 B/PH 2c (see section 3.5c) was diminished in numbers or pollen productivity, or actively retreated from the area.

Gramineae and associated grassland taxa, including the plantains, show percentage losses. The incongruous persistence of the relatively thermophilous Plantago major/media type can be explained by reworking of interstadial soils (see discussion: zone PH 1 D).

Caryophyllaceae are restricted in their pollen dispersal (Birks, 1973) and are common in fell-field communities where competition is low, but Smith (1970a) considers palaeoecological conclusions too dangerous in view of the considerable range of the family. The inconsistent presence of <u>Thalictrum</u>, together with <u>Dryas</u> pollen could indicate a calciphilous low-alpine heath (Kirk and Godwin, 1963). <u>Thalictrum</u> is thought to be under-represented in the pollen record (Pennington, 1980), implying local presence (Davis, 1980), although Rymer (1973) found it well-represented in Iceland. Being basophilous, the taxon grows with <u>Dryas</u> and with the Saxifragaceae, present consistently for the first time in this zone. Limiting summer temperatures are given as lying between 22°C and 24°C for arctic saxifrages (Conolly and Dahl, 1970). <u>Dryas</u> itself is not temperature dependent (Iversen, 1954; Ferreira, 1959; Conolly, 1961), but is chionophobous, unable to resist more than a transient snow-cover (Iversen, 1954). The low representation of <u>Lycopodium selago</u> and <u>Selaginella selaginoides</u>, given their strong dispersal (Birks, 1973), and the absence of <u>Lycopodium alpinum</u>, a good chionophilous indicator, do not encourage postulating extensive snow-patches in the basin. Both of these spore taxa can be found on solifluxial base-rich soils.

With the obvious reduction in competition it might be anticipated that _Rumex_ would expand. The pollen concentration diagram (fig 3.6) shows an unchanging low contribution to the pollen spectra, so that the percentage increases are probably a result of over-representation. Its failure to respond cannot be explained by edaphic preferences (basiphilous conditions), while temperature sensitivity is of uncertain value, the data of Conolly and Dahl (1970) relating to _Oxyria digyna_. _Rumex_' moisture demands are unknown in any detail, and comments must remain purely conjectural in the absence of ecological information.

It may be suggested that the climate, or at least the micro-climate at Pulpit Hill, became increasingly arid throughout this period. The Chenopodiaceae and _Artemisia_ curves increase in unison towards the end of the zone, best seen at PH 2 (fig 3.5) as PH 1 appears to be affected by anomalous values (discussed later; zone PH 1 D), confirmed by the concentration diagram (fig. 3.6). Statistical artefacts are not thought responsible as the pattern occurs at both sites, and it is not thought differential preservation has produced the pattern given the uniformity of deterioration curves throughout. Increasing bare ground would provide niches for all open-ground taxa, so that the apparently selective increases in these two taxa cannot be explained by edaphic changes, and this selectivity might be climatically significant. A similar relation between Chenopodiaceae (probably C. album or C. rubrum: Godwin, 1975) and Artemisia is noted by Walker (1975b) at Loch Etteridge, while Frenzel (1979) considered the Artemisia - Chenopodinae assemblage as a typical full-glacial development, and more importantly, defined it as a steppe rather than a tundra indicator. Steppe conditions are typified by very cold winters and dry, often warm summers. Organic matter production would be greater here, reflected in the organic sedimentation, than in true tundra,with average temperatures for three summer months of below 6°C (Miller, 1959). Both Chenopodiaceae and Artemisia are associated with very dry soils (Bell, 1969) and are halophytic. Their occurrence together should be stressed, for assertions of continentality of climate for Artemisia alone is undoubtedly an over-simplification (Bell, 1969; Moore, 1980).

Aridity might also be implied by the basophilous plants discussed above. Calcium carbonate accumulates in continental arctic soils where leaching is reduced by the limited precipitation. This would seem a likely pre-requisite at Pulpit Hill given the meagre amounts of calcium in the catchment rock-types (Kynaston _et_. _al_., 1908) and the neutral to slightly acid plantain-rich grasslands of the preceding zone. The nearest limestone bedrock, on the island of Lismore 9 km distant (fig 1.3) is not a likely source for the pollen grains given their limited dispersal abilities.

ZONE PH 1 D

This zone, not seen at PH 2, is characterized by anomalously high levels of _Artemisia_, _Betula_ and _Pinus_ (fig 3.3). The high values for these taxa at 644 and 640 cm are not considered environmentally significant, being bounded and separated (642 cm) by spectra comparable to zone PH 1 C, but are believed to be a product of contamination of the contemporaneous pollen rain by inwash from the catchment containing reworked or secondary pollen.

To an extent, all pollen spectra from catchment-derived minerogenic sediment probably contain an element of reworking, but usually this cannot be detected because the effects induced are not so large as to be distinctive, or because the reworking appears as a consistent background to more usual pollen depositional processes.

Lithostratigraphic unit E_5 coincides with the pollen spectrum at 644 cm. No similar band occurs at 640 cm. In other cores two moss-horizons are seen (section 3.2v), and sporadic basin-edge collapse is inferred for both anomalous pollen spectra, despite sedimentological evidence for only one. The large numbers of pebbles, poorly sorted nature of the deposit and the well-structured moss-mat of Drepanocladus fluitans, a terrestric fen species (see below) indicates that a break-up of lake-edge fen communities and sediments occurred, with redeposition as an essentially undisturbed mass. This raises the question as to the frequency of this type of catastrophic sedimentation in the basin. This litho-unit occurs as two horizons, at most, in all cores (fig 3.8), but the absence of mosses and stones at 640 cm where the palynological evidence is strongly suggestive of this form of sedimentation (see below), and the scattered finds of D. fluitans throughout litho-units E_2 - E_5 (section 3.2v) might suggest these events are "disguised" by the soliflucted clays, which in turn leads to the questioning of the validity of the pollen spectra. This is a very difficult and almost intangible problem, in which pollen deterioration studies (chap. 7) can aid greatly, but at Pulpit Hill the peculiar "complacency" of the deterioration curves provides no assistance (section 7.7).

The small (5% T.L.P.) increases in crumpled and split grains at 644 cm, and the increases in split grains at 640 cm can be attributed almost exclusively to Pinus (section 7.7).

At Loch Fada, Birks (1970) recognized inwashing of a moss-band on three counts, the state of preservation of the pollen, the macro- and micro-fossil content, and lithological changes. Deterioration was dominated by high levels of corroded pollen, not seen at Pulpit Hill, and Birks (1970) felt able to regard the moss-band as derived from a localized montane-spring community: such precision is not possible here. On the other hand, the pollen spectra were not so clearly anomalous at Loch Fada, and over-representation by a few taxa not nearly so noticeable.

At Pulpit Hill a tentative approach to determining the scale of contamination can be made from fig 3.2. *Pinus* is exclusively long-distance transported by wind (see above). Assuming constant sedimentation rates the influx of pine pollen should also remain constant, such that the mean value of *Pinus* for zones PH 1 B, C, E, and F (excluding 646 cm, adjacent to zone PH 1 D) is fairly uniform at 1.80% T.L.P. (+/- 1.09; n = 29). The anomalous spectra (646 cm = 8%; 644 cm = 7%; 640 cm = 8% T.L.P.) have 2.8 times the contemporaneous "fall-out", presumably equated with the scale of the reworking. This figure is certainly only an approximation, and calculations based on percentage data can be questioned, but similar values are produced for *Betula*, e.g., 2.2 times over-representation (for zones PH 1 B, C and E; n = 15; $\bar{x}$ = 5.5% +/- 1.7% T.L.P.) in spectra 646, 644 and 640 cm.

Artemisia peaks occur in the intervening levels, and the values at 646, 644 and 640 cm are suspected to be depressed statistically by the tree pollen. Whether the high values of *Artemisia* are themselves partly a product of reworking cannot be determined, but at PH 2, where evidence for contamination is absent, due, possibly, to fortuitous sampling and avoidance of moss-bands, *Artemisia* reaches 25% T.L.P., with very high concentration values of 4,500 grains per cm^3 (fig 3.6).

Successful dispersal of these tree-species means that even as long-distance components their pollen concentration values may exceed those of the local components, including Gramineae. A two-fold increase in numbers due to reworking is not so distinctly recognized in local taxa which, because of their poor pollen production and/or dispersal, are only ever recorded at 1% T.L.P. or less. If litho-unit E_5 is derived from fen communities, this niche would perhaps not be expected to contain pollen of the only locally-dispersed Chenopodiaceae and Artemisia, while the tree pollen would fall on all areas of the catchment, and its proportions selectively increased.

Topogenous fens at a time of high aridity might be thought contrary to expectation, and although the mosses themselves might be reworked, there is no evidence from the sediments that a lake ceased to exist at any time in the Lateglacial. The marked decline in concentration values for the Cyperaceae perhaps signifies a reduction in fen communities. Brown (1977) records an increase in Filipendula in Loch Lomond Stadial sediments at Hawks Tor, and he makes the point that increased solifluction will enrich drainage waters in nutrients, producing a relative flush of mire plants at a time of general low plant productivity.

Filipendula ulmaria is a common marsh-dweller, but F. vulgaris is indicative of steppe conditions and dry soils (Bell, 1969), with Helianthemum, which is recorded continuously at low values at PH 2.

ZONES PH 1 E / PH 2 Db

The slightly increasing T.L.P. concentration values, coinciding with a decline in far-travelled birch and pine concentration, suggests that these are not due to reductions in the sedimentation rate, and may indicate the end of the climatic deterioration of zones PH 1 C and D / PH 2 Da. The appearance of sediment related to litho-unit E_5 at PH 2 at this time is thought not to indicate synchroneity with the same litho-unit at PH 1, but that basin-edge collapse occurred on several separate occasions. Terrestrial taxa change little, with Artemisia and Chenopodiaceae still important, though declining at the end of the zone, whereupon the grasses and Rumex expand.

Ranunculaceae exceed all herb taxa except Gramineae in pollen concentration terms. Again the pollen type is thought to represent aquatic buttercups. R. lingua is associated with Typha latifolia in shallow-water communities, or above the water table with Phragmites. R. flammula is found in deeper water with Myriophyllum alterniflorum and Potamogeton natans (Spence, 1964), and both are known from Lateglacial sediments (Godwin, 1975).

At PH 1 a pronounced rise in Myriophyllum alterniflorum is noted, with Myriophyllum undiff., principally M. spicatum, and in Typhaceae undiff. Similar increases are seen in the ferns and Equisetum. Such an assemblage does not allow closer definition of the buttercups involved, but clearly resembles the development of fern meadows at zone PH 2Ba.

Virtually nothing is seen of this expansion at PH 2, the increases in aquatics and spores occurring in the overlying zone PH 2 Eb, with the juniper expansion. The apparent time-lag between cores does not appear great, Juniperus rising at PH 1 in zone F, and it seems a more detailed sequence is seen at PH 2, 16 cm of sediment (PH 2) compared to 8 cm (PH 1) for, presumably, the same time-span. This pattern of more rapid sedimentation at the near-shore site is not consistently demonstrated, but such examples might suggest that in a small basin such as Pulpit Hill, with restricted wind-generated wave disturbance, sediment focusing (Lehman, 1975) may not be operative to any great extent.

The Typhaceae and *Equisetum* would appear to be related to topogenous fens similar to but more extensive and/or more productive than in the underlying zone, associated with *Epilobium* (*E. palustre*?) and *Galium*-type (*G. palustre*?). Alternatively, *Galium hercynicum* is a constant in McVean and Ratcliffe's (1962) *Cryptogrammeta - Athyrietum* chionophilum nodum. Although the major elements, *Cryptogramma* and *Athyrium alpestre* are not recorded, and inferences about the presence of snow beds are accordingly uncertain, this nodum is closely related to an association in Norway with *Thelypteris* spp. and *Dryopteris* spp., common in areas of highest precipitation (Knaben in McVean and Ratcliffe, 1962). The ecological affinities of *Athyrium filix - femina* are uncertain, being distinctive of woodland or scrub (McVean and Ratcliffe, 1962).

This suggested change to damper, more oceanic climatic conditions appears to herald a more general climatic improvement, seen distinctly in the chemical analyses rising through zone PH 1 E from 4.5% carbon (0.5% nitrogen) to 22.4% (2.08%). Little of this improvement is as yet seen in terrestrial taxa. Aquatic eco-systems are known to show an earlier response to ameliorating temperature (Iversen, 1954; Webb, 1977), and this seems to be the case here.

ZONE PH 2 Ea

A phase of vegetational development not clearly distinguished at PH 1, due to the comparatively condensed lithostratigraphy there occurs at PH 2 where changes are few, but many bare-ground taxa die out, and Rumex rises in both relative and concentration terms. This increase coincides with the inferred change to oceanic conditions, and may imply some form of climatic control. The Compositae Liguliflorae curve rises briefly, again illustrating the close relationship of these two pollen-types.

A climatic amelioration, with the vegetation closely following a course shown in the earlier pollen zones PH 2 A and PH 1 Ac/PH 2 Bc, can be recognized, and a change to organic clay (lithostratigraphic unit F) endorses the proposal of climatic improvement.

ZONES PH 1 F / PH 2 Eb

The highest pollen concentration values are attained in the basal level of this zone. Betula expands markedly, although the value of 9,000 grains per cm^3 (fig 3.6) still does not equate with local growth according to Pennington (1977a). The increase in Pinus at a time of high local pollen input could indicate the approach of pine stands near Scotland, though pine is not believed growing in the country at this time (Moar, 1969a).

The modest rise in Empetrum and Ericaceae at a time of increasing pollen concentration is likely to signify the establishment once more of ericaceous heath. Whether sufficiently acidic soils were present, perhaps on the O.R.S. sandstones, or whether rapid leaching of the base-rich soils formed in the arid conditions of zones PH 1 C - D/PH 2 D was necessary for this is not known.

Very rapid increases in the pollen concentration of Gramineae signifies its prominence in the vegetation, but the continued records of pioneer herbs implies areas of bare ground still, although once again Rumex declines, and in the overlying zone PH 1 G disturbed ground taxa are, by and large, absent from the pollen counts.

The principal taxon in this zone is Juniperus, at levels exceeding 6,000 grains per cm^3. Juniper avoids damp and prefers basophilous soils, but edaphic conditions are not limiting (Gilbert, 1980), micro-climatic factors such as shelter being more important. Juniper can establish itself "to an appreciable extent in short turf" (Miles and Kinnaird, 1979; p.110) and has a distinct advantage over birch in being able to germinate in tall grasslands. Seedling dispersal is restricted to areas near the parent plant. Birks and Matthewes (1978) have suggested survival of Juniperus through the stadial, and temperature restrictions on regeneration are unimportant (Miles and Kinnaird, 1979). The dwarf-form, J. communis nana, has very low pollen productivity, and may be significantly under-represented in pollen diagrams, but the dramatic expansion of Juniperus in the early post-glacial is commonly thought to be due to the change from dwarf to erect shrub form (Iversen, 1954; Birks, 1973; Prentice, 1978; Markgraf, 1980).

The reason for this change is not widely discussed. *Juniperus* appears not to be thermophilous. No climatic inferences are proposed by McVean and Ratcliffe (1962) from their analyses. Iversen (1954) relates its growth to conditions whereby juniper could extend its branches above the protective ground-layer or snow-cover without injury, implying, as Gilbert (1980) has, that exposure is the controlling factor in *Juniperus*' development (see chap. 4).

ZONE PH 1 G

The change to fen peat immediately prior to this pollen zone indicates the probable cover of the pollen sites by fen-swamp communities. The high values for *Filipendula* are probably a result principally of this cover. Carbon and nitrogen analyses were not performed above 624 cm because these would no longer reflect changes in the terrestrial soils around the basin.

The percentage increases in *Betula* to 35 - 45% T.L.P. are taken to indicate the plants' local presence in the absence of concentration values. Although *B. nana*-type pollen is reported from most spectra it is thought that tree-birch is chiefly responsible for these increases. Some doubts as to the successful separation of these pollen types may be suspected from the common hybridization of species (Burrows, 1974; Beckett, 1981). A mature soil is likely for Betula regeneration (McVean and Ratcliffe, 1962; Birks and Matthewes, 1978) and Persson (1964) suggests that nitrogen enrichment by mycorrhizal activity is necessary. High nitrate release is suggested by McVean and Ratcliffe (1962) to be characteristic of juniper scrub, and this might be indicated by the frequent occurrence of Urtica-type pollen (Florin, 1979).

If the suggestion of Faegri and Iversen (1975) that the A.P./N.A.P. ratio is a valid measure of the canopy cover of woodlands, then it appears that birch trees did not monopolize the landscape at any time depicted in the pollen diagram. This view is supported by consistent values for Juniperus, and a barely significant drop in values for Empetrum, which suggests that communities featuring these plants persisted with little competition from birch. Although Gramineae percentages decline it is clear from the rise in Plantaginaceae that a neutral to slightly acid grassland continued to develop, while the presence of taxa such as Cruciferae and Artemisia show persistence on the steeper, drier slopes around the basin.

ZONE PH 1 H

The very low and infrequent records of coryloid grains in zones preceding zone PH 1 G are regarded as the result of long-range dispersal. The appearance of small numbers of these grains, and of *Ulmus* and *Quercus* is interpreted as being the result of long-range transport rather than contamination in their appearance in periods of low pollen concentration (PH 1 Ab: PH 1 C/D). Above zone PH 1 F the coryloid grains probably indicate the immigration of hazel. Although the grains of *Corylus* and *Myrica* could not be consistently distinguished (see Appendix), the pollen of *Myrica* is poorly dispersed (Davis, 1980), and the writer considers that *Corylus* is the most reasonable contributor.

With the probable arrival of hazel into the area most taxa decline in value, probably as a result of statistical suppression by the over-represented hazel (Markgraf, 1980).

It is very difficult to conclude anything about the areal cover of _Corylus_ from relative data. Firstly, it is generally felt that high percentages are not from under-storey shrubs but from canopy components (Godwin, 1975). Not only is the pollen over-represented, but the effects of deterioration have to be borne in mind. Havinga (1967) regarded this genus to be the most susceptible of those tested to perforation-type corrosion (see chap 7). _Corylus_ accounts for most of the increases in this form of deterioration in this zone. It is likely in view of the continuing high percentages of birch that these taxa were co-dominants on the better-drained soils of the area.

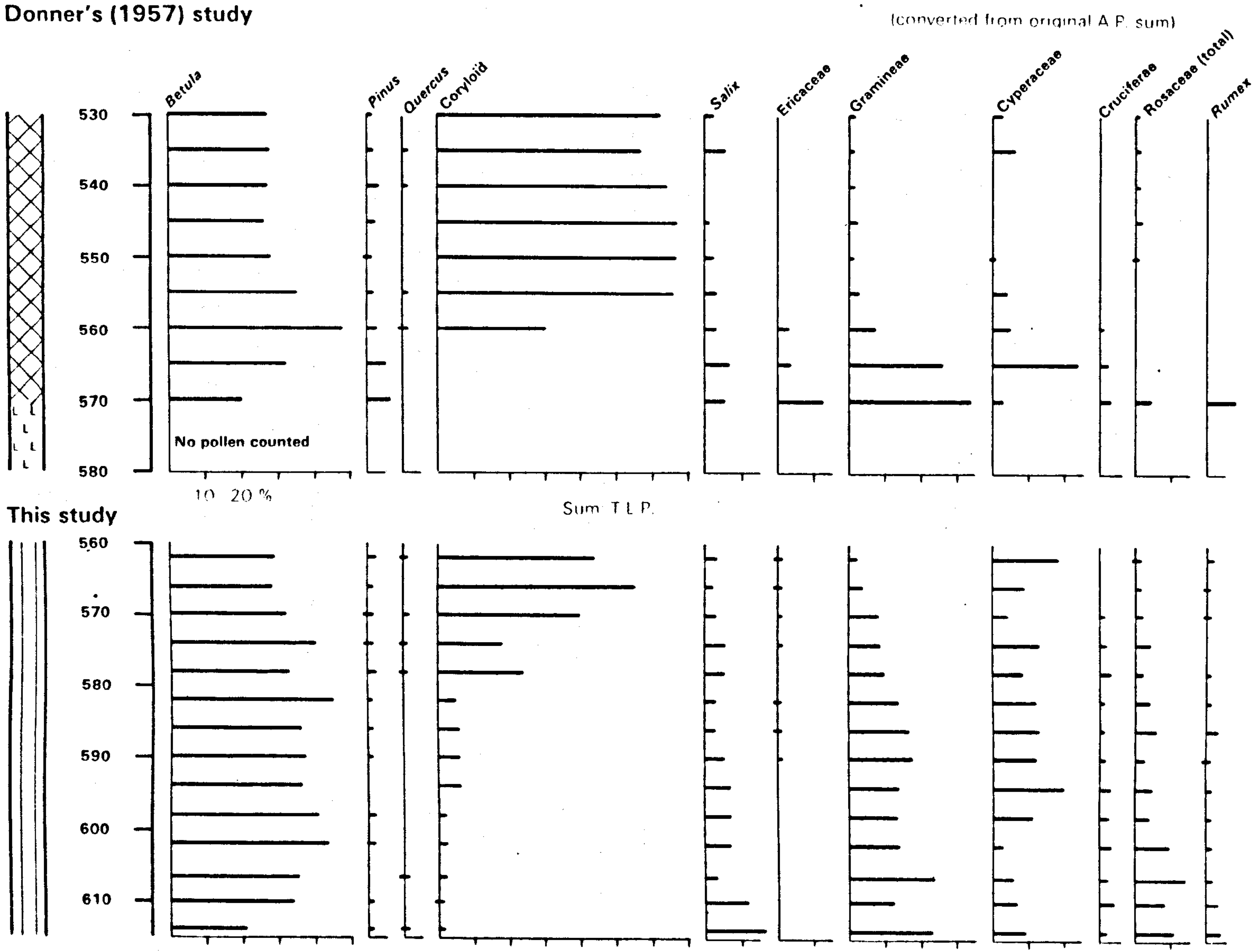
The general vegetational succession from, at Pulpit Hill, zones PH 1 E/PH 2 Ea is discussed in more detail in chapter 4.

3.2 viii Comparison with Donner's (1957) Pollen Diagram

Fig 3.4 presents the uppermost 55 cm of PH 1 and the basal 50 cm of Donner's fig 18 (1957), from his Oban 2 site (see section 3.2ii), recalculated from an original A.P. sum to accord with the results of the present study. The diagrams can be seen to agree very well.

Only in the herbaceous taxa, principally in the

Fig. 3.4: Comparison of major taxa -



Rosaceae, do differences occur, where Filipendula is high at PH 1. This probably bears some relation to the difference in lithostratigraphies. Donner's sequence shows a large thickness of gyttja extending through the Corylus rise, so that the high Filipendula counts experienced within the fen-peat at PH 1 would not be discerned. Clearly the lake-basin was not completely infilled with peat in the early post-glacial.

3.2 ix Radiocarbon Dating

(a) Introduction

From the initial pollen diagram (PH 1) it was thought desirable to obtain a series of radiocarbon dates to allow correlation with other sites. This site was chosen because

(i) it has the thicker of the two Lateglacial sedimentary sequences sampled, so providing the greater resolution (fig 3.7)

(ii) the organic matter content at Loch Barnluasgan was thought on visual estimation to be too low for C14 assay

(iii) C14 dates on the climatic fluctuation at the base of the Pulpit Hill profile would be of considerable strati graphic significance, and

(iv) the rock types in the basin were thought suitable

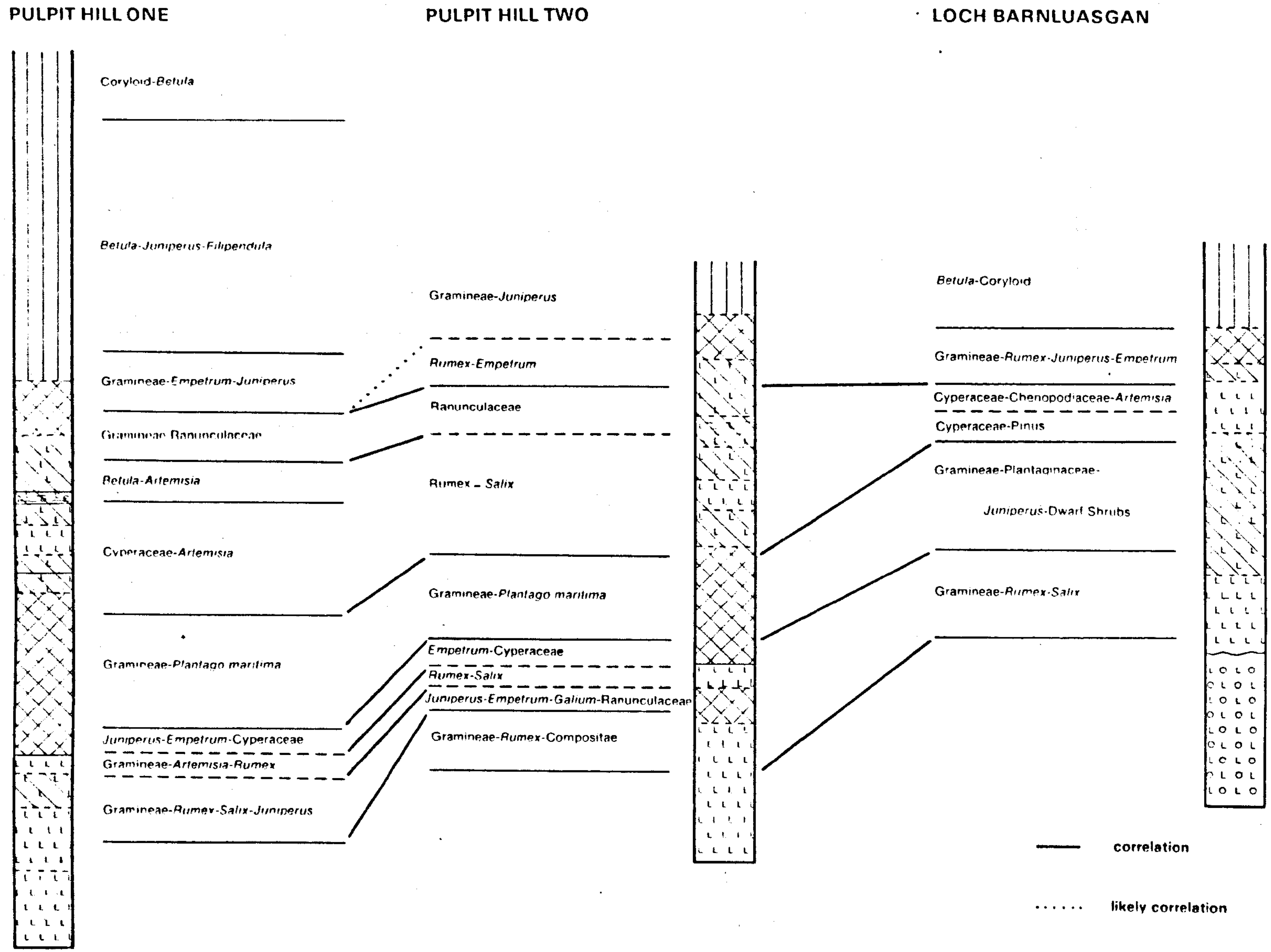


Fig. 3.7: **Biostratigraphic Correlation: Late-glacial sites**

due to the absence of possible contaminants (Sutherland, 1980).

(b) Definitions

Material from eight bio- and litho-stratigraphical horizons were accepted for analysis by the N.E.R.C. Radiocarbon Laboratory at East Kilbride. Four are defined on lithological changes, the remainder on distinctive changes in the pollen spectra, considered of environmental significance.

The following definitions were taken from the diagram of PH 1 (fig 3.2), the depths below surface relating to that diagram.

DATE ONE : 696 - 697 cm.

Lithostratigraphic boundary: initial onset of organic sedimentation; transition from litho-unit A to B.

DATE TWO : 691 - 692 cm.

Lithostratigraphic boundary: junction between litho-units B and C.

DATE THREE : 684 cm.

Biostratigraphic boundary: prominent peak in Juniperus at local p.a.z. boundary PH 1 Ac/PH 1 B.

DATE FOUR : 661 cm.

Lithostratigraphic boundary: transition between litho-units D and E.

DATE FIVE : 634 cm.

Lithostratigraphic boundary: transition between litho-units E and F.

DATE SIX : 628 cm.

Biostratigraphic horizon: rise of Empetrum percentages from 1 - 2% to 4% T.L.P.

DATE SEVEN : 622 cm.

Biostratigraphic horizon: major (12% T.L.P.) peak in Juniperus.

DATE EIGHT : 580 cm.

Biostratigraphic boundary: local p.a.z. boundary PH 1 G/PH 1 H; Corylus rises to 10% T.L.P.

(c) Field Sampling

The technique of multiple-shot bulk sampling has been described in chapter 2.

Figs 3.8a and 3.9a illustrate the lithostratigraphies of the 33 piston-cores (60 cm chamber length; 5 cm internal diameter) and their correlations. Series A (fig 3.8a) cores were taken within 2 sq. m of the PH 1 sampling point (fig 3.1c), and Series B from an area near the PH 2 borehole. Thus this latter series are not comparable in depth but agree well lithostratigraphically. The cores in fig 3.9a for the Corylus rise (date 8) are also from this locality.

On the figures the full 60 cm chamber length is drawn so as to gauge the compression (blank area) common in these sediments. Stratigraphic boundaries are well-preserved, and little disturbance was suspected.

(d) LABORATORY SAMPLING

Cores were stored in a cold-store at $5^{o}C$ until sampling.

For all dates (except 1 and 2) biostratigraphical correlation was thought necessary. Material for dates 1 and 2 were combined on sedimentological criteria from cores 1, 2, 3, 4, 5, 6, 7, 8, (fig 3.8a). For other dates skeletal pollen counts were undertaken on cores thought on lithological criteria to relate to the horizon in question. Figs 3.8b, c, d and 3.9b provide the details of these analyses. Although palynological changes between PH 1 and PH 2 occur with some consistency, it was felt unreasonable to assume that marker-horizons occur at uniform depths in all cores. Variability in this must reduce the accuracy of the date

Fig 3.8a: C[14] Bulk Sampling

Depth correlation of cores

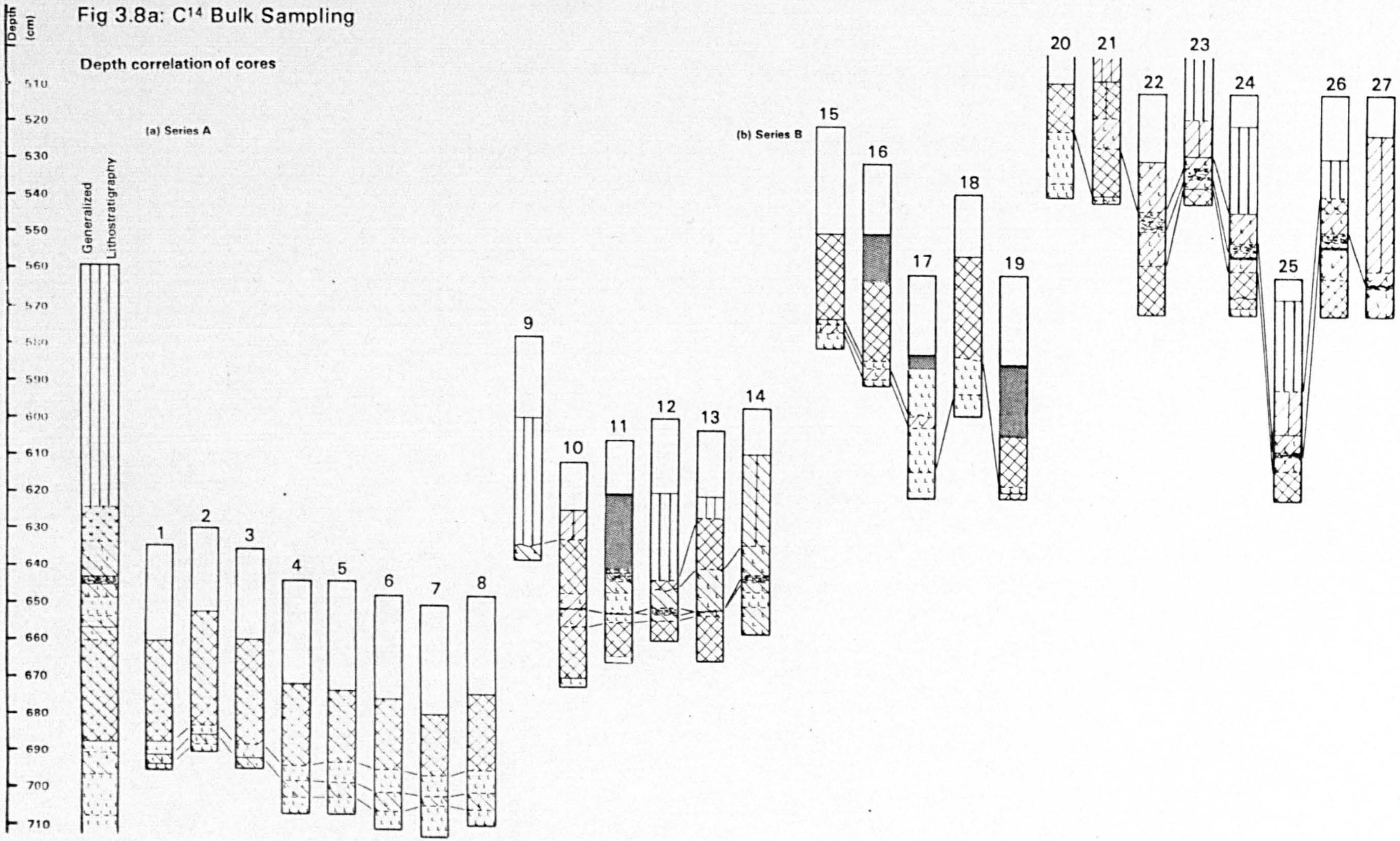
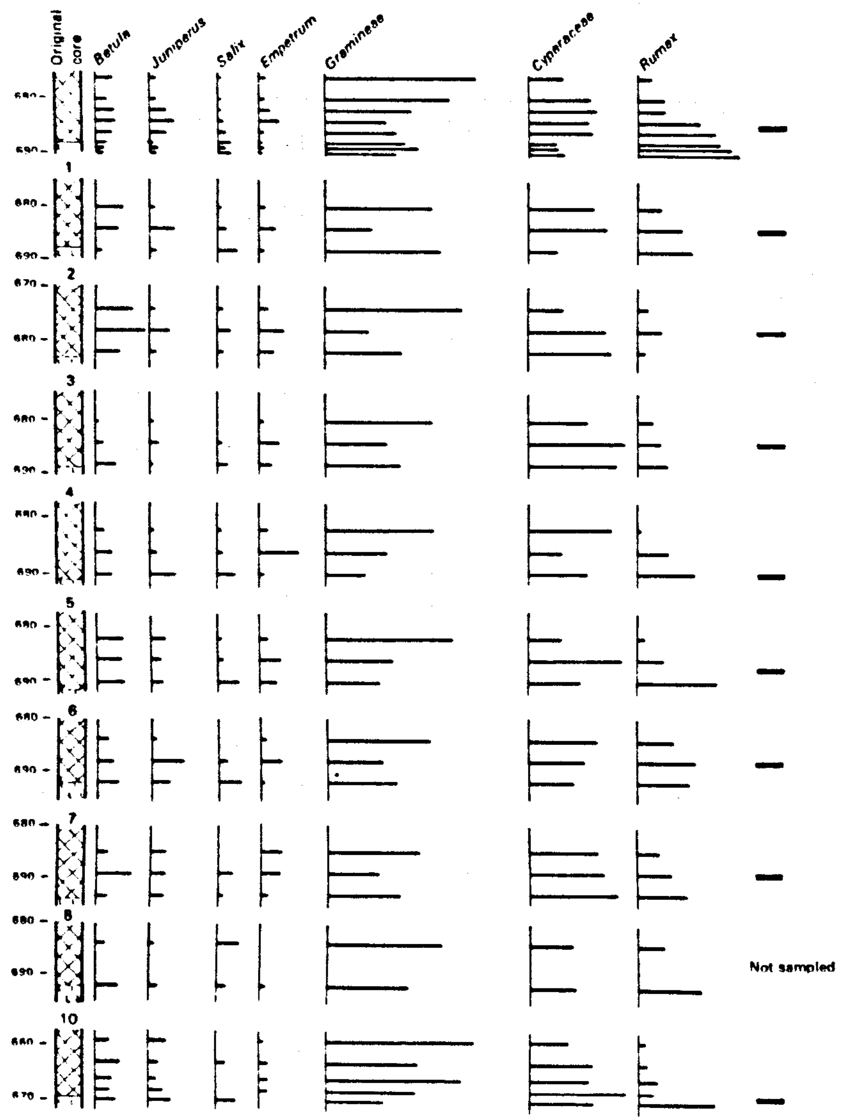


Fig 3.8b: C14 Bulk sampling

Correlation chart: Date 3



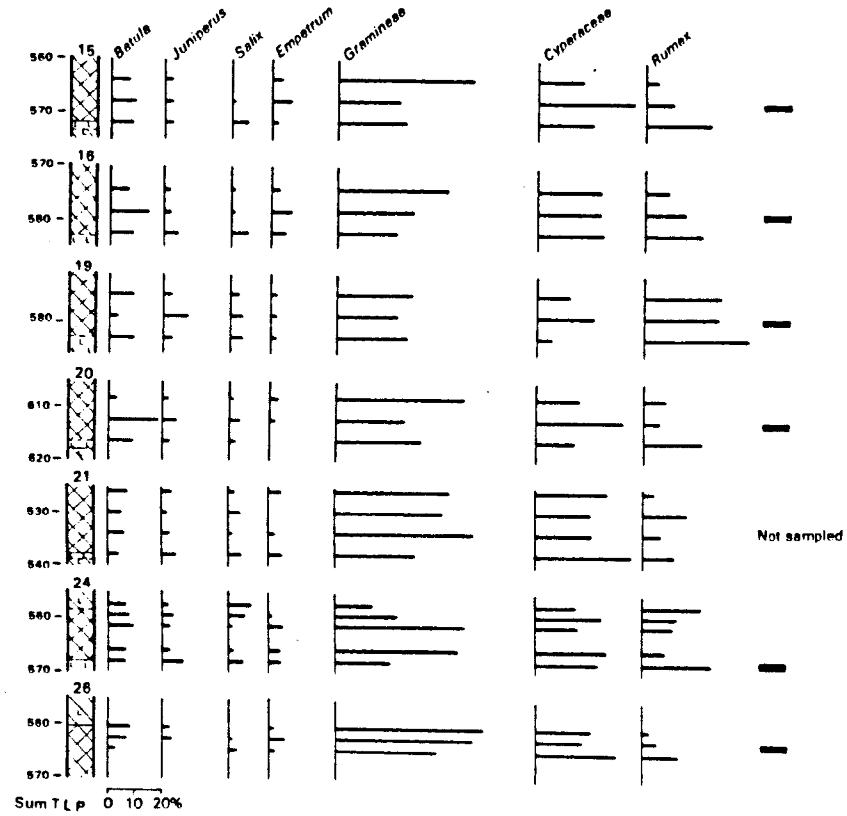


Fig. 3.8c: C^{14} Bulk sampling

Correlation chart: Date 4

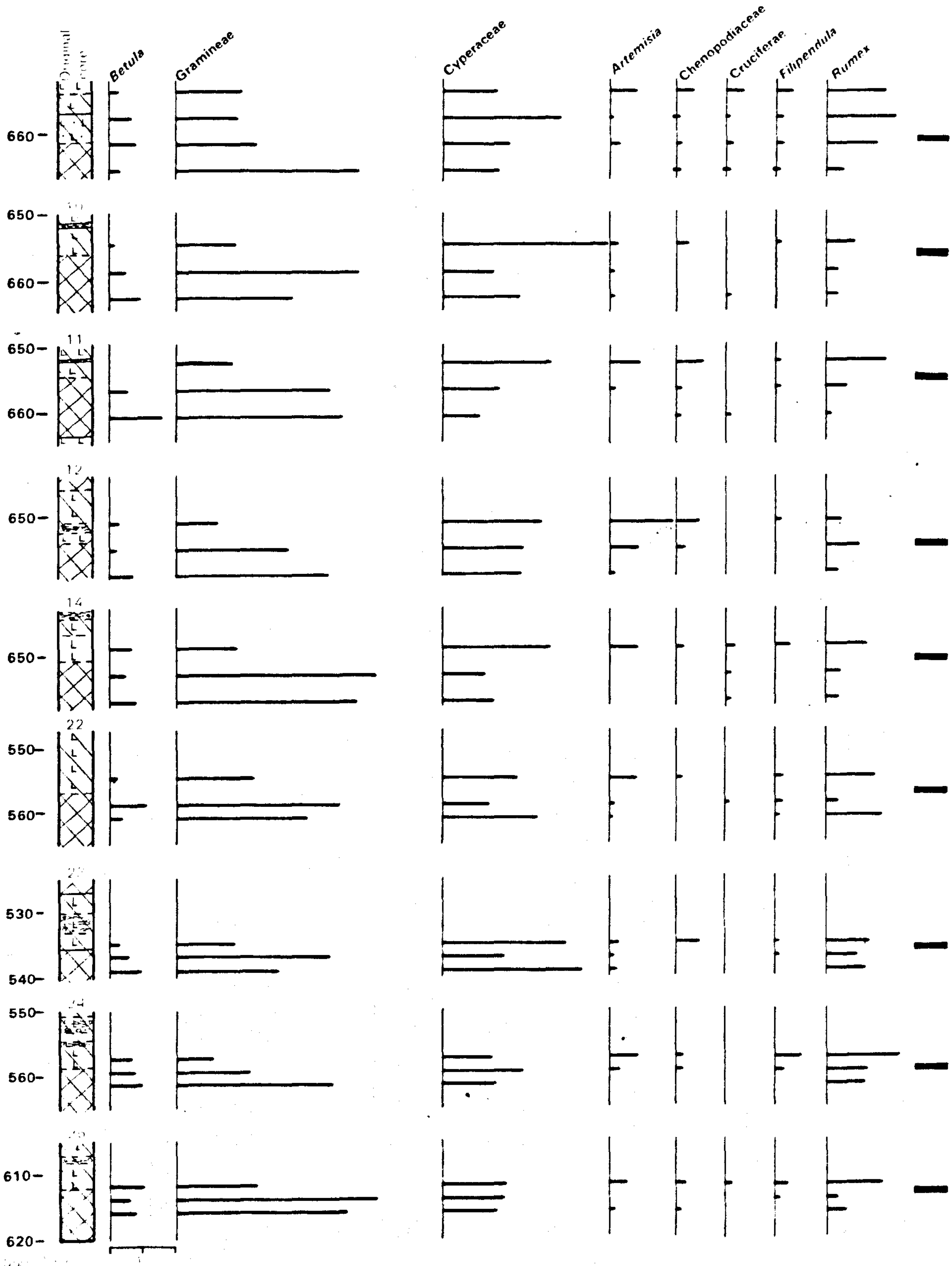


Fig 3.8d: C14 Bulk sampling

Correlation chart: Dates 5,6,7

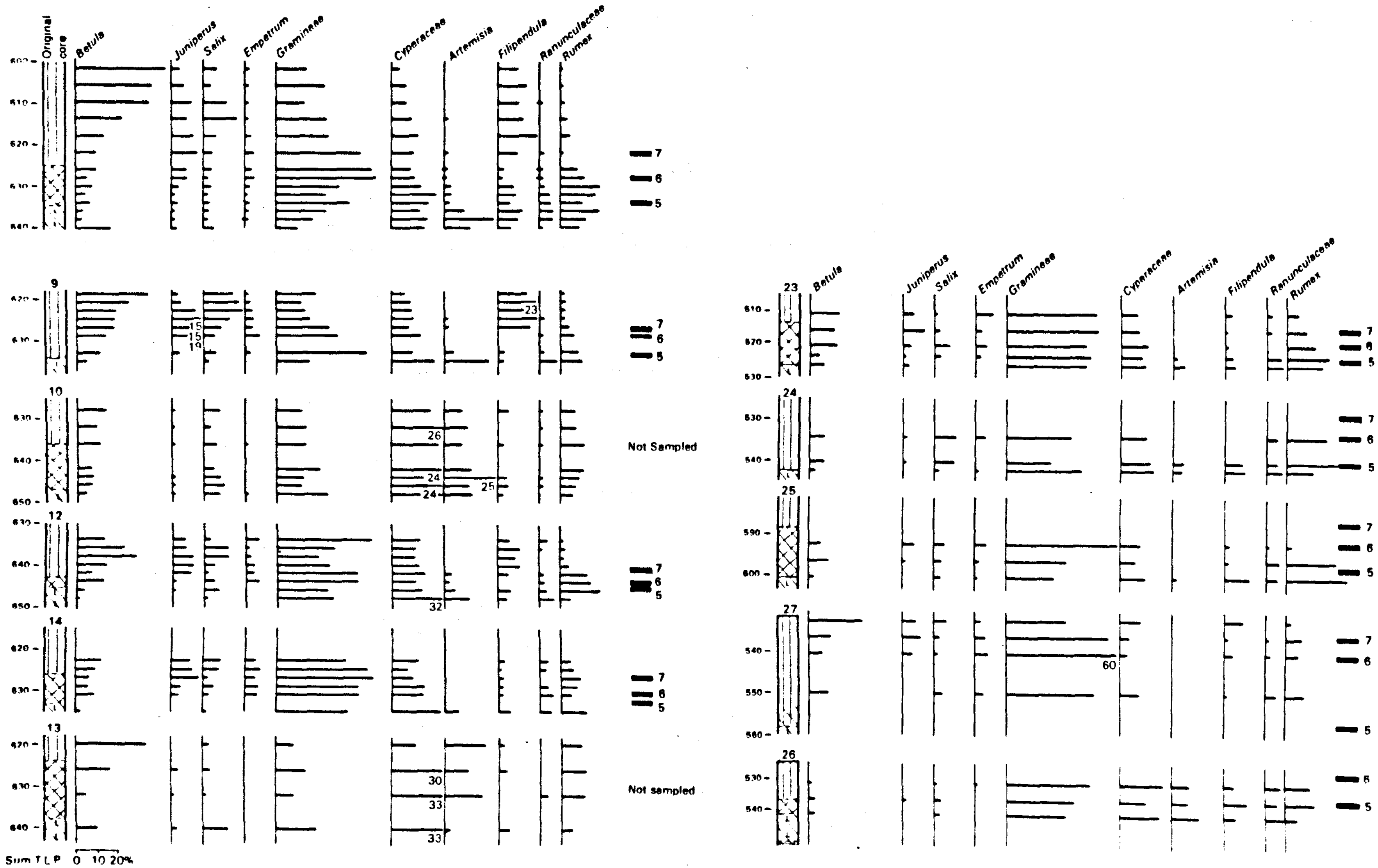


Fig.3.9a: C^{14} Bulk sampling

Depth correlation of cores: Date 8

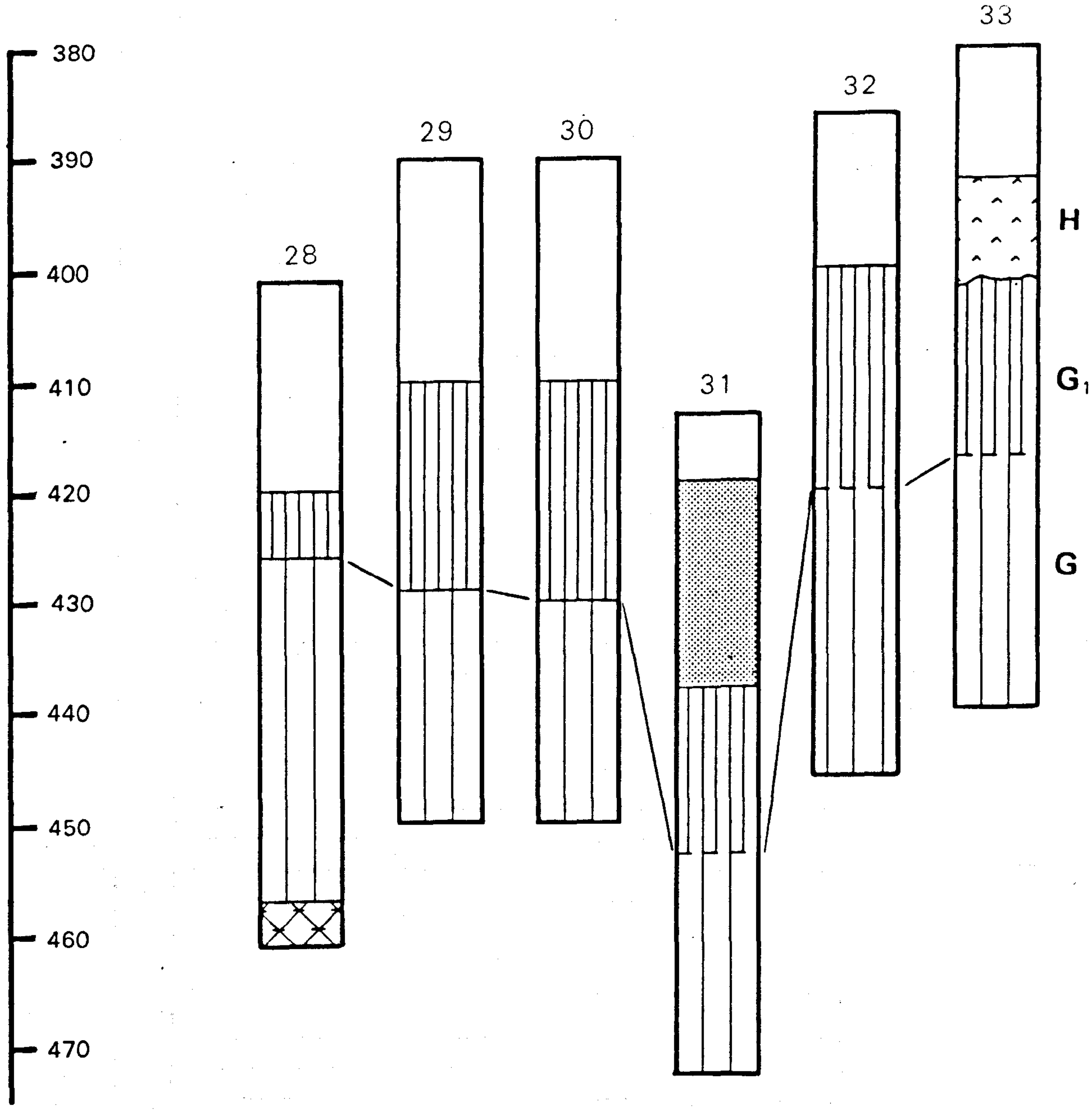
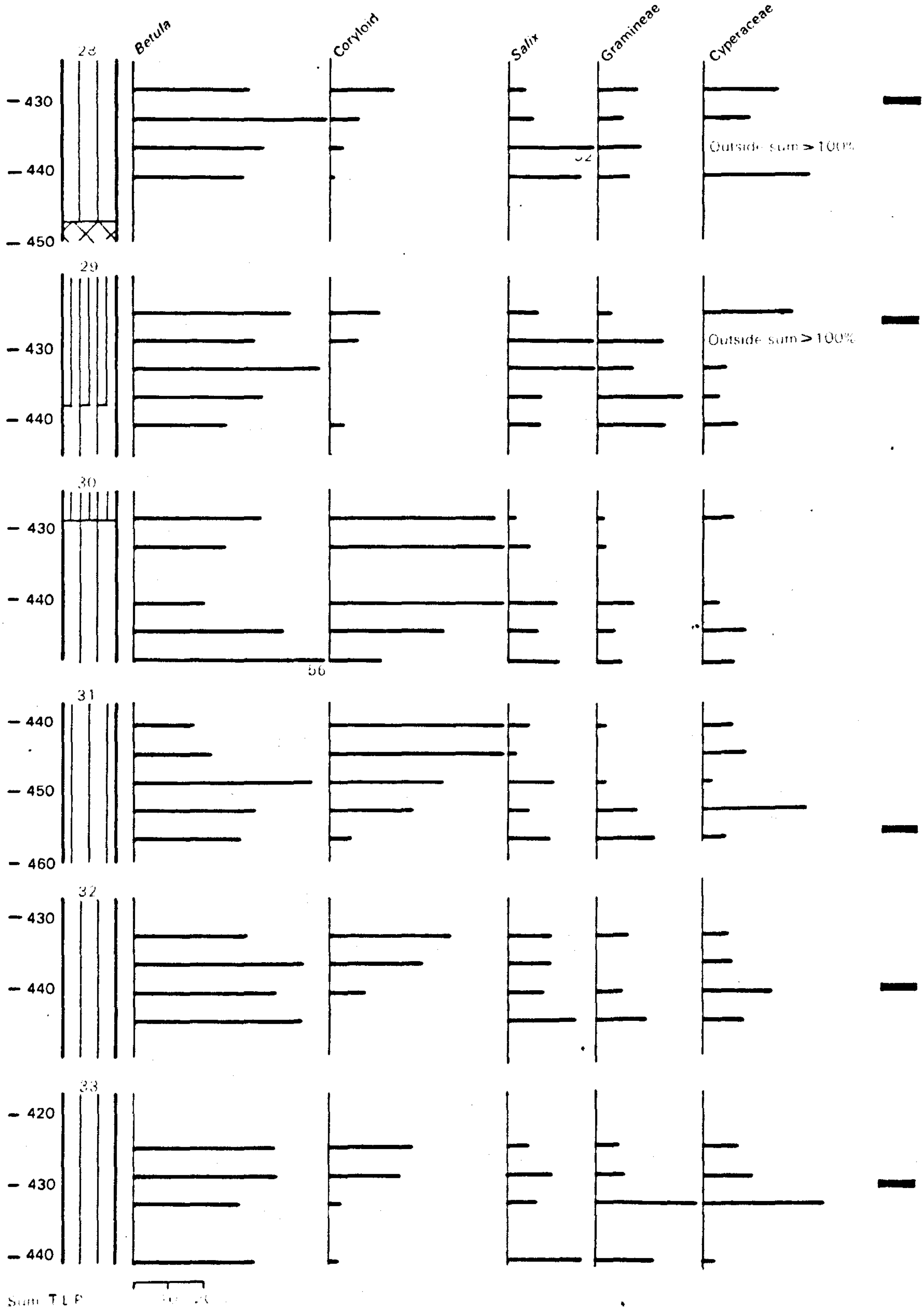


Fig. 3.9b: C[14] Bulk sampling

Correlation chart: Date 8



obtained.

Because of expected percentage variations between cores attention was paid more to synchronous changes in several taxa than to individual pollen curves. The low pollen sum should be borne in mind when assessing the results, but changes are generally consistent. Attention is drawn in fig 3.8b to date 3, where the palynological evidence shows that the sedimentological criteria are not always consistent, demonstrating the necessity of this rather time-consuming approach. Certain cores were not sampled following skeletal counts due to inconsistencies in the pollen spectra.

The sample location is indicated on the figures. For dates 1 and 2 slices 2 cm thick were used (due to the low organic matter content): for dates 3 - 8 slices 1 cm thick were taken. From these slices the outer 0.3 - 0.5 cm was discarded, the central portions placed in pre-washed polystyrene boxes before posting to the Radiocarbon Laboratory.

Table 3.1 lists the information on the eight samples sent for assay.

(e) Results

Table 3.1 also shows the approximate date anticipated for each horizon from previous investigations, as follows:

DATE ONE

this is probably very variable between sites (Lowe and Walker, 1977), and no assessment could be given.

DATE TWO

the only widely accepted major climatic revertence in northern Europe prior to the Loch Lomond Stadial, the Older Dryas phase (Mangerud et. al., 1974), commences at 12,000 B.P.

DATE THREE

by correlation with Irish sites (Watts, 1977; Craig, 1978) and Mull (Walker and Lowe, 1982) a date of 11,800 - 12,000 B.P. was expected.

DATE FOUR

a date of 11,000 B.P. seems reasonable for the commencement of the Loch Lomond Stadial (Mangerud et. al., 1974; Lowe and Gray, 1980).

DATE FIVE

from the same sources, a date of 10,400 - 10,300 B.P. was anticipated.

DATES SIX AND SEVEN

dates of 10,200 B.P. (date 6) and 9,600 B.P. (date

Date	Sediment type	Thickness (cm)	No.Cores sampled	Weight (wet) of sample: gms	Carbon content %	Carbon content gms (approx)	Laboratory No.	Date (C^{14} Years B.P.)	Standard Deviation	C^{13} Value ‰	Expected date: Years B.P.	Error: Years B.P.	Contamination %
One	Gyttja	2	7	16.95	6.4	1.08	SRR-2159	14790	±340	-22.4	?	-	-
Two	Gyttja	2	8	32.73	3.5	1.14	SRR-2158	13590	±240	-24.0	12 000	1590	5
Three	Gyttja	1	14	209.64	8.0	16.77	SRR-2157	12850	±110	-27.2	11 800	1050	3
Four	Gyttja	1	8	126.08	6.5	8.19	SRR-2156	11800	±220	-26.5	11 000	800	3
Five	Gyttja	1	8	140.60	6.5	9.13	SRR-2155	11290	±100	-23.7	10 400	890	4
Six	Gyttja	1	8	143.39	22.8	32.69	SRR-2154	11080	±90	-25.1	10 200	880	4.5
Seven	Gyttja/ Fen Peat	1	7	120.79	>24	>28.98	SRR-2153	11130	±170	-25.8	9 600	1530	9
Eight	Fen Peat	1	5	52.84	>25	>13.21	SRR-2152	10190	±130	-31.6	8 800	1390	9

Table 3.1: C^{14} Data - Pulpit Hill

7) were expected (see chapter 5; section 3v).

DATE EIGHT

the published dates from Mull (Walker and Lowe, 1982) are taken as valid. The controversy over the apparently early rise of <u>Corylus</u> in western Scotland (Birks, 1973; Deacon, 1974; Rymer, 1977) is discussed in chapter 4.4.

It is immediately clear that none of the eight dates accord with the estimated age estimates. Date one cannot reliably be assessed, but this is likely to be in error also.

There would appear on visual estimation to be no correlation between the size of the errors and carbon content, or with increasing age/depth. The consistency of the errors (Table 3.1), particularly in dates four, five and six, and the errors for dates two and seven being almost exactly double this error, has led to a tentative consideration of the similarities with C14 reservoir effects in marine sediments (e.g. Stuiver and Polach, 1977; Donner and Jungner, 1980), in which all dates are affected by a consistent error: the possible mechanisms for this at Pulpit Hill are unknown.

There have been several recent assessments of errors in radiocarbon dating (Olsson, 1974, 1979; Bowen, 1978; Walker and Lowe, 1980; Lowe and Walker, 1980; Sutherland, 1980), and only those errors giving "old" dates need be considered here.

Field and laboratory sampling is not suspected given the care and vigorous scrutiny afforded each sediment slice (see above). Radiocarbon counting errors are not thought a potential source of error (D.D. Harkness: pers. comm.). Reworked organic matter (e.g. Donner and Jungner, 1973) is considered unlikely in the absence of anomalous pollen taxa in the diagrams (figs 3.2; 3.5) and in the absence of sediments older than 15,000 years B.P. over most of Scotland (Sissons, 1981). Hard-water error is ruled out principally because of the low calcium content of the two bedrock types in the basin (Kynaston et. al., 1908). Evidence for more calcareous soils has been presented in specific pollen zones (above), but this effect, if present, cannot account for all the dates in error.

Although graphite does not occur in the basin (Kynaston et. al., 1908), graphitic shales of Dalradian age (Easdale Slates) are mapped in the valley of Gleann Sheilach and in Oban Bay, less than 0.5 km to the south-east, east and north-east, and underlie the Lower O.R.S. succession. It is doubtful that these shales floor the basin as the lavas have a recorded thickness of over 40 m at this locality (Kynaston et. al., 1908). Ice moving westward would, however, incorporate graphitic shales and thence pass over Pulpit Hill, and this source appears to represent the likeliest contaminant. However, till is not sufficiently prominent within the basin to be mapped, and J.S. Bibby (pers. comm.) reports that till is only patchily present around Oban, and where present often occurs in structural crevices and small basins, its thickness being extremely variable, from inches to 2 - 3 feet (0.66 - 1.0 m). It can be difficult to recognize following pedogenic modification, but even so its occurrence, if present, within the basin must be very localized, the writer not recognizing it in several visits to the catchment, although sections are few.

Unfortunately no data on the graphite content of the local bedrock or of the till is available, and soil chemical analyses at the McCaulay Institute for Soil Research on soils in the region do not differentiate between elemental and combined carbon (J.S. Bibby, pers. comm.). Although Ostrem (1965) describes an approximate assessment of graphite concentration, this method's validity is uncertain, and was not adopted by the author. Contamination by old carbon of between 3 and 9% is needed to produce these errors (Olsson, 1974), which seems a remarkably high amount to be derived from a substrate of which there is no clear evidence. Olsson (1979) describes a 1,500 year error from gyttja containing 1 - 2% graphite, and the mineral's importance is emphasized in sediments of low carbon content. The carbon contents quoted in Table 3.1 are taken from the semi-micro chemical analyses, and organic carbon levels can be expected to be significantly lower following pre-treatment for C14 assay. Given the size of standard deviation and approximate age of each sample the weight (gms) of carbon (total) available for assay can be deduced to be between 0.75 and 1.5 gms for dates 1, 2, 4, 7 and 8, and between 2.0 and 2.5 gms for dates 3, 5 and 6.

The insolubility of graphite is problematic when it is found that the second and third largest errors are seen in dates 7 and 8 from gyttja / fen-peat and fen-peat respectively. However, the peat is not ombrotrophic, and mineral grains from slope wash could still be incorporated. Interestingly, however, no demonstrable relation is seen between the errors and inferred increases in slope-wash sediments during the Lateglacial.

No separation of soluble and insoluble components of the sediments before C14 assay was performed, although recommended by Olsson (1979), and this must be an important aspect of any future work on this problem. Very detailed mapping of the soil parent materials in the basin coupled with accurate and discriminative chemical analyses is required to demonstrate the presence of graphite-bearing till. In addition, modern samples, both terrestrial and aquatic, should be assayed to determine any systematic errors, perhaps approaching the 800 - 850 year error thought detected in these samples. Confirmation of this pattern would be a considerable advance, allowing the oppportunity to demonstrate a "reservoir effect" of the kind inherent in dating marine carbonates, and further, potentially to correct these C14 dates in the same way marine shell dates are adjusted, which has not been attempted on terrestrial material.

3.3 LOCH BARNLUASGAN (g.r NR 79389147:lat.56°03'58" N.long.5°12'36" W)

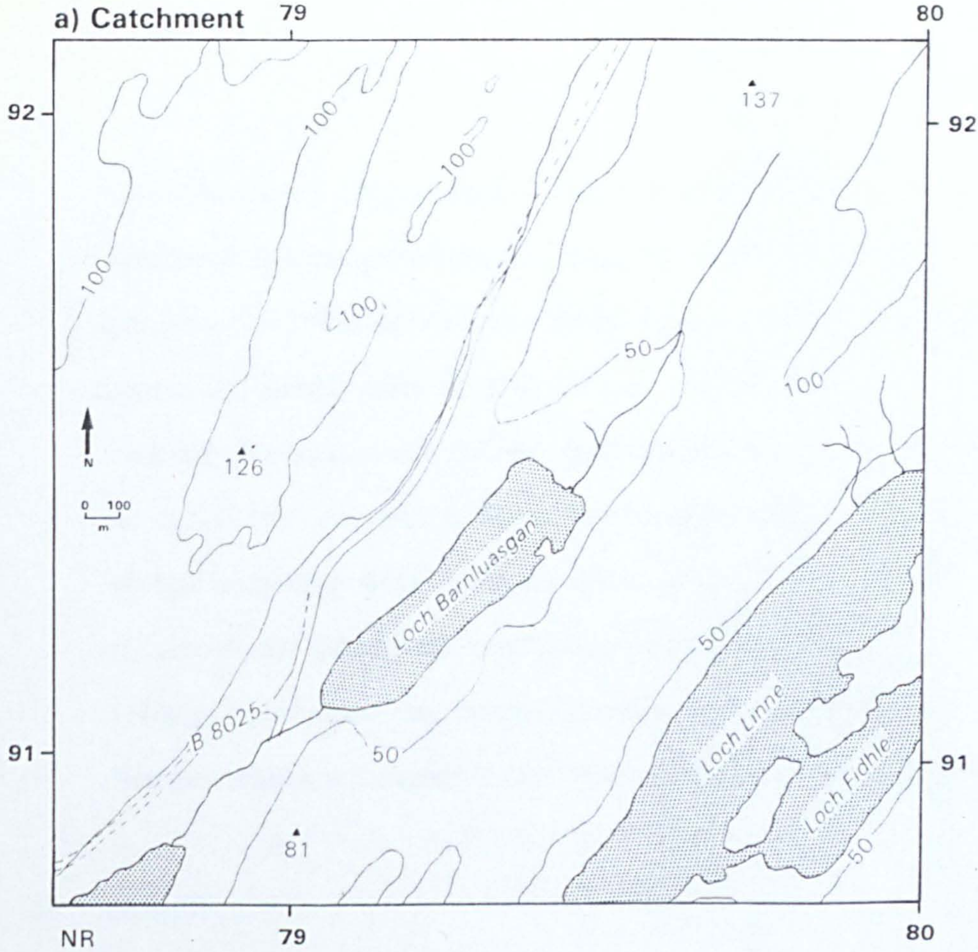
3.3 i Site Location and Description

The Lateglacial succession (fig 3.11) was found at the base of a sedimentary wedge prograding into the northern end of Loch Barnluasgan (fig 3.10).

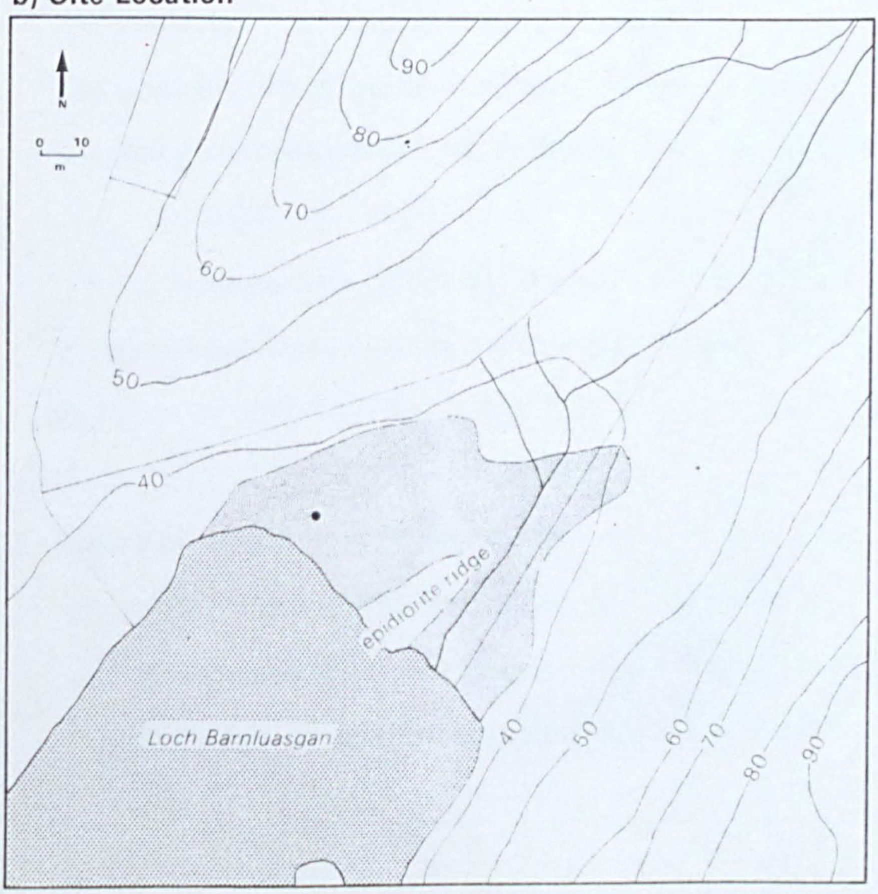
The loch lies on the eastern side of the B 8025 Bellanoch - Tayvallich road in a low col (c50 m O.D.) between Loch Crinan and an arm of Loch Sween (fig 1.3). Lithological control of geomorphic features is seen in the strong N.E.-

Fig. 3.10: Loch Barnluasgan

a) Catchment



b) Site Location



S.W. alignment of valleys. Loch Barnluasgan lies in a small syncline in otherwise gently dipping (12°W) Dalradian quartzites. Two epidiorite ridges are upstanding at the north and south ends of the loch. The catchment and surface area of the basin are larger than other sites in this study, at c.1.0 sq. km and 0.5 sq. km respectively. The surface of the sampling site lies at 39.5 m O.D. Unlike other sites in the study prominent inflowing streams are present (fig 3.10a), and these may have an effect on pollen entrainment characteristics (Peck, 1973; Bonny, 1976, 1978).

3.3 ii Sampling

The deepest point was found 20 m from the lake-edge (fig 3.10b). An epidiorite ridge divides the basin in two, the easterly half being shallower at just over 5.0 m. The sampling site reached 8.23 m below the bog-surface.

A combination of 50 cm Russian cores and one 1.0 m Russian core comprise the lithostratigraphy seen in fig 3.11.

3.3 iii Generalized Lithostratigraphy

LITHOSTRATIGRAPHIC UNIT A : 823.5 - 798 cm.

olive gray (5 Y 5/2) silty clay with gravels, angular to sub-angular muscovite, phyllites, subordinate quartz

(0.25 - 1.5 cm.) and muscovite flakes; sharp and irregular boundary to

LITHOSTRATIGRAPHIC UNIT B : 798 - 785 cm.

pure clay, (5 Y 5/1) gray, darkening to dark gray (5 Y 4/1), with dark streaks; low carbon and nitrogen content; transitional boundary to

LITHOSTRATIGRAPHIC UNIT C : 785 - 761.5 cm.

dark olive-gray (5 Y 3/2) organic silty clay, with coarse, angular stones and minerals (as above) plus feldspar, biotite and mafics, with poorly-preserved seed-cases, possibly Characeae, at the top: C and N contents rise at the base and decline at the top of this unit: transitional boundary to

LITHOSTRATIGRAPHIC UNIT D : 761.5 - 753 cm.

olive-gray (5 Y 4/2) silty clay, macrofossil and minerogenic residue as litho-unit C; C and N contents low; transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 753 - 750 cm.

transitional unit between litho-units D and F.

LITHOSTRATIGRAPHIC UNIT F : 750 - 744 cm.

very dark grayish brown (2.5 Y 3/2) organic gyttja with woody fragments, occasionaly <u>Chara</u> oospores, several moss filaments (indeterminable) and leaves. C and N contents rise sharply; transitional boundary to

LITHOSTRATIGRAPHIC UNIT G : 744 - 711 cm.

dark grayish brown (2.5 Y 3/2) fen-peat, coarsening upwards to wood-peat.

3.3 iv Biostratigraphy

823.5 - 795 cm. : non-polleniferous.

795 - 781 cm. : local p.a.z. BARN A

Gramineae - *Salix* - *Rumex*

Herb pollen dominates, exceeding 60% T.L.P., prominent being Gramineae and *Rumex*, with sedges also well-represented, and *Artemisia* and other Compositae (*Bidens*-type in particular), plus Cruciferae and *Poterium sanguisorba* intermittently. *Salix* is better represented than in other zones, pine is conspicuous, but *Betula* is poorly represented.

781 - 763 cm : local p.a.z. BARN B

Gramineae - dwarf shrubs - *Juniperus* - *Rumex*

Shrub values are maintained by increases, somewhat erratically, of *Empetrum* and Ericaceae undiff., and of *Juniperus* to 7 - 8%, except for one level where the pollen exceeds 20% T.L.P. Gramineae and Cyperaceae percentages remain high. *Rumex* declines after an early peak, but *Artemisia* persists at >1% T.L.P., and Chenopodiaceae appear in the diagram; also distinctive are *Galium*, Leguminosae, Plantaginaceae, *Mentha*-type, Ranunculaceae, *Filipendula* and Umbelliferae.

Nearly all aquatics increase, in particular *Myriophyllum alterniflorum*. Total deterioration is lower than the 40% T.L.P. and indeterminable grains of zone Barn A.

763 - 753.5 cm : local p.a. zone BARN C

Cyperaceae - Chenopodiaceae

The local p.a. zone has 2 subzones, thus:

(a) 763 - 758 cm.

The rapid increases in the sedges have little effect on the percentage values of Gramineae or of dwarf shrubs and *Juniperus*. Taxa declining at the subzone a/b boundary include Caryophyllaceae, *Plantago maritima*, *Filipendula* and *Myriophyllum alterniflorum*. *Pinus*, *Salix*, Polypodiaceae undiff., *Selaginella selaginoides* and *Lycopodium selago* expand.

(b) 758 - 753.5 cm.

The decline in the taxa described above allow pronounced increases in *Artemisia* and Chenopodiaceae. *Rumex* and Ranunculaceae rise through this subzone, and *Thalictrum* is strongly represented.

Deterioration rises to 65%, almost exclusively composed of crumpled and split grains.

753.5 - 744 cm : local p.a. zone BARN D

Gramineae - Rumex - Empetrum - Juniperus

Herb pollen totals, initially > 50% T.L.P. decline to below 20% T.L.P. due to increases in Empetrum, Ericaceae and Juniperus. Birch increases to 47% T.L.P. at the top of the zone, and Pinus is prominent. Gramineae and Filipendula, Plantaginaceae, Ranunculaceae, Caryophyllaceae and Rumex are important early on, but only the grasses and Filipendula persist.

Few aquatics show any increases, but Dryopteris rises to 39% T.L.P. and spores, Polypodiaceae continuing to be important, with Thelypteris-type grains. Total deterioration again declines.

744 - 739 cm : local p.a. zone BARN E

Coryloid - Betula

Birch and hazel dominate the spectra, Corylus rising to 59% at the top of the diagram. Ericaceae persist at low percentages, as do Salix and Filipendula, but few herb taxa are recorded. The spore producing taxa suffer losses. Total deterioration continues to decline.

3.2 v Interpretations

ZONE BARN A

The exceedingly low pollen concentration values in these basal spectra make it questionable whether they reflect local vegetation, given the strong dispersal of the grasses and docks, although the limitations of *Salix* in this respect have been noted earlier. The high percentage peaks of *Pinus*, *Juniperus* and *Empetrum* are shown on fig 3.12 to be artefacts of the low pollen sum, and their local presence is not suspected.

The gravels of litho-unit A are all of local derivation. The fineness of the clays in this and litho-unit B suggests weathering and at least incipient soil-formation, while the initially very low carbon contents, which increase to 1.5% in the upper part of the zone, also supports the likelihood of local plant colonization at this stage.

Gramineae and *Rumex* concentration values rise in tandem towards the zone A/B boundary, and only in the upper half of zone A do other bare-ground and grassland taxa appear consistently. The initially high *Artemisia* percentages are again taken to be statistical artefacts, the numbers declining as T.L.P. concentration values increase. *Bidens*-

type pollen is distinctive, and although the members of this large pollen taxon (Moore and Webb, 1978) are principally thermophilous, _Bidens_ or _Senecio_ might appear likely types from Lateglacial macrofossil and pollen records (Godwin, 1975). Brown (1977) relates the taxon to _B. cernua_, a moist-loving Compositae. Matthews (1978) records two species of _Gnaphalium_, included in the _Bidens_-type pollen taxon, among seven dominants in his Snowbed Species Group at the retreating glacier at Storbreen. _Gnaphalium supinum_ is found only in late snow-bed communities in Scotland (McVean and Ratcliffe, 1962), with _Rhacomitrium_ and _Carex bigelowii_, and this community may have been present, but other chionophilous plants are not recorded.

At the zone A/B boundary the terrestrial plant communities appear to be of open-grassland type, with Caryophyllaceae, Compositae Liguliflorae, Cruciferae, _Helianthemum_ and _Poterium sanguisorba_. Calcicolous indicators are limited to the latter two taxa, but _Poterium_ can survive progressive leaching and increasing acidity (Grime and Lloyd, 1973), and Godwin (1975) suggests it to persist through the Devensian, despite a southern distribution, encouraged by open habitats. The importance of bare-ground at this time is reflected in the continuation of minerogenic sedimentation.

ZONE BARN B

The change to organic sedimentation is not reflected immediately in the carbon and nitrogen values, but throughout this pollen zone C and N contents are high, and the C:N ratio centring on an average of 10 indicates, as at Pulpit Hill, the fertility of the local soils.

Tree pollen values are so low in this zone that neither birch nor pine are considered to have been growing around the site. Juniperus expands until 770 cm and during this period exceeds 10% T.L.P. Empetrum is also more strongly represented here than at Pulpit Hill, and it seems reasonable to suggest that the shrub and dwarf-shrub communities were more common at this site. Ericaceae pollen is as prominent as Empetrum. Partly this must reflect the diverse range of the heathers, being common in many separate communities, and also the number of species within the pollen taxon. Vaccinium is most commonly associated with Empetrum (Fredskild, 1973) and with juniper (McVean and Ratcliffe, 1962), and on exposed ground (Matthews, 1978). The variety of communities containing heathers makes it inadvisable to pursue this problem further, however. Calluna pollen is recorded at too low a frequency to be regarded as local (Birks, 1973), although Rymer (1977) considers it present in the interstadial at Drimnagall (fig 1.5).

Gimingham (1972) defines three climatic zones of dwarf-shrub heath, of which two, the sub-arctic and high-altitude types are not thought to have been present at Loch Barnluasgan given the inferred maturity of the soils. The third type develops in cool-temperate climates, where oceanic conditions exclude forest development. Discussion of this feature is found in section 3.5c.

Open ground appears to have persisted through this zone, with Caryophyllaceae, Cruciferae, Artemisia and the calcicole Helianthemum. Low pollen concentration values of Rumex suggest it to be only scattered in its distribution, and it may have suffered competitively against the grasses. As at Pulpit Hill, the plantains are characteristic of open grassland, with Thalictrum, Crataegus-type, Umbelliferae and sparsely represented Leguminosae. The grains of Mentha-type pollen cannot be attributed to a specific member of the Labiateae (Moore and Webb, 1978), and the same problem applies to the undifferentiated Compositae.

At Loch Barnluasgan both aquatic and terrestrial Ranunculus pollen types occur. Fen communities probably developed, perhaps containing Ranunculaceae and Galium-type, and Typhaceae, comparatively well-represented at this site. No pattern is seen in this taxon suggestive of that deduced by Watts (1977) for Ireland, where T. angustifolia appeared prior to T. latifolia in the Lateglacial record. There seems to be no major expansion of aquatics comparable to that at Pulpit Hill, perhaps symptomatic of the lack of nutrients in waters draining the quartzitic bedrock.

While the percentage diagram shows few variations in this pollen zone, the concentration data (fig 3.12) reveal that above 770 cm Gramineae rise dramatically to 45,000 grains per cm^3, which is sustained until the zone B/C boundary. T.L.P. concentration does not increase, and the increases are thus probably the result of community changes. Taxa seen to decline in concentration are Juniperus (slightly) and Rumex. It is difficult to see what these changes mean vegetationally, as other bare-ground plants, Chenopodiaceae and Artemisia, show no reductions (fig 3.12). Increased pollen representation need not always imply spatial expansion, but with so little information on the ecology of the grasses involved further conjecture is unproductive.

Discussion of the anomalously high peak of Juniperus at the end of this zone is left until section 3.5D, where this feature is compared with similar patterns at other sites.

ZONE BARN C

This local pollen assemblage zone is correlated with zones PH 1 C/PH 2 D as showing a clear vegetational and climatic revertence. This is based on several lines of evidence: (i) sharply decreasing carbon and nitrogen values returning to values of those in zone Barn A, lower than at Pulpit Hill; (ii) absence of organic material in litho-unit D; and (iii) a marked decline in total land pollen concentration values to the very low values of zone Barn A, despite the generally higher concentration values than Pulpit Hill and the low sedimentation rate of litho-unit D (assuming the same time-span). It is possible that the climatic deterioration was much more intensely expressed at Loch Barnluasgan.

The C:N ratio also declines at this site, in contrast to its behaviour at Pulpit Hill, but it is not known whether this reduction results from lower fertility during the severe climatic episode or whether the paucity of nutrients (in comparison to the basic lavas at Pulpit Hill) on the siliceous Dalradian bedrock is responsible.

The suggested harsher environment at Loch Barnluasgan is not clearly seen in the pollen data (fig 3.11), but it is perhaps difficult to envisage how such a feature can be discerned. Most, if not all, taxa of arctic character do not thrive in, but merely tolerate, the harshness of the climate. Consequently even their pollen productivity declines. Chionophilous taxa might be expected to appear, and their absence may imply that few snow-patches developed in the catchment, as at Pulpit Hill.

From the concentration values for T.L.P., it might be thought that vegetation around the catchment was virtually destroyed, and the very low carbon content supports this view. The representation of Juniperus, Empetrum and ericaceous species at very low concentration values does not imply their presence in the basin, and their persistence may be due to inwashing from interstadial soils. This subzone (Barn Ca) is characterized by falling carbon and nitrogen values, subzone Barn Cb by consistently low figures, and with the absence of Juniperus and heathers from subzone Cb, it might be suggested that throughout zone C a gradual depletion of humus and included pollen occurred through slope-wash and solifluction, to the point at the subzone a/b boundary when the soils became exhausted of organic material and contained pollen. This idea is supported by similar patterns of depletion in Gramineae and Plantago maritima pollen, both prevalent in zone B but probably having no role in the catchment during this later period.

Pollen deterioration increases in zone C. Analysis of individual pollen curves is hindered by the low numbers of grains in this zone, which render the statistical treatment of the data of little value (chap. 7). Only Gramineae are present in all levels at sufficiently high numbers for analysis, and within zone Barn C crumpling increases from 35% of grass grains to 46.5%, declining to 33% above 753 cm. A similar picture is obtained for broken Gramineae grains (chap. 7).

The absence of many grains of suspected inwash origin in subzone Barn Cb (above) will inevitably lead to percentage increases in other taxa, and in the absence of decisive palaeoenvironmental indications the high Chenopodiaceae and _Artemisia_ values need not imply a significant climatic change as proposed for Pulpit Hill. Comparisons with the distinctive changes at Pulpit Hill are therefore not convincing, and the sequence here cannot be said to endorse the interpretations at that site.

Two prominent taxa not important at Pulpit Hill but significant at Loch Barnluasgan are _Selaginella selaginoides_ and _Lycopodium selago_. _Selaginella_ is not clearly chionophilous, but thrives also in montane herb communities and fens also, in association with Carex (Cyperaceae), Thalictrum and mosses (McVean and Ratcliffe, 1962). Lycopodium selago can indicate snow-patches when recorded at very high percentages, c18% T.L.P. and spores (Birks, 1973), particularly in association with L. alpinum, (Kirk and Godwin, 1963; Birks, 1973; Matthews, 1978). However, this is not the case at Loch Barnluasgan, and true chionophilous indicators are absent.

ZONE BARN D

A small peak of Ranunculaceae at the lower zone boundary is thought from the pollen morphology to indicate an initial response to ameliorating conditions by members of the aquatic ecosystem, although again there is no increase in Myriophyllum. It seems that a lack of competition (Berglund, 1966) is not the sole control on this plant's behaviour.

The presence of fern-meadows (Dryopteris, Polypodiaceae undiff., P. vulgare, Thelypteris-type) probably indicates the increasing dampness of the climate, as proposed for Pulpit Hill, but the decline in values for Selaginella is unexpected, as it grows in the Dwarf Herb nodum associated with late-snowbed fern communities.

The response to ameliorating climate of T.L.P. concentration, carbon and nitrogen values, lithology and successional changes is clear. The establishment of grasslands, initially with Rumex, later by Empetrum, Juniperus, Betula and in zone Barn E, Corylus, is similar to that elucidated at Pulpit Hill, though here the sedimentation rate is too slow to allow a clear understanding of the sequence (see chap. 4).Of interest in zones D and E is the increase in concentration values for Pinus coincident with the Juniperus expansion. This could be attributed to pine communities approaching the Scottish mainland, as at Pulpit Hill (cf. chap. 6).

3.4 REGIONAL CORRELATIONS

Correlations between Pulpit Hill and Loch Barnluasgan have been discussed in the above section, and are illustrated in fig. 3.7. The majority of zones can be correlated successfully, except the earliest climatic revertence at Pulpit Hill (see later: sect. 3.5b). Lithostratigraphic comparisons show that the sedimentological changes (fig.3.7) are also broadly correlatable, and probably imply regional environmental changes, as concluded for the Lake District by Mackereth (1966).

Comparisons of T.L.P. concentration values show that in the mildest climatic periods those at Loch Barnluasgan exceed the pollen concentration values of Pulpit Hill by a factor of three, yet within the major cold phase the opposite obtains. The catchment area and inflowing streams must undoubtedly have a considerable effect on pollen influx, and this is thought to be the determining factor in the higher pollen input at Loch Barnluasgan (as noted by Pennington (1979) in the Lake District). Variations of this kind within the same environment have been described by Davis _et_. _al_., (1973), and it is clear that pollen concentration/influx is currently of limited value in comparing pollen sites.

In the absence of radiocarbon dates synchroneity cannot be demonstrated, but the close comparison of pollen zones leads the writer to assume that the vegetational changes are synchronous within the region. Comparison with the nearest radiocarbon-dated profiles, Loch an t' Suidhe and Mishnish on Mull (Walker and Lowe, 1982; Lowe and Walker, pers. comm.) makes it clear that the pollen zonation elucidated at the study area sites can be extended in general, and often with remarkable similarities, to the island of Mull. Using the radiocarbon dates from these sites (Walker and Lowe, 1982) the Lateglacial age of the deposits on the mainland can be proven.

The basal _Rumex_-dominated zones are dated at Loch an t' Suidhe from before 13140 +/- 100 B.P. to 11860 +/- 80 B.P., whereupon with the decline in Rumex, Empetrum and Gramineae rise (11860 B.P.), and a Gramineae - Plantago maritima sequence (zones Md-e) is established at Mishnish. Thus as at the mainland sites (this study) ericaceous heath appears to persist more strongly at one site, but at both Mull sites Juniperus declines, particularly sharply at Mishnish.

The Loch Lomond Stadial is characterized by minerogenic clay bands at both sites dated between 10730 +/- 60 B.P. and 10000 +/- 70 B.P. at Mishnish, 10690 +/- 70 B.P. and 10440 +/- 80 B.P. at Loch an t' Suidhe, and characterized by Cyperaceae, Caryophyllaceae, Lycopodium selago and Selaginella, and rising Artemisia through the clay, again best seen at Mishnish.

The early postglacial succession has been dated at Loch an't' Suidhe, where the transition from Rumex-rich grasslands to scrubland is dated at 10,200 +/- 70 B.P. (Walker and Lowe, 1982).

3.5 DISCUSSION

A INTRODUCTION

In discussing the biostratigraphy of the Lateglacial in a more general framework, the period has been divided into several topics for consideration. Sites in the British Isles and Ireland are briefly considered, but more quantitative analyses are restricted to Scottish Lateglacial sites. Table

3.2 lists the 42 sites included in the analyses. This is not a complete collection of data from all Lateglacial sites in Scotland. Sissons (1976) mentioned 58 such sites, but many of these remain unpublished after seven years and are unavailable for scrutiny. On the other hand, many unpublished sites have been made available (notably in H.J.B. Birks (1980) unpub.).

During the analyses it became apparent that some sites did not accord with criteria (Watts, 1970) for distinguishing climatic recessions, such as the Loch Lomond Stadial. It is felt these sites, discussed below, cannot be regarded as local anomalies.

Vasari (1977) remains the one worker to question the Lateglacial age of Birks' (1973) Skye sites, and certainly the high standard of palynological techniques employed in this study makes one wary of criticizing Birks' interpretations, but nevertheless there are some strikingly unusual facets of the work which are difficult to relate to the sequence on the Scottish mainland. It could be proposed that being an island the climate was different to the mainland, but it is felt unreasonable to assume this to be the case in every detail (see later). The demonstrably Lateglacial sites of Lochan Doilead (fig 1.5; Williams, 1977) and Glasscnock in the Torridon massif (Robinson, 1977; fig 1.5) emphasize the palynological anomalies in Birks' (1973) results.

Vasari's (1977) criticisms hinge around the seven C14 dates Birks (1973) obtained, of which four were from the site of Lochan Coir 'a' Gharbhainn. Vasari's arguments are not repeated here, but accepted as valid. Gray and Lowe (1977) report that valid Lateglacial C14 dates have been obtained, but these have yet to be published.

The pollen assemblage zones thought to reflect the Loch Lomond Stadial at three sites (Lochs Meodal, Fada, Mealt) are defined on increases in Betula nana-type, a pollen taxon of uncertain determination (Wain-Hobson, 1981), and few other changes define convincing contrasts with preceding zones. At Lochan Coir 'a' Gharbhainn the sequence accords most closely with the typical early Flandrian succession of Ericaceae, Juniperus and Betula. Taken as such the radiocarbon dates from this site make excellent sense, as Vasari (1977) pointed out, and their dismissal as being in error (Birks, 1973) is unwarranted. No conclusive evidence of vegetational revertence is presented at these sites, with no or little expansion of open-ground herbs. Only at Loch Cill Chriosd is a Lycopodium selago - Cyperaceae assemblage zone defined, but again few other changes occur. Lithological changes are of only minor significance with gyttja deposition constant at most sites above the basal clay, and the limited palynological fluctuations associated with these changes could be ascribed to inwashing, as Birks (1970) had demonstrated at Loch Fada. These sites, examined objectively, appear to fail Watts' (1970) criteria for defining climatic oscillations, and a revertence phase is regarded as unsupported. The simplest interpretation is, then, that these sediments are of postglacial age, and in proposing this, other problems are resolved. The radiocarbon dates are seen to be in good agreement with others on similar biostratigraphic horizons (see chap. 5; sect. 3), the calculations of age by assuming uniform sedimentation rates (a questionable approach in any case) becomes unnecessary, and the marked variance of Skye with other Lateglacial sites is resolved. The problem of <u>Corylus</u> refugia largely resolves itself by the dismissal of the basis for assuming early growth of hazel in western Scotland, and the date of the Flandrian <u>Betula</u> expansion (9691 +/- 150 B.P. (Q - 956), although still slightly early, is in much better agreement with other sites.

The reasons for the absence of Lateglacial sediments need not be as significant or widespread as Vasari (1977) implies. All Birks' (1973) sites are from fens at the edges of extant lochs, and, as at Loch Barnluasgan, deeper and older sediments probably lie under water.

In the following discussion the sites of Amulree and Cambusbeg (Lowe and Walker, 1977) are considered not to satisfy Watts'(1970) proposals either, and are excluded from further analysis. At Cambusbeg the sediment is very thin and minerogenic throughout the sequence, until the appearance of *Betula* in the Flandrian. There is then no organic interstadial sediment, and the pollen assemblage zones C la - f (fig.9, Lowe and Walker, 1977) are better seen as a continuing postglacial succession from grass-*Salix*, to *Rumex*, *Empetrum* and *Juniperus*, all with high counts of regional birch, to the appearance of *Betula* itself in zone C 1f. Local p.a. zone C le, defined as a *Rumex*- Cyperaceae - *Selaginella* zone, has only limited increases in these taxa and contains a *Juniperus* maximum, which in turn depresses statistically the background *Betula* count. Thus no recourse to invoking very slow accumulation rates at this site is now needed, and the contrasts with Tynaspirit 2, only 1 km away, are reduced.

At both Amulree and Cambusbeg the clay was felt to be contaminated by organic streaks and coryloid pollen, but the "contamination" could have been contemporaneous if the sites are regarded as Flandrian.

At Amulree 2 the palynological sequence is at variance with other sites (Lowe and Walker, 1977; p.106), and the notable lack of major changes does not lead to the immediate recognition of a Lateglacial biostratigraphy. The period of "revertence", zones Am 2d and e, is by no means characteristic or distinctive, and in the absence of supporting evidence, in lithological changes, for instance, this site is not considered Lateglacial in age.

B THE OLDER DRYAS PHASE IN BRITAIN

The pre-Loch Lomond Stadial climatic revertence at Pulpit Hill is interesting in the apparent corroboration of this pattern at sites such as Blelham Bog and Cam Loch (Pennington, 1975), Tadcaster (Bartley, 1962), which has stood as an Older Dryas site for over 20 years without serious criticism, Loch of Park (Vasari and Vasari, 1968), Corrydon (Walker, 1977) and Stormont Loch (Caseldine, 1980). With, in certain cases, proposed correlations with the Older Dryas stage of the continent (Mangerud et. al., 1974), it is timely to review the present standing of this period in the British Lateglacial.

Watts (1970) has furnished suggestions to test the regional significance of fluctuations at any one site:

> "the same pollen sequence in all its stages can be found at all sites with sediments of the appropriate age within the region." (p.144).

No other site within or near the study area, e.g., Loch Barnluasgan, Drimnagall (Rymer, 1977), Mishnish or Loch an t' Suidhe (J.J. Lowe and M.J.C. Walker; pers. comm.) shows the expected palynological fluctuations.

> "Radiocarbon dating should show a high degree of synchroneity between sites." (p.144).

Radiocarbon dating proved disappointingly unsuccessful (sect. 3.2ix), and this point cannot be pursued further.

This two-pronged approach of Watts (1970) provides a suitable way of analysing the British sites, by
(1) the undoubted demonstration of a real vegetational revertence at any one site, and
(2) the successful correlation of sites with each other and with the continental chronostratigraphy through C14 dating.

(1) At Tadcaster, Bartley (1962) subdivided Godwin zone 1 into three subzones on the fluctuating birch

percentage curve, declining to below 10% T.P. in subzone Ic. This subzone of inferred climatic deterioration features a strong rise of Juniperus (40% T.P.). Few herb taxa expand, and Betula nana, which might be expected to increase, actually declines. No lithological changes accompany these fluctuations (contrary to the comment by Pennington and Sackin (1975), p.445), and this site does not justify the support for its importance (e.g., Pennington, 1969), failing to satisfy in any way Watts' (1970) criteria. Blelham Bog (Pennington, 1975) does not show a distinctive pollen flora at the inferred period of climatic harshness, and in the original paper on the site (Pennington and Bonny, 1970) this "Older Dryas" phase was not distinguished as a distinct bio-assemblage zone, the authors stating there was no evidence for a "general climatic recession" prior to the Loch Lomond Stadial (Pennington and Bonny 1970; p.873). The deterioration was reported later (Pennington,1975), to be revealed by decreasing concentration values for Betula, Juniperus, Filipendula and Myriophyllum alterniflorum, all considered thermophilous (but the three latter taxa are questionable in this respect: see previous discussions in this chap.). Yet Juniperus concentration and influx values decline well before the "Older Dryas," in local p.a. zone Bb,as does

Myriophyllum, so that their absence is not characteristic of the deterioration. When 90% confidence intervals are considered there is no change in pollen influx of *Filipendula*. Nor do the herbaceous taxa increase, and Watts' (1970) condition of a distinctive pollen flora is not met. The reduction in carbon content of 6 - 9% within the "Paler Organic Mud" of this period is of uncertain relevance in the absence of carbon values for overlying material.

Blea Tarn (Pennington, 1964; 1970) is regarded as showing a climatic recession within the pre-*Betula* juniper phase (Pennington, 1970), and the palynological changes associated with local p.a. zone 4b are probably the most convincing in the Lake District. These are endorsed by chemical (Pennington and Lishman, 1971) and pollen concentration analyses (Pennington, 1973). Principal Components Analysis (Pennington and Sackin, 1975) demonstrated the aptness of the original subjective zonation at this site. This site, however, stands out among other English sites in the clarity of the sequence.

Cam Loch, in northern Scotland (fig 3.13; table 3.2), correlated with Blea Tarn (Pennington and Sackin,

1975) fails Watts' (1970) second criterion, for distinctive single pollen spectra do not provide support for a climatic oscillation. That this spectrum carries some statistical significance (Pennington and Sackin, 1975) does not imply that it has any validity in vegetational terms.

Other sites from northern Scotland (Pennington, 1977b) are similarly subdivided into regional p.a. zones A1, A2 and A3. The proposed recession, zone A3, is defined over the region as having high Rumex and Artemisia, with reduced Empetrum and Juniperus, much as at Pulpit Hill. At Lochan an Smuraich and Loch Tarff subzone A3 is defined on only two pollen spectra, in which Juniperus does not decline, while at Loch Sionascaig Empetrum maintains high values. Lochan an Smuraich and Cam Loch, on which pollen influx analyses were performed, show only smoothly increasing pollen productivity throughout regional p.a. zone A.

At other sites the zonation is more convincing, and whether the patterns can be dismissed as statistical artefacts as Pennington et. al. (1972) originally suggested is uncertain. Bare-ground herbs do respond, particularly Rumex, at all sites, Thalictrum at

Loch Sionascaig, and Caryophyllaceae at Lochan an Smuraich and Loch Borralan (fig 3.13), and this apparent replication of results in taxa expected to rise in a climatic decline perhaps justifies the climatostratigraphic interpretation for certain sites. However, the absence of significant lithological, chemical or microfaunal changes indicative of soil erosion (Pennington, 1977b; Pennington et. al., 1972; Pennington and Sackin, 1975) does not suggest climatic deterioration, but neither can the alternative explanation of basin-edge collapse be supported from this evidence. Although Pennington and Sackin (1975) mention the appearance of sub-aerial diatoms in subzone A3 at Loch Sionascaig this is not supported by fig 10a of Pennington et. al. (1972), and Haworth's depiction (in Pennington, 1977b) of a corresponding regional Diatom Zone Ic is at best only a tentative assertion.

Pennington's (1977b) suggestion that the proposed climatic deterioration was of minor importance is similar to that asserted for Pulpit Hill, but Pennington's (1977b) arguments are regarded as unconvincing. The sites remain enigmatic, and the writer feels it necessary to remain non-commital on them.

The eastern Grampians is a second area from which several sites appear to show early Lateglacial climatic oscillations. Loch of Park (Vasari and Vasari, 1968; Vasari, 1977) appears from the sawtooth diagram (1968) to be subzoned on one spectrum, as at Cam Loch, while a second diagram (1977) shows such variation in the spectra that, contrary to Vasari's assertions (1977; p.146), no oscillation can be recognized.

At Corrydon (Walker, 1977) a marked decline in Juniperus and Betula, and increases in Compositae, Rumex and Selaginella occur with a change from gyttja to detritus mud, in local p.a. zone C3. The replacement of a higher seral stage by open grassland occurs over 12 cm (3 levels), and although Walker (1977) is necessarily tentative in assuming the fluctuation to be climatically induced in the absence of pollen concentration and chemical analyses the site accords with Watts' (1970) articles, and can be regarded as tentatively indicating a revertence phase.

Fifteen km south of Corrydon, and 274 m lower lies the site of Stormont Loch (Caseldine, 1980). Two pollen profiles both record major decreases in Juniperus, Empetrum and, less distinctly, Betula with

Cyperaceae and Rumex expansions, seen in both percentage and concentration analyses. In neither profile are lithological changes seen, however, and it is difficult to regard the increase in sedges as an unequivocal response to deteriorating climate, while also no increases occur in bare-ground herbs (except Rumex), but it is concluded, principally on the scale of the changes depicted, that this site is also one of the few examined to justify the authors' interpretation of an early interstadial climatic deterioration.

(2) Only Cam Loch and Blelham Bog have been radiocarbon dated, or have published dates for their stratigraphies. Blea Tarn is dated (Pennington and Sackin, 1975) by comparison with Blelham Bog.

Criticism has been made of Pennington's technique of sampling for radiocarbon dates before (Watts, 1977; Lowe and Gray, 1980) and nothing here need be added regarding the precision with which her chronostratigraphies can be assessed. In addition, the series of 11 C14 dates from Blelham Bog have been considered inaccurate on several occasions (Pennington, 1975; Pennington and Bonny, 1970; Pennington and Sackin, 1975), and correlation based on these dates is therefore extremely problematic.

Summary

Suggestions of a climatic recession equivalent to the Older Dryas of north-west Europe (Mangerud et. al., 1974) at sites in Britain are not supported by valid radiocarbon dates.

The case has been made (Watts, 1980) that on the continent the Bölling - Older Dryas transition is not totally proven. Although glacier readvances or halts are known from Scandinavia, though not all synchronous with the Older Dryas chronozone (Mangerud, 1980), these need not be reflected in the vegetation some distance away (Watts, 1980). Critical in this respect are the investigations of Bjorck and Hakansson (1982) from south Sweden, where no Older Dryas phase is detected in the biostratigraphy despite the radiocarbon dates indicating continuous deposition from Bölling times. Although recommending the adoption of the "Older Dryas" chronozone, they do so on theoretical arguments (e.g., Lowe and Gray, 1980) rather than their evidence. They accept Mangerud et. al.'s (1974) proposals, and conclude that many of the 62 C14 dates assembled are too

old. A simpler proposal might be that the glacier fluctuations recorded by Mangerud (1980) are determined by glacial

mass-balance changes not necessarily climatically induced (e.g., Hillaire-Marcel et. al., 1981).

Nevertheless, several sites in Scotland are considered to show vegetational oscillations most reasonably explained as climatic in origin. Contemporaneity remains unproven,(and thus whether these fluctuations represent the same event),and little more can be said until this point is demonstrated. The problem remains as enigmatic as ever.

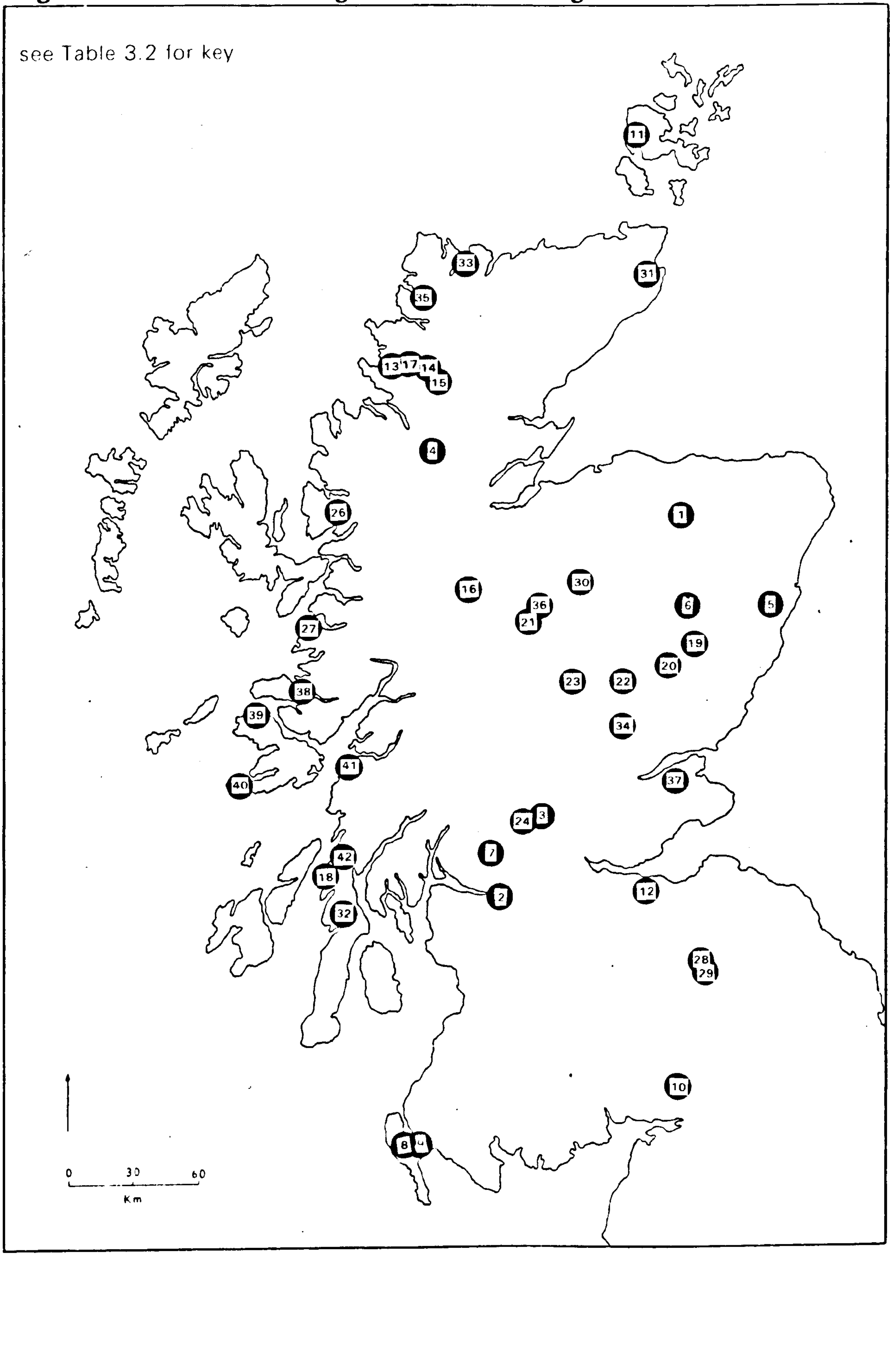
C REGIONAL VARIATION IN INTERSTADIAL VEGETATION

The regional analysis of vegetation, inferred from pollen diagrams, has been attempted at varying scales of space and time (Birks and Saarnisto, 1975; Turner and Hodgson, 1979). This section attempts an elementary synthesis of the available data from Scotland for the period of the Lateglacial Interstadial (Gray and Lowe, 1977). Fig 3.13 and Table 3.2 illustrate the data-base. The taxa selected for analysis were Betula (fig 3.14) and Empetrum (fig 3.15), the major tree and shrub taxa in interstadial pollen assemblage zones. Maximum percentages (excluding clearly anomalous single spectra) of these taxa are plotted on the figures by a scheme of proportional circles. It is assumed that these are a better measure of a taxon's representativity at maximum

Site Number	Site	Site References Principal reference used first	Grid Ref. where known c.=approx. location	Betula %	Empetrum %	Gramineae %	Artemisia %	Firn-Line Altitude	Regression Residual
				INTERSTADIAL			STADIAL		
1	Garral Hill	Donner (1957)	NJ 444551	20	45	60	NP		
2	Garscadden Mains	Donner (1957), Mitchell (1952)	NS 533713	15	5	10	NP		
3	Loch Mahaick	Donner (1958)	NN 705072	10	5	25	NP		
4	Loch Droma	Kirk and Godwin (1963)	NH c.270750	10	70	5	10	6	+1.4
5	Loch of Park	Vasari & Vasari (1968)	NO 772988	20	20	40	10	8	+3.4
6	Loch Kinord	Vasari & Vasari (1968)	NO 435997	50	25	20	20	8	+2.4
7	Drymen	Vasari & Vasari (1968), Donner (1957)	NS 490923	15	15	35	5	3	-1.1
8	Culhorn Mains	Moar (1969b)	NX 085593	15	10	55	10		
9	Little Lochans	Moar (1969b)	NX 076578	5	5	50	20		
10	Bigholm Burn	Moar (1969b)	NY 316812	8	0	40	<5		
11	Yesnaby	Moar (1969a)	HY 237152	17	40	30	8		
12	Corstophine	Newey (1970)	NT 214727	20	5	50	<5		
13	Loch Scionascaig	Pennington et al (1972)	NC c.120410	20	40	30	5	4.5	+0.3
14	Loch Borralan	Pennington et al (1972)	NC c.260110	20	30	40	10	5.5	+0.9
15	Loch Craggie	Pennington et al (1972)	NC c.330070	20	40	20	20	6	+0.4
16	Loch Tarff	Pennington et al (1972)	NH c.425100	20	40	45	35	7	-0.09
17	Cam Loch	Pennington et al (1972)	NC c.220121	10	10	20	20	5	-0.6
18	Drimnagall	Rymer (1974, 1977)	NR 714848	5	0	50	15	2.5	-2.6
19	Blackness	Walker (1975a)	NO 463786	18	+10	35	5	6	+1.9
20	Rhoineach Mhor	Walker (1975a)	NO 331728	10	5	35	5	6	+1.9
21	Loch Etteridge I	Walker (1975b)	NN 688929	26	55	17	25	7.5	+1.4
22	Corrydon	Walker (1977)	NO 132674	14	9	14	25	7	+0.9
23	Tirinie	Lowe & Walker (1977)	NN 889678	40	23	30	30	6.5	-0.1
24	Tynaspirit 2	Lowe & Walker (1977)	NN 667047	43	17	24	10	4	-0.6
26	Glasscnock	Robinson (1977)	NH 858454	1	48	20	2	4	+0.1
27	Lochan Doilead	Williams (1977)	NM 677946	5	30	35	5	4	-0.1
28	Beanrig Moss	Webb (1978), Webb & Moore (1982)	NT 517293	38	9	32	23		
29	Blackpool Moss	Webb (1978), Webb & Moore (1982)	NT 517289	10	8	30	11		
30	Abernethy Forest	Birks & Matthewes (1978)	NN 967175	30	35	20	65	10	-0.6
31	Loch of Winless	Peglar (1979)	NR 295545	10	10	25	<5		
32	Loch Cill an Aonghais	Peglar, in Birks (1980)	NR 776617	5	15	35	<5		
33	An Druim, Eriboll	Birks, H.H., in Birks (1980)	NC c.430570	7	52	23	NP		
34	Stormont Loch I	Caseldine (1980)	NO 1942	22	11	45	20	5	-0.6
35	Lochan an Smuraich	Pennington (1977b)	NC c.320390	10	65	35	15	4	-1.1
36	Tom na Moine	MacPherson (1980)	NN 683961	NP	NP	NP	25	8	+1.9
37	Pitbladdo	Donald (1981)	NO 361175	25	10	40	16	4	-1.2
38	Salen	Wain-Hobson (1981)	NM 6865	18	35	26	0	3.5	-0.1
39	Mishnish	J.J. Lowe & M.J.C. Walker (pers comm.)	NM 455565	25	20	32	10	2.5	-2.1
40	Loch an' t' Suidhe	J.J. Lowe & M.J.C. Walker (pers comm.)	NM 370215	8	15	42	8	2.5	-1.9
41	Pulpit Hill	this study	NM 851291	5	3	55	25	3.5	-2.6
42	Loch Barnluasgan	this study	NR 794915	5	10	46	7	2.5	-1.8

Table 3.2: Scottish Lateglacial Pollen Diagrams

Fig. 3.13: Scottish Lateglacial Pollen Diagrams



development than the mean percentages used by Turner and Hodgson (1979), although the writer is aware of the inherent weaknesses of this method of calculation in the control of the representation of pollen of one taxon by all other taxa. However, pollen influx measures have similar limitations to relative diagrams, such as pollen over-representation, and the limited number of pollen concentration analyses would sharply limit the data-base.

The distributions of the two taxa are described briefly, and reasons for the observed pattern suggested before the region of western Scotland, incorporating the present study area, is considered. Detailed discussions of individual sites is thought unnecessary given the numerous recent summaries of Scottish regions (e.g., Pennington _et. al._, 1972; Gunson, 1975; Lowe and Walker, 1977) and other parts of the British Isles (Pennington, 1977a; Watts, 1977).

BETULA

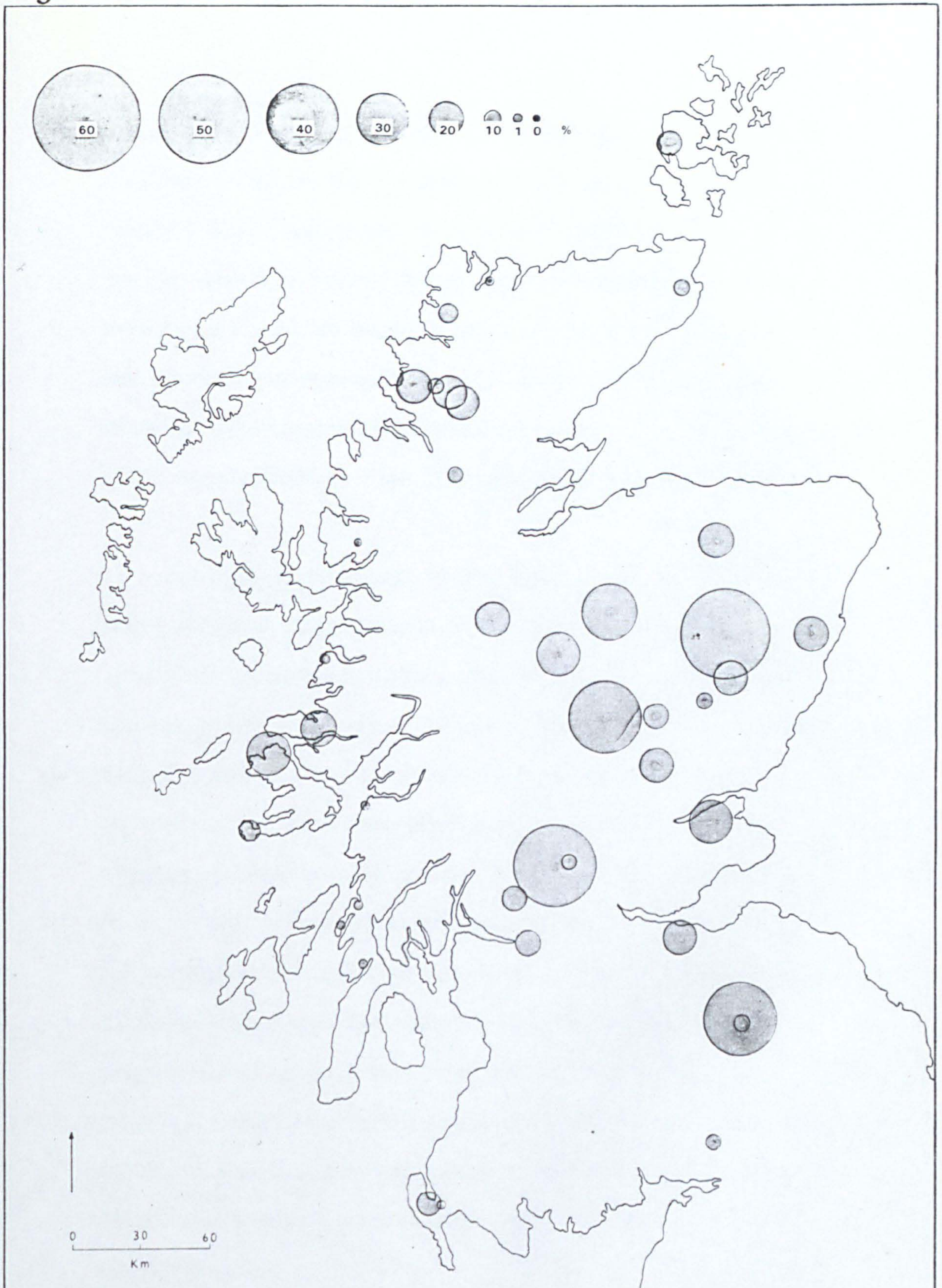
The broad picture of birch parkland, with subordinate juniper, over much of northern England and southern Scotland is complicated by smaller-scale differences believed induced by altitude (Pennington, 1970; Sissons _et._ _al._, 1973), aspect (Lowe and Walker, 1977), soil differentiation and exposure

(Gunson, 1975; Watts, 1977; Craig, 1978). Thus birch is thought to have been replaced upslope by Juniperus and Empetrum, tended to grow best on south-west facing valley floors, and inland on the thickest soils. These local factors closely controlled tree growth, partly resulting in the patchy representation of high percentages in fig 3.14. There is, however, no evidence that birch approached a climatic threshold as far south as the English border, as argued by Bartley et. al. (1976) and Webb (1977). Given suitable conditions it is clear that birch growth could be highly successful as far north as the Grampians. Vasari and Vasari (1968) also regarded the localized establishment of Pinus sylvestris as likely at Loch Kinord. The Grampians were undoubtedly a stronghold for birch, and elsewhere, even in northern Scotland, the consistent contribution (20% T.L.P.) perhaps suggests that birch was a constant subordinate component of the vegetation. The west coast is discussed later.

EMPETRUM AND ERICACEAE

North of the Great Glen numerous diagrams (Pennington et. al., 1972; Pennington, 1977b; Kirk and Godwin, 1963; Robinson, 1977; Birks, H. H. unpub.) confirm the existence of ericaceous heath as the dominant plant community. The

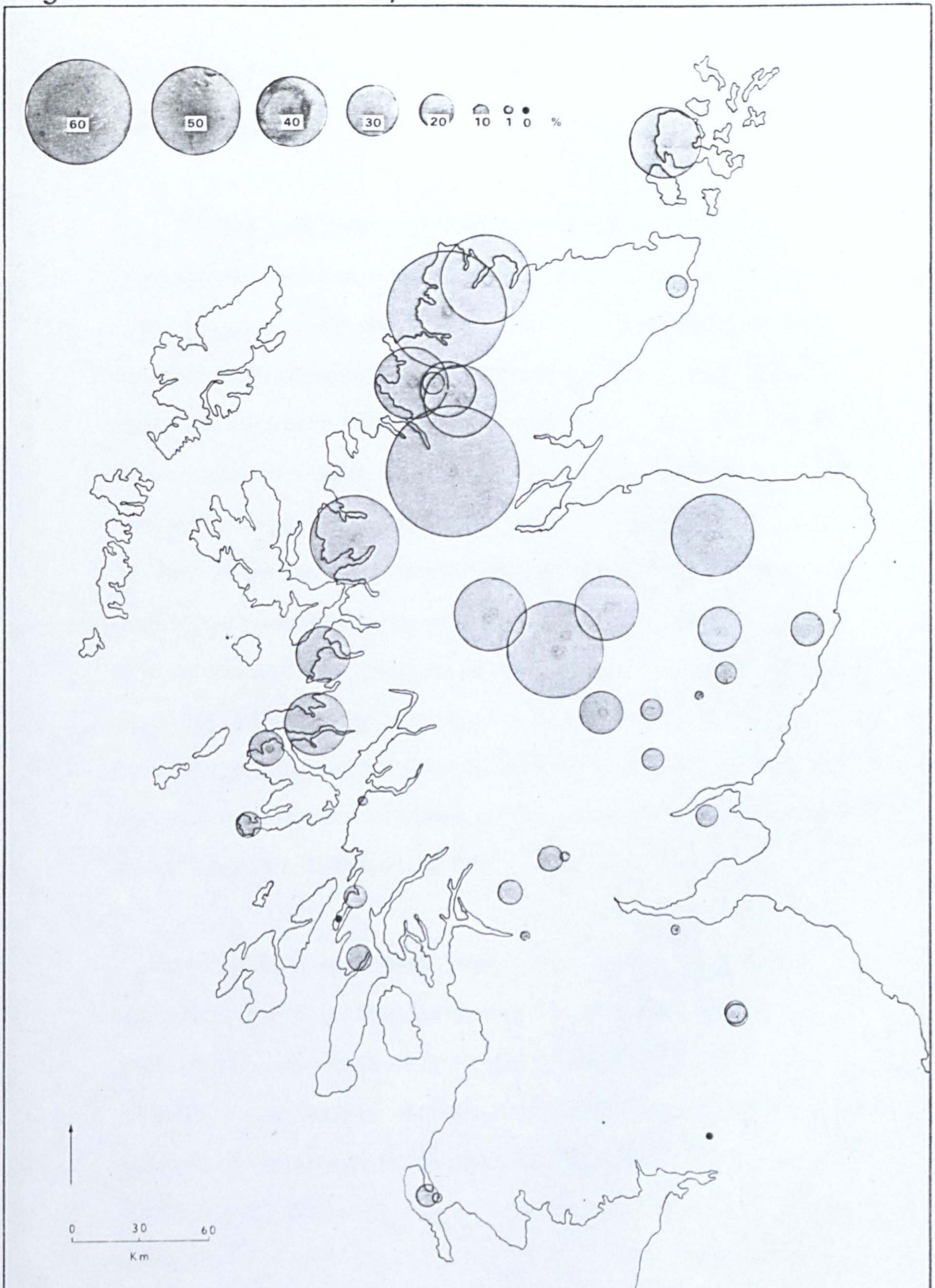
Fig. 3.14: Interstadial *Betula* Distribution



suggestion of Empetrum-dominance (Pennington et. al., 1972), in accord with Jessen's (1949) results from north-west Ireland is not supported by Robinson (1977) or Birks (H. H. unpub.) who both report Vaccinium-type and Calluna grains, predominantly at An Druim Eriboll (Birks H. H. unpub.). The same pattern exists on the outer isles also (Moar, 1969b), although the diagram from Caithness (Loch of Winless; Peglar, 1979) is affected by high, possibly local sedge values.

High Empetrum values (>30% T.L.P.) are found as far south as Salen (Wain-Hobson, 1981) and Abernethy Forest (Birks and Matthewes, 1978). There appears to be a sharp decline below this zone. If oceanicity were the determining factor (Brown, 1971) it should be expected that western Scotland might also have high representation. Instead, Empetrum is practically absent, as it is further south in Wales in the interstadial and postglacial. The outpost of Empetrum-heath on Dartmoor is anomalous for southern Britain, although most sites lie towards the west of the country. There appears to be a more distinctive correlation with rock-type, viz., the Moinian granulite-facies and granites of Scotland (fig 3.15) and granites of Dartmoor, and these siliceous, strongly acidic rocks would naturally support Empetrum-heath.

Fig. 3.15: Interstadial *Empetrum* Distribution



WESTERN SCOTLAND

On the west coast of Scotland trees were absent: Empetrum is probably absent due to changes in lithology with the siliceous rocks further north. This low representation of trees and shrubs extends south to Galloway, the Isle of Man, the majority of Ireland (Watts, 1977) and sites in north Wales (Seddon, 1962; Ince, 1981), although Moore (1970, 1977), Simpkins (1974) and Lowe (1981), have demonstrated the strong growth of tree-birch over most of mid and north Wales. There are dangers, however, in relating low pollen percentages to the absence of the tree, as at Ballaugh, Isle of Man (Dickson et. al., 1970) B. pubescens macrofossils were found, although Betula percentages did not exceed c12% T.L.P.. The nearest macrofossil evidence for tree-birch to the study area is at Greenock (Dickson, 1977).

In Ireland occasional high percentages of Betula are recorded, and macrofossils reported, as at Ballybetagh, Carrowreagh, Roundstone I (Jessen, 1949; Watts 1970) and Lecale (Singh, 1970), and open birchwoods are thought to have existed in sheltered conditions (Smith, 1970b; Mitchell, 1976; Watts, 1977).

It appears that temperature and precipitation were not deleterious to birch growth. Although Craig (1978) has suggested that a climatic decline at c12,000 B.P. (see later, sect.3.5D) might explain the demise of Betula, the inferred drop in temperature to c12° C (Bishop and Coope, 1977), if valid, would be unlikely to hinder birch growth (Iversen, 1954). Indeed, Coope and Joachim (1980) argued that temperature reductions at this time encouraged birch expansion.

Lamb (1964a) quotes McVean as providing an example of the effect of exposure on birch regeneration:

> "New birch seedlings fail to appear for a variety of reasons only one of which is directly climatic, namely, when and where desiccating winds are too strong during the fruiting period so that the catkins get blown off before maturing." (p.385)

This comment endorses what has been said about the ineffectiveness of many climatic factors. Other major controls are seen to be competition and grazing intensity (Kinnaird, 1968, 1974; Miles and Kinnaird, 1979) and must be considered briefly. Open grasslands are adequate for birch establishment. The diet of Megaceros has been proposed as a threat to birch development in Ireland (Watts, 1977; Craig, 1978), but although the Giant Elk and other large mammals are reported from Lateglacial Scotland (Stuart, 1982) it is difficult to imagine them confined to the west coast.

McVean (in Lamb, 1964a) mentions that exposure to wind does not restrict birch at the present day, and if this be the reason for the tree's absence it would appear necessary to invoke more intense westerly winds during the interstadial. Coope and Joachim (1980) have argued for a similar circulation pattern to the present day, but Lamb (1977) has also reasoned that on recovering from the Main Devensian ice-maximum, isobars over the Atlantic would have been very much closer together, and wind speeds consequently stronger. With a more energetic circulation system the dominant westerlies would not only suppress Betula but Juniperus also, as seen at Pulpit Hill and other sites in western Britain.

D PRE-STADIAL CLIMATIC FLUCTUATIONS

Workers have on occasions recognized two independent climatic fluctuations in the Lateglacial interstadial prior to the onset of the Loch Lomond Stadial. The first to be discussed is a climatic deterioration recognized initially by Craig (1978) at the southern Irish sites of Coolteen and Belle Lake. The evidence from these and other sites will be considered before appraising the sites of Pulpit Hill and

Loch Barnluasgan in this respect. Some workers (see later) have distinguished a slight climatic improvement immediately prior to the Loch Lomond Stadial, and this is considered later in connection with the anomalously high *Juniperus* in the late interstadial at Loch Barnluasgan (sect. 3.3v).

In south-west Ireland Craig (1978) recognised a major reduction in pollen concentration and influx values coincident with a vegetational revertence from a *Juniperus-Filipendula* pollen assemblage zone (12400 - 12000 B.P.) to a Gramineae phase. At Coolteen geochemical assays show the carbon content falls, but this is not apparent at Belle Lake. In England, similar changes in pollen stratigraphy were seen in the later part of the interstadial in the Lake District (Walker,1966; Pennington, 1970) but remain undated. Evidence from cladoceran assemblages (Watts, 1977) and Coleoptera (Coope, 1977, 1981; Coope *et. al.*, 1971; Coope and Brophy, 1972) suggest the warmest part of the interstadial to be before 12000 B.P., with a sudden deterioration at that date.

The pollen-spectral changes at Pulpit Hill are clearly in agreement with those at Coolteen and Belle Lake (Craig, 1978). The Loch Barnluasgan sequence is less conclusive, but a similar response can be seen in the expansion of grasslands in the interstadial (sect. 3.2vii; 3.3v). Close to the study area in Mull the radiocarbon dated site of Loch an 't' Suidhe (J.J. Lowe and M.J.C. Walker, pers. comm.) a revertence is seen from Juniperus to Empetrum-dominated zones, dated at 11860 +/- 80 B.P. (Walker and Lowe, 1982), while at the sister site of Mishnish the juniper phase gives way to a Gramineae-Plantago maritima zone clearly akin to Pulpit Hill and Loch Barnluasgan, and with the Gramineae zone defined by Watts (1977) for Ireland. Also adjacent to the study area, at Drimnagall (fig 1.5), Rymer (1977) recognizes a climatic decline in his pollen assemblage zone D 3 (a Cyperaceae dominated zone with reduced amounts of Salix and Juniperus), and the sediment becomes more minerogenic, implying increased soil erosion.

The carbon content of the sediments increases at both Pulpit Hill and Loch Barnluasgan. It may be that vegetational changes of this kind, which need not have induced an increase in bare ground, and which may have actually increased biomass,given its increase in grassland ecosystems, are not well reflected in chemical changes, bearing in mind that what is being measured need not be closely related to pedological changes. Working on estuarine deposits of this age in south-west Scotland, Bishop and Coope (1977) also noted that the climatic deterioration was associated with enriched organic sediments, but in these situations the changes may be related to hydroseral successions associated with changing sea-levels.

More problematic to the suggestion that the palynological changes indicate climatic deterioration of the two study sites are the expanding pollen concentration values, contrary to Craig's (1978) conclusions. Such increases occur exclusively in one pollen taxon, Gramineae, which is known to be over-represented (Markgraf, 1980), and concentration values need to be considered in relation to the pollen source in this case, such that the increases need not have palaeoclimatic significance.

Regarding the geographical extent of this presumed climatic pattern, it seems Craig's (1978) correlation of his and Moar's (1969a) sites in south-west Scotland (fig3.13) can be extended to include the western seaboard as far as the present study area. North of this the Empetrum heath may have been sufficiently robust to resist this phase of deteriorating climate. It certainly appears that the west of the country was more sensitive in reflecting this change. Elsewhere, birch continues to expand through this period. Even in west Wales, at Llyn Gwernan (Lowe, 1981), there is a marked expansion in Betula pollen at 12120 +/- 130 B.P., and this may reflect the suggestion of Coope and Joachim (1980), that the late-interstadial expansion of birch was a climatically controlled response to deteriorating climate, the country being too warm and dry for successful regeneration prior to this time. Thus only in areas where birch failed to establish itself is the climatic revertence recognized.

An oscillation in woody taxa close to the onset of the Loch Lomond Stadial is taken by some workers (Bartley et. al., 1976; Pennington et. al., 1972; Walker, 1975a; Robinson, 1977) to indicate a climatic amelioration at Bradford Kaims, Loch Tarff, Blackness and Glasscnock respectively. This apparent warming phase might be correlated with that thought recognized in marine sediments at Ardyne, on the Cowal Peninsula (fig.1.5) by Peacock et. al. (1978) and Peacock (1981), but the interpretation of marine palaeo-climatic sequences is complicated by time-lag effects, reworking of earlier sedimentby wave action and bioturbation etc.

A similar pattern to these might be seen in the dramatic expansion of Juniperus at Loch Barnluasgan (sect. 3.3v), although the increase is seen only in one spectrum, despite the close sampling of the sediment for pollen analyses, and at this site the effect may be explained by statistical distortions. In addition, doubts have been cast (sect.

3.2vii) on the reliability of juniper as a thermophilous indicator. Instead, it is argued that increases in certain taxa need have no thermophilic origin, but are a reflection of a deteriorating environment, both climatic and edaphic. At Bradford Kaims (Bartley <u>et</u>. <u>al</u>., 1976) and Blackness (Walker, 1975a) tree-birch is thought present, yet shows no response to the apparent ameliorating climate. In a continually deteriorating climate from c12000 B.P. juniper would be expected to expand either spatially or in pollen production when the shade-imposing birch retreated from the country. The same explanation cannot apply to areas where <u>Betula</u> was absent, but the increasingly deleterious climate would promote the break-up of the recently established grasslands and heath as 'stadial' conditions developed. This is perhaps seen in the decreasing carbon content analyses at Loch Barnluasgan (sect. 3.3v), and in the increasingly minerogenic nature of the sediments at Drimnagall (Rymer, 1977). This in turn may have promoted temporarily the expansion of shrub taxa, perhaps in sheltered areas, previously hindered by the competitive expansion of grasses. This interpretation is tentative, but perhaps most easily explains the similarity of changes seen in contrasting vegetational regions, and agrees more completely with the demonstration (above) of a climatic revertence at c12000 B.P.

E CLIMATIC DIFFERENTIATION WITHIN THE LOCH LOMOND STADIAL

Two aspects of this period are discussed in relation to its palynology; firstly, spatial differentiation, and secondly, temporal.

Suggestions of varying climatic (precipitation) intensity come principally from Birks and Matthewes (1978), in discussion on the percentage representation of Artemisia pollen in Scotland, relating its distribution to the influence of snow-bearing winds from the south and south-west. Sissons (1980b) suggested that the distribution of Artemisia conformed with the regional firn-lines constructed for the Scottish Highlands, with high Artemisia percentages reflecting aridity and, thus, precipitation-starvation. Presented below is a statistical analysis of these proposals, which goes some way to, apparently, demonstrating this relationship.

Fig 3.16 shows the maximal percentages of Artemisia, in proportional circles, at 42 Lateglacial pollen sites (see table 3.2 and discussion; sect. 3.5 C), with the regional firn-linesof Sissons (1980b; fig 4) superimposed. Anomalous peaks in pollen diagrams are discounted where possible, but given that some diagrams are "sawtooth" in outline this is not always possible. The disadvantages of percentage data have already been described (sect. 3.5 C). Errors may have occurred in extrapolating Sissons' (1980b) firn-line altitudes to the extreme east of the country, as at Pitbladdo (Donald, 1981; no. 37). Finally, caution must be applied in the environmental interpretations of Artemisia pollen (Iversen, 1954; Bell, 1969; Moore, 1975, 1980), in the absence of species recognition (Webb's (1977) study is one of the few to define Artemisia types, but only Artemisia total is used here for consistency).

The Spearman's Rank correlation coefficient r is highly significant at > 99% (0.5558) when the pollen percentages are compared with the nearest firn-line altitude (estimated to the nearest 50 m.), suggesting the relationship proposed by Birks and Matthewes (1978) and Sissons (1980b) to be correct. However, in chapter 8.2 concluding arguments will point to the recrudescence of glaciation in Scotland following the interstadial as being significantly earlier than currently thought, to be followed by a period of increasing aridity (see later in this section), such that the period of glacierization, to which the firn-line data is related, may be divorced in time from the period of Artemisia abundance. Thus the correlation may well prove to be, though statistically significant, ecologically spurious.

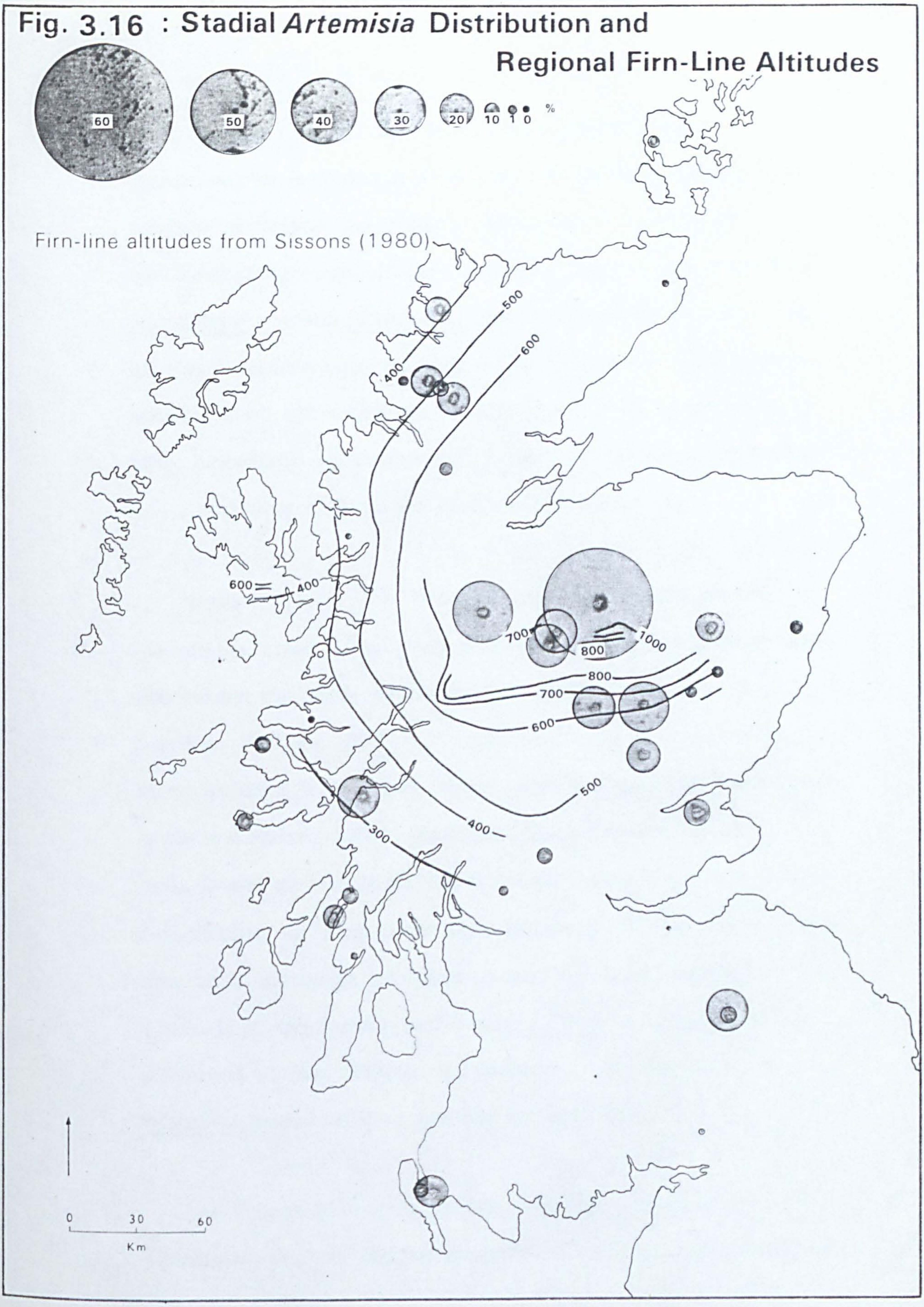


Fig. 3.16 : Stadial *Artemisia* Distribution and Regional Firn-Line Altitudes
60
50
40
30
20
10
1
0
%
Firn-line altitudes from Sissons (1980)
500
600
400
600
400
700
800
1000
800
700
600
500
400
300
0
30
60
Km

Changes through time in the Loch Lomond Stadial are emphasized by Macpherson (1980) at Tom na Moine, where she inferred a tripartite climatic sequence of oceanicity-continentality - oceanicity, based on varying percentages of Salix/Empetrum and Artemisia. Her conclusions can, however, be questioned on many counts, e.g., low pollen sums, single spectra used for zonation, adventurous use of percentage data, uncertain ecological affinities of the taxa discussed, etc., and this site is not discussed further.

Nevertheless, with the application of local pollen assemblage zones since approximately 1970, many workers have subdivided the Loch Lomond Stadial palynologically, e.g., Corrydon (Walker, 1977), Tirinie (Lowe and Walker, 1977), Stormont Loch (Caseldine, 1980), Beanrig and Blackpool Mosses (Webb and Moore, 1982), Mishnish (M.J.C. Walker, pers. comm.), and at Pulpit Hill and Loch Barnluasgan (this study). In addition, at Loch Etteridge, Walker's (1975b) local p.a. zone LE 4, although included within the interstadial has low birch, high Cyperaceae and rising Artemisia values, and is contained within minerogenic sediment. At Drimnagall Artemisia peaks only at the end of zone D4.

At Pulpit Hill this pattern has been related to increasing aridity during the stadial. Caseldine (1980) has proposed a similar pattern for the S.E. Grampians, and it appears this pattern is reproduced in varying degrees of clarity across Scotland. At the Whitlaw Mosses (Webb, 1977; Webb and Moore, 1982) the type of Artemisia has been defined as the chionophobous A. norvegica. The consistent increases of Artemisia through time are likely to reflect general climatic changes leading to precipitation-starvation at later stages of the stadial. This must undoubtedly have had a considerable effect on the development and expansion of Loch Lomond Readvance glaciers, and these implications will be discussed in chap. 8.

Fig. 3.2 PULPIT HILL 1 POLLEN PERCENTAGE DIAGRAM

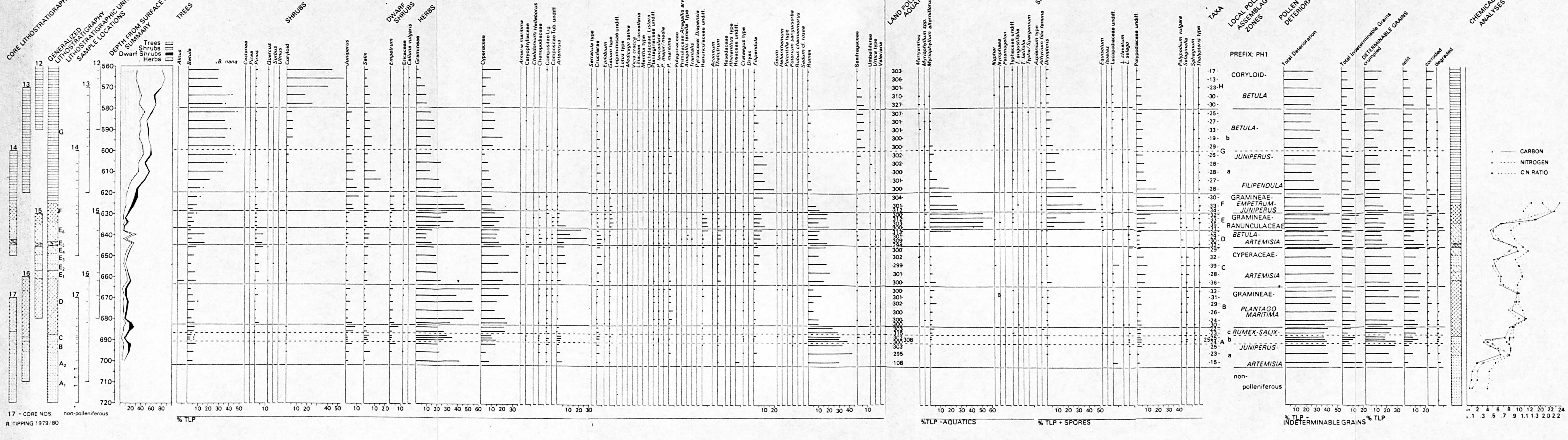


Fig. 3.5/6
PULPIT HILL 2 POLLEN PERCENTAGE/CONCENTRATION DIAGRAM

R. TIPPING 1981

Fig. 3.11 LOCH BARNLUASGAN POLLEN PERCENTAGE DIAGRAM

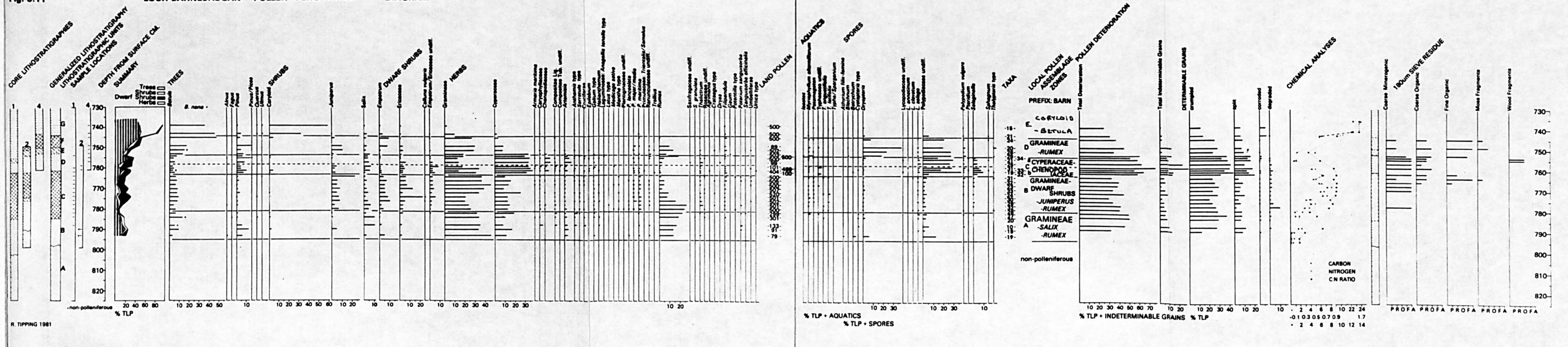
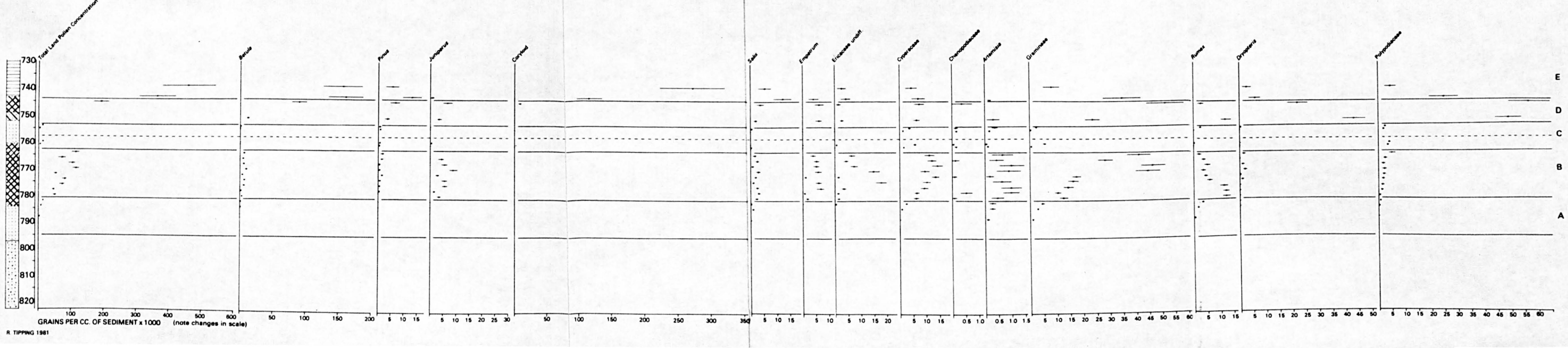


Fig. 3.12
LOCH BARNLUASGAN POLLEN CONCENTRATION DIAGRAM



CHAPTER FOUR

TWO FURTHER LATEGLACIAL SITES

4.1 INTRODUCTION

These sites are distinguished from those in chap. 3 by having only limited developments of Lateglacial sediments. As will be seen, it appears that at both sites, Na Lona Min and Lon Glas, interstadial and pre-interstadial sediments (sensu Pennington et. al., 1972) are absent, so that only deposits of Loch Lomond Stadial age underlie post-glacial and Flandrian sediments. These distinctive sequences are argued to be directly related to the behaviour of valley glaciers in the stadial.

Both sites will be described initially, and their geomorphic significance analysed, before the data from these sites, the full Lateglacial sequences at Pulpit Hill and Loch Barnluasgan, and other sites from western Britain are combined to demonstrate the consistency of the early Flandian vegetational succession.

4.2 NA LONA MIN (g.r. NS 046881; lat.56°02' 48" N: long. 5°08' 15" W)

4.2.i Site Location and Geomorphic Setting.

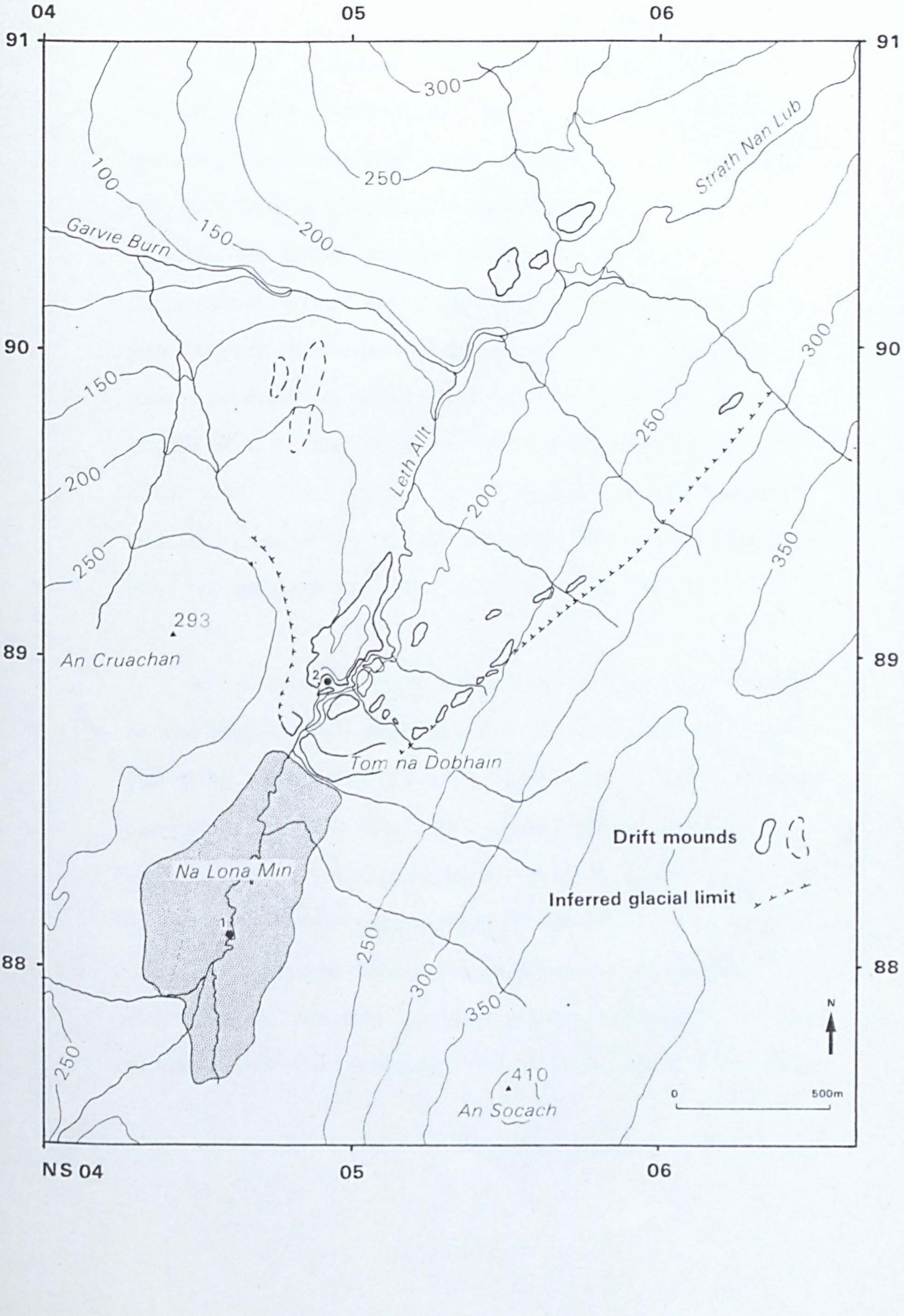
The site lies some distance from others in the study area, south of Loch Fyne in the Strath nan Lub (fig. 4.1), a valley parallel to the larger Glendaruel valley (fig. 1.3).

The basin of Na Lona Min lies on Forestry Commission land at an altitude of 207 m O.D., surrounded by hills some 200 m higher (fig. 4.1). Immediately south of the area shown on fig. 4.1 the valley-head reaches 230 m O.D., so that the river, the Leth Allt, drains northward through the peat-bog of Na Lona Min before joining the west-flowing Garvie Burn (fig. 4.1).

Also depicted are the results of geomorphic mapping of the valley-system. Mapping was hampered by spruce plantations on An Cruachan and An Socach, but between Na Lona Min and the Garvie Burn was successful.

Immediately north of Na Lona Min is the prominent, 15 m high crescentic moraine ridge of Tom na Dobhain (fig. 4.1), bisected by the present Leth Allt. Within this ridge, interpreted as a terminal moraine, are drift mounds 4-5 m high, grading into featureless till over 10 m thick (seen in sections in the Garvie Burn at N.S. 053900). These mounds have the appearance of hummocky moraine, sections showing a basal silty, micaceous-rich matrix-supported till overlain generally by thin laminated silts and clays and finally by well-bedded fluvial sands and gravels, the sequence interpreted as deglacial in origin, lake-clays overlain by fluvioglacial deposits.

Fig. 4.1: Na Lona Min. Location of pollen sites and geomorphic setting



These mounds are separated by small, shallow kettle-holes (i.e. site 2; fig. 4.1; see later).

A series of hummocks is aligned roughly parallel to the valley-side (N.S. 053888) and a clear drift limit, demarcated by a break of slope, stream incision into the till and bedrock exposures above this limit, can be seen from the end of the terminal moraine at 220 m O.D. to 290 m some 1600 m up-valley, beyond which plantations made mapping difficult. Gunn et. al. (1897) trace this tongue of morainic drift beyond the Col of Strath nan Lub at 350 m O.D. into the north-flowing Glen Branter (fig. 1.3). Gunn et. al. (1897) argued that the terminal moraine "clearly caused the formation of the moss Na Lona Min by damming the drainage outlet". (p. 257).

On the western valley-side a drift limit is delineated on the slopes of An Cruachan (N.S. 048898), rising from 220 m to 230 m O.D. in 600 m before it is lost, although Gunn et. al. (1897) describe several sets of moraines running W.S.W. down Garvie Burn. Two low linear ridges trending N - S were mapped at N.S. 049898: their origin is unclear. Augering revealed coarse sands as with other drift mounds, but they are unrelated to a drift-limit, are linear rather than hummocky, and lack the steep inner slope of lateral moraines. Their position on the ridge-top is anomalous, and they may represent crevasse fills, but this is very uncertain. No geomorphic evidence was found on the slopes of the Glendaruel valley to demonstrate continuity of these deposits with those mapped by Sutherland (1981) in Glendaruel (fig. 1.2).

At Glendaruel clear evidence of fluvioglacial deposition is found in the form of eskers, kames, possible kettle-holes and fluvio-glacial terraces graded to "a sea-level at least as low as 12.5 m." (Sutherland, 1981; p.135). Regarding the dating of these deposits, Sutherland considered them to be post-Otter Ferry stage (post-13,000 yrs. B.P.), but suggested that the ice-front retreated only a few hundred metres between the high (37.5 m. O.D.) sea-level of the Otter Ferry stage to the later deposits, during which time sea-level dropped at least 25 m (on the basis of absence of sea-level evidence within this limit)(cf. chap. 8.3). Later he briefly considered the possibility that the second ice-front is related to the Loch Lomond Readvance, but considered such a correlation would "pose a considerable problem as to the origin of the glaciers" (p. 247).

Related to the Otter Ferry stage is an alluvial fan debouching from a gorge leading from the valley-head of Leth Allt, at an altitude of 38 m O.D. (Sutherland, 1981), believed to have been fed by melt-water from a glacier occupying Leth Allt, which Sutherland (pers. comm.) associates with the Tom na Dobhain moraine and the Na Lona Min lake-basin. No lake shore-lines could be mapped because of the Forestry Commission plantations, and this relationship remains unproven.

4.2.ii Sampling

Given the very large size of the basin, (3800 m^2), regular depth-probing was not attempted. Efforts to determine the sub-surface morphometry were thwarted by extensive spreads of gravel beneath the 2.0 - 2.5 m of blanket-peat covering the old lake-surface. It is uncertain whether the sampling point (1: fig. 4.1) is the deepest point of the basin, and the absence of interstadial sediments cannot thus be proved. Shallow seismic surveying was considered in proving this point, but this method gives anomalous readings induced by buried gravel lenses.

A series of 12 x 1.0 m Russian cores were taken with 50 cm overlaps to a depth of 6.50 m when bedrock was struck (fig. 4.2). Relative pollen counts were completed principally in autumn 1981, and 17 pollen concentration analyses (fig. 4.3) were performed six months later, indicated on fig. 4.3: "Sample Locations".

4.2.iii Generalized Lithostratigraphy.

The complexity of the sequence portrayed in fig. 4.2 necessitates the generalizing of individual lithological units, so that litho-units can include several changes in lithostratigraphy.

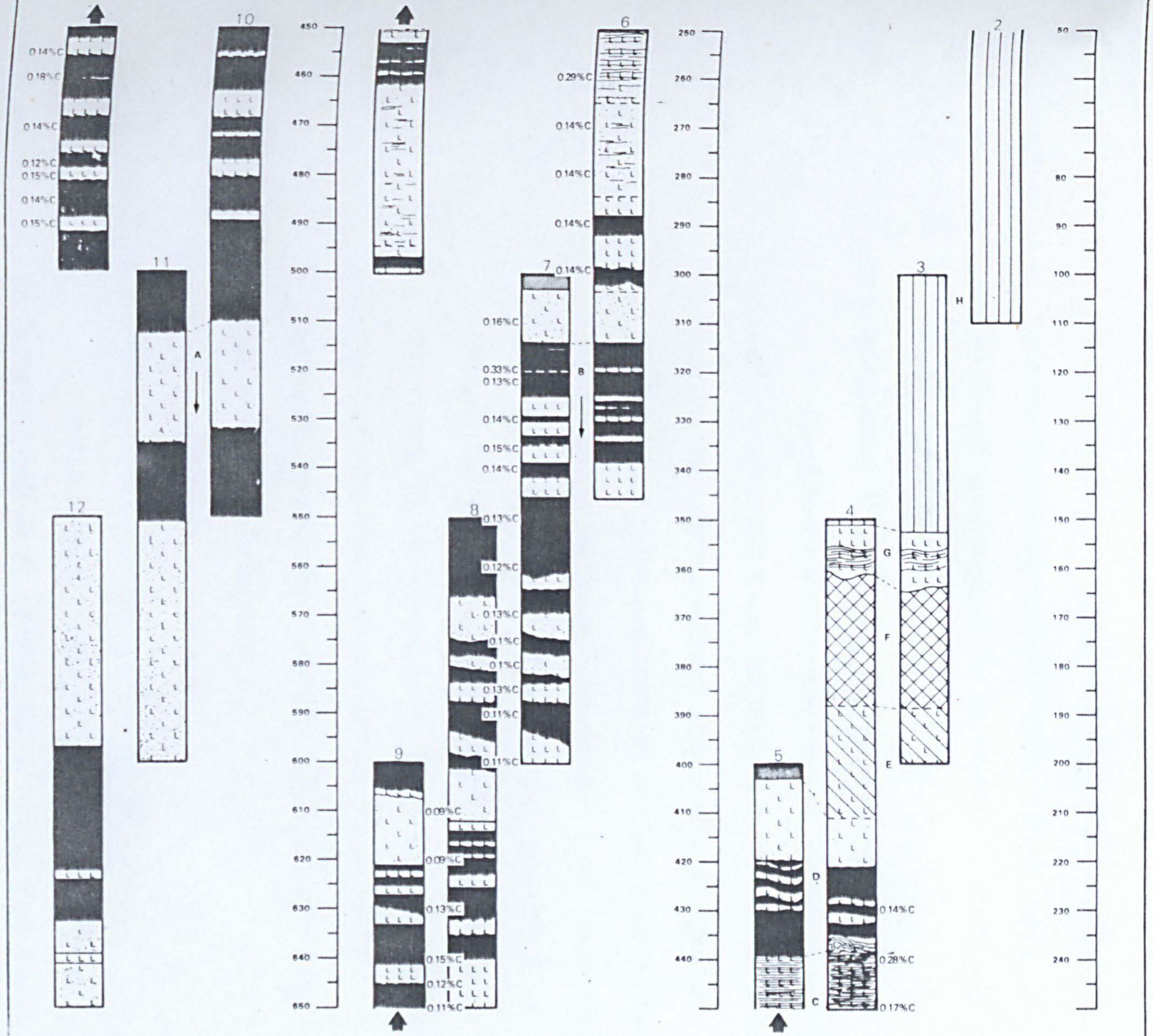
LITHOSTRATIGRAPHIC UNIT A : 650 - 511 cm.

predominantly silty-clay or clayey silt, but with two clay-bands in core 12, and areas of clay-enrichment in other bands: major sub-units differ in colour, from 5Y 3/2 dark olive gray (dark bands) to 5Y 5/1 gray (light bands); occasional stones; boundaries within unit sharp, but transitional to

LITHOSTRATIGRAPHIC UNIT B : 511 - 314 cm.

characterized by generally finer and more clayey bands, banding or laminations distinguished principally on colour (dark = 2.5 Y 5/2 grayish brown; light = 10 YR 5/3 brown) though dark bands have slightly increased silt content (not depicted on fig. 4.2); dark bands consistently thicker than light ones, although both types range in thickness

Fig. 4.2: Na Lona Min: Lithostratigraphy



considerably (6 mm - 9 cm for dark, 3 mm - 4 cm for light) and although lower bands are usually thicker fine laminae appear, poorly defined, with vague boundaries, within all sub-units; occasional stones; boundaries usually sharp, though not truncated or eroded (x 20 stereoscopic microscope); sharp boundary to

LITHOSTRATIGRAPHIC UNIT C : 314 - 238 cm.

essentially similar sequence of colour - and texture - banded clays, silts and silty-clays, darker colours closely correlated with high silt-content, the unit being distinguished on a clearly recognized fining-upward sequence, with bands 1 cm thick below 255 cm , finer above and exceedingly fine, (< 1mm) between 247 and 239 cm , clay laminae more uniform in thickness than more variable silts, and increasing silt content down-unit accounting for such changes, although fine laminae are still found, as between 261 - 294 cm (core 5);

transitional boundary to

LITHOSTRATIGRAPHIC UNIT D : 238 - 203 cm.

initially very finely (mm scale) laminated alternations of 10 YR 5/2 grayish brown clay and 10YR 5/1 gray muscovite-rich silty clay, showing penecontemporaneous contortions, changing upward to

5YR 5/3 reddish brown clayey silt/silt, with laminae thickening rapidly and disappearing above 228 cm due to increasing silt input; increasingly organic above 224 cm ;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 203 - 187 cm.

10 YR 3/1 very dark gray organic-rich micaceous silty clay, macrofossils common;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT F : 187 -162 cm.

high silt input decreasing upward to organic-rich silty clay, and very dark brown (10 YR 3/2) clay/gyttja above 181 cm , darkening on exposure to 5 YR 2.5/1 black, with macrofossils (leaves, stems, seeds) common;

sharp,wavy boundary to

LITHOSTRATIGRAPHIC UNIT G : 162 -152 cm.

10 YR 3/2 very dark grayish brown pure clay, changing at 158 cm to faintly laminated (0.5 - 1.0 cm) clays with organic gyttja bands, reverting to clay above 155 cm ,

sharp boundary to

LITHOSTRATIGRAPHIC UNIT H : 152 - 35 cm.

fine sedge-peat, well-humified, few macrofossils:

transitional boundary to

LITHOSTRATIGRAPHIC UNIT I : 35 - 23 cm. (not depicted on fig. 4.2)

very coarse sedge-peat; 5YR 2.5/2 dark reddish-brown;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT J : 23 - 4 cm.

coarse sedge-peat with increasing minerogenic (sand) influence;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT K : 4 - 0 cm.

mixture of coarse sedge-peat and veins of fluviatile stones, sand and silt.

4.2.iv Biostratigraphy (figs. 4.3; 4.4)

650 - 295 cm : Non-polleniferous

Spectra depicted on fig. 4.3, and others sampled at 20 cm intervals through cores 10, 11 and 12 failed to attain the criteria defined in chap. 2 (sect. 2.7) for polleniferous sediment, despite using much larger sediment samples than usual.

295 - 222 cm : local p.a. zone NLM 1

Cyperaceae - Gramineae

Herbs exceed 70% T.L.P., principally sedges and grasses. Few other taxa are distinctive, although

Chenopodiaceae, Compositae Liquliflorae, Epilobium and Artemisia are conspicuous. Pinus and coryloid values are infrequently high also.

Total deterioration is very high, with crumpled grains prominent, and indeterminable grains also numerous.

222 -209 cm : local p.a. zone NLM 2

Rumex - Gramineae

While sedges decline and Gramineae values remain high, Rumex values increase to 22% T.L.P., accompanied by Ranunculaceae undiff., restricted to this zone, and slowly rising values of Empetrum. Compositae continue to register high values, while Chenopodiaceae, and, of the spore-producing taxa, Lycopodium selago, Selaginella and Polypodiaceae decline from their former high values. Betula values, with B.nana-type grains now determined, increase notably with Juniperus and Salix.

Pollen concentration is very low, only rising slightly above 210 cm. Total deterioration is significantly lower than zone 1.

209 - 197 cm : local p.a. zone NLM 3

Empetrum - *Juniperus* - Gramineae

Ericaceae undiff. pollen is recognized in every spectrum, but *Empetrum* is the principal dwarf shrub, rising smoothly to 17% T.L.P., while juniper expands as prominently in the latter half of the zone. Trees and other shrubs show no change, and although Gramineae persist strongly few herbs, except *Filipendula*, are distinctive, and many are unrecorded in this zone (e.g., *Armeria*, Chenopodiaceae, *Epilobium* and Leguminosae). Polypodiaceae and *Dryopteris* expand, albeit very erratically.

Deterioration is again reduced but very consistent within the zone, while total pollen concentration shows no change.

197 - 183 cm : local p.a. zone NLM 4

Betula - *Juniperus* - *Plantago maritima*

Juniperus rises to a peak of 25% T.L.P., but declines to 4% T.L.P. within the zone, whereas *Betula* rises consistently to 47% T.L.P. throughout. *Salix* begins to increase, while the grasses maintain values around 15% T.L.P., with *Filipendula* and *Plantago maritima* expanding, the latter declining abruptly at the upper zone boundary. Pollen concentration rises steadily.

183 - 171 cm : local p.a. zone NLM 5

Betula - Coryloid - *Salix*

With birch consistently high, coryloid grains expand dramatically to 54% T.L.P., and *Salix* reaches maximum representation as *Juniperus* returns to very low values. *Salix* also declines within this zone, however. All herbs suffer percentage reductions, except *Filipendula*. Compositae are not recorded in this zone, nor are aquatics, and most spore-producing taxa decline also.

Total deterioration is now at its lowest in the diagram, while total pollen concentration continues to rise consistently.

171 - 161 cm : local p.a. zone NLM 6

Coryloid

Coryloid grains dominate the zone at a maximal 77% T.L.P., whereas *Betula* grains decline very rapidly to below 15% T.L.P.

Juniperus is only recorded at one level (one grain), *Salix* values are also reduced, dwarf shrubs rarely recorded, and herbs total only 10% T.L.P.

Total deterioration values increase.

161 - 136 cm : local p.a. zone NLM 7

Coryloid - Mixed Oak Forest - Alnus

this zone sub-divided, thus:

(a) 161 - 155 cm.

Betula percentages decline no further, Pinus shows a small peak, while coryloid grains, though still very important, are recorded at much lower values. Elm and oak expand, apparently synchronously.

Sedge percentages expand only slightly, but major changes are seen in the aquatic taxa, with Isoetes reaching 72% T.L.P. + aquatics, and in the spores where Polypodiaceae and Sphagnum increase also.

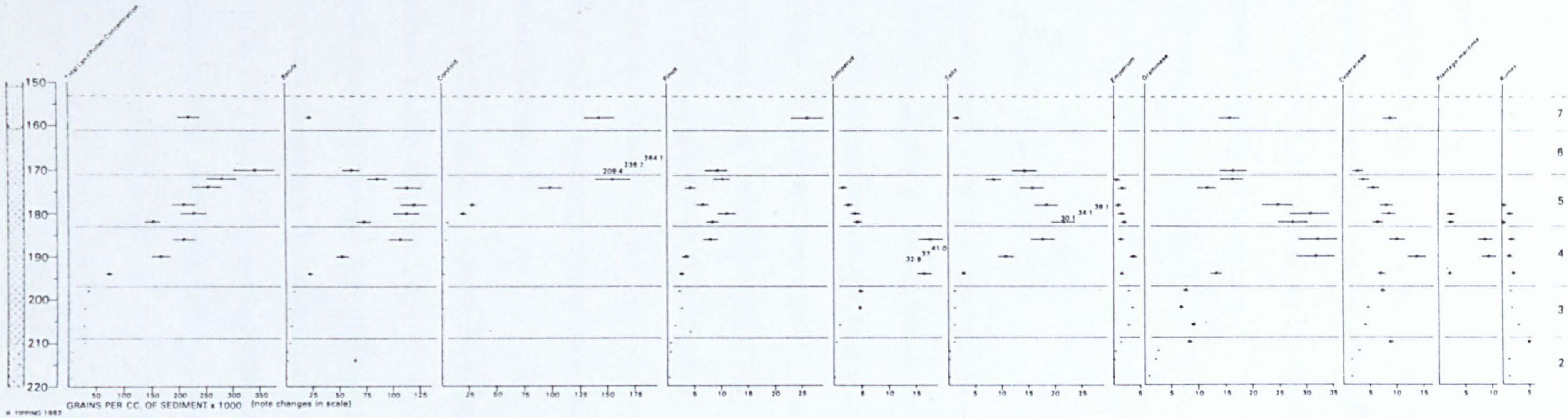
Marked increases in corrosion mean total deterioration is again very high.

(b) 155 - 136 cm.

The major taxa remain consistent, and the subzone is marked by a rise to over 10% T.L.P. of Alnus.

Fig. 4.4

NA LONA MIN POLLEN CONCENTRATION DIAGRAM



4.2.v Geomorphic Significance

The basal sediments of the site are believed to date from some period within the Loch Lomond Stadial (sect. 4.1), and related directly to the Tom na Dobhain moraine. These conclusions are based on two independent lines of evidence, (a) palynological and (b) sedimentological.

(a) Palynological results

It is clear from the few pollen spectra (fig. 4.3) from the non-polleniferous sediments below 295 cm. that interstadial vegetational assemblages (viz. chap. 3) are not recorded. Two reasons are thought likely to explain the non-polleniferous nature of the sediments; (i) the very limited pollen productivity of the vegetation, and (ii) the extremely rapid sedimentation rate at this time (discussed below).

The earlier pollen assemblage zone is similar to the spectra below 295 cm., and it appears that there is little change between the two zones. From the fining-upward sequence in the sediments (sect. 4.2.iii) it is suggested that at this phase the sedimentation rate was reduced rather than that pollen productivity rose.

There is a close comparison between this zone and those described from stadial sediments at Pulpit Hill (sect. 3.2.vii) and Loch Barnluasgan (3.3.v). Cyperaceae numbers are seen to exceed the counts for grasses, Chenopodiaceae reach 5% T.L.P., with Artemisia consistently recorded, though at this site not abundantly. More importantly, in view of what was argued in chap.3 regarding climatic control of the expansion of docks and sorrels in the earliest post-glacial, Rumex is low here despite the tendency for this taxon to be over-represented in pollen rain. The pollen-taxon is seen to rise in percent and concentration terms in zone NLM 2, and another important taxon here is Ranunculaceae undiff., also believed (chap. 3) to mark the change to milder climatic conditions in the earliest post-glacial. The major vegetational changes in this lower part of the diagrams (figs. 4.3; 4.4) occur at the pollen zone 1/2 boundary, with grasses and grassland plants, Leguminosae, Caryophyllaceae, Plantaginaceae, Ranunculaceae (Thalictrum) and Rosaceae expanding, and bare-ground plants declining.

Galium also rises in zone NLM 2. It has been associated with Epilobium at the Late-glacial sites (chap. 3), but here the taxon declines in percentages at this period. *Epilobium* is known to be closely related to pioneer herb communities, Cooper (1939) describing *E.latifolium* as growing on dry, minerogenic substrates, *E.palustre* in damper areas in Alaska at the earliest colonization stage. Matthews (1978) describes a similar role in Norway. Both species die out with increasing competition, Viereck (1966) pointing out that in closed grasslands the plant does not flower, and it appears to be a good indicator at Na Lona Min of open conditions. *Lycopodium selago* and *Selaginella selaginoides* are conspicuous, with *Lycopodium clavatum* in zone NLM 1, again comparable with stadial assemblages.

There seems little doubt that the transition from zone NLM 1 to 2 marks the environmental change from stadial to post-glacial conditions. The spectra below zone NLM 1 provide meagre evidence for vegetational change in these sediments. There might be thought the possibility of a major unconformity between, for instance, the clays, which might be considered of pre-interstadial age, and overlying Flandrian organic sediments, but the consistency of the palynological fluctuations in spectra sampled at

2 cm intervals is felt to preclude this possibility.

The stages of vegetational succession in zones NLM 2 - 7 cannot be interpreted as reflecting an interstadial sequence in the way each pollen assemblage zone follows the pattern described briefly at Pulpit Hill (chap. 3) for the Flandrian, without vegetational revertences, until the rise of Corylus, unmistakably indicative of the Flandrian (Godwin, 1975).

(b) Sedimentological results

No major erosion surfaces or unconformities are seen in the detailed lithostratigraphy presented (sect. 4.2.iii; fig. 4.2), or are suggested in the results of the carbon content analyses therein. It is thought the sequence was deposited in one uninterrupted period of time.

The descriptive term "band" in sect. 4.2.iii refers to sedimentary sub-units several centimetres thick, principally silt or silt-dominated, while "laminae" are the very fine millimetre thick clay-rich sub-units. Both are, however, thought to relate to essentially the same sedimentary feature, in that generally each dark band is capped by a light one in a very regular and repetitive sequence, to which the term rhythmic sedimentation can certainly be applied, the couplets of light and dark sub-units being defined as rhythmites. Such a definition does not imply seasonality. The rhythmites here cannot be demonstrated to be varves, and arguments for such an origin must remain inferential. Rather than simply assume such an origin, as is commonly done (Smith, 1959), comparisons with recent studies on varved sediments are presented which make such a conclusion seem very likely given the environmental setting.

Studies of proglacial lake-deposits left during the Wisconsinan glacial retreat on the northern American continent (Fulton, 1965; Gustavson, 1975; Shaw, 1975, 1977; Shaw and Archer, 1979; Ashley, 1975), in the English Lake District on Late-glacial clays (Smith, 1959; Holmes, 1968) and of the theoretical and observational mechanism of varve deposition (Agterberg and Bannerjee, 1969; Church and Gilbert, 1975; Sturm, 1979) provide a sizeable body of data from which to draw comparisons. It is now well-known, however (Schluchter, 1979) that not all varves are glacio-lacustrine in origin, but are certainly regarded as typical of such environments (Flint, 1957).

Classifications of varve-like sediments are generally based on grain-size, thickness of couplets and/or individual laminae, types of contact between couplets and sedimentary structures. According to Agterberg and Bannerjee (1969) a varve is composed of three "genetically dissimilar" parts (p. 647), a silt "summer" layer deposited in a short time-period by turbidity currents, and a clay "winter" layer comprising (a) a component deposited by the turbidity current after stagnation, and (b) an upper layer deposited by slow, continous settling. Reference has already been made (sect. 4.2.iii) to the more-or-less constant thickness of light-coloured clay laminae in the litho-units, and this characteristic has commonly been observed in varves (Ashley, 1975; Smith, 1959; Shaw, 1977) and attributed primarily to the uniform settling of suspended sediment.

The contrast between proximal-to-the-source deposits, thick, sandy units with prominent ripple-drift cross-laminated features and distal, comparatively thin silty and clayey units, occasionally but not always showing graded bedding, has been described by Gustavson (1975) and Shaw (1975). Depth-probing near the moraine at Tom na Dobhain (N.S. 048886) failed to penetrate a sand and gravel layer beneath blanket-peat c 2.0 m deep. With the idea that this may represent the proximal pro-glacial delta an attempt to penetrate this layer, or at least to prove its persistence with depth, was made using a power-corer, but the attempt was unsuccessful. The only successful sample retrieved showed thinly laminated clays (litho-unit C), but what lies below this is unknown. In the absence of coarse sand layers and current-bedding the deposits at the sampling site are regarded as distal. (The terms "distal" and "proximal" used in the following discussion, when related to the lithostratigraphy at Na Lona Min are not intended to imply spatial fluctuations of the sediment-source: see later).

Investigations at Glacial Lake Hitchcock in Connecticut by Ashley (1975) dealt with, principally, distal varved sediments, which she classified into Groups I, II and III according to whether clay thickness was greater than, equal to or less than that of the silt, respectively. This is a classification that could be applied to the deposits at Na Lona Min. Litho-unit A seems clearly to resemble Ashley's Group III, with clay bands (including those blurred and not included on fig. 4.2) of constant thickness (2 cm). Silt layers can be up to 250" (635 cm : Fulton, 1965), well within the range represented at Na Lona Min. These silts can show several fining-upward sequences within one unit (several turbidites in one year, rather than annual deposits), but such could not be detected in the Na Lona Min cores. Thin laminations can be found within these silt bands (Ashley, 1975; fig. 8a), and may mark the tops of successive turbidites.

Varves of Group III are thought more proximal than the remaining groups, and the increasing clay content of litho-unit B is taken to represent a more "distal" location. Although couplets vary considerably in thickness, Group III rhythmites are still represented. Again, the dark, silt-enriched bands vary more than the clays, and fine laminae occur. The fining-upward sequence continues in litho-unit C, where below 255 cm Ashley's Subgroup

II c varves, couplets exceeding 1.25 cm thick, of equal proportions, appear to be present. Above 255 cm these couplets narrow (Sub group II b), and then between 247 and 239 cm appear as micro-laminations of Subgroup II a (Ashley, 1975). This transition is also regarded as an increasingly "distal" trend, with Subgroup II a representing an "unusually small amount of sediment entering the lake annually at the time of deposition. Varves from this subgroup are found only at the top of the lake section, which suggests that they represent a sediment-starved final stage" (p. 308).

This is not quite the final stage at Na Lona Min. Before unlaminated and organic-rich lake sedimentation (litho-units D and E) commences, the lower part of litho-unit D is characterized by a few distorted Subgroup II c couplets, implying temporarily increased "proximality". It is tempting to relate this to a final period of stronger sediment discharge with deglaciation, and to correlate this with the gravel layer overlying litho-unit C at Tom na Dobhain.

Boundaries between couplets, and between sub-units are more frequently sharp than transitional. Emphasis has in the past been placed on the silt layer grading into the clay (e.g., Smith, 1959), but this is not generally held today (Ashley, 1975; Sturm, 1979). Colour differences are not discussed by the above workers, though are noted, and the dark colour is generally assumed to relate to organic slope-wash sedimentation in the winter; hence the clays are usually darker. Smith (1959) also relates the differences to water content and grain size. This is not the case at Na Lona Min, where the silt is darker, the colour being derived from concentrations of mafic minerals, coarser and probably denser than the light muscovite-rich clays. Comparison of the carbon contents of light and dark bands (fig. 4.2) showed no differences, dark bands (12 determinations = average 0.133 +/- 0.02%) having the same low enrichment as light (9 determinations : 0.132 +/- 0.016%). It seems reasonable to suggest the colour differentiation seen in the sediments to be the result of density grading, where the mafic minerals sink to the lake-floor faster than the lighter, platy, micaceous minerals. Sources of mafic minerals within the catchment are few. Dolerite dykes provide the only potential source, the micaceous schists of the valley containing only a limited assemblage of minerals, principally epidote and chlorite. The sediment-source may in this case be charged with rock-types exotic to the catchment, and glacial transport must be a likely candidate in the absence of fluvial sources from mafic bedrock.

The rhythmic sedimentation suggests that bursts of sediment input are responsible, and soliflucted slope-wash is felt an unsatisfactory explanation. Turbidity currents are a more likely source, but from the investigations of Lambert and Hsu (1979), in Swiss lakes where varve-like sediments are related to stream-borne turbidity currents, this mechanism cannot be presented as proof of glacio-lacustrine origin.

Fining-upward sequences as recorded at Na Lona Min are very common in proglacial lakes where the source of sediment, the glacier, retreats up-valley, sediments becoming increasingly distal. It is apparent, however, that a glacial source could not have approached nearer the sampling site than Tom na Dobhain, and retreat from that position would, with the gradient of Leth Allt (fig. 4.2), probably result in drainage down-slope away from the lake, cutting off the principal sediment supply to Na Lona Min. Reductions in sediment input or meltwater discharge, perhaps through climatic fluctuations, would explain the apparently "distal" appearance of the rhythmites. Granar (1956, in Church and Gilbert, 1975) notes a strong correlation between varve thickness and discharge. Whether this can be related to the increasingly arid nature of the stadial (chap. 3) is unknown.

One major argument for a glacial source for the deposits must be the remarkable thickness of deposits in the basin, related to the Loch Lomond Stadial. The thickest sequence of stadial deposits in the British Isles known to the author, at Rhyd-y-fen in N. Wales (Lowe,S. unpub.) are some 150 cm thick. Even given the catchment size at Na Lona Min it is difficult to account for the 4m 30 cm of clay by slope or stream-processes alone.

Together, the varve-like rhythmites, fining-upward sequence and appearance of "exotic" minerals, and the great thickness of sediment are considered to indicate that the most likely source of sediment was a glacier, presumably that which formed the moraine at Tom na Dobhain, and that the sediment deposited by this glacier was of Loch Lomond Stadial age.

The sediments are considered to be varves. It might be thought that an estimate of the time the glacier remained at Tom na Dobhain might be obtained by counting the couplets, but counts were not made because the indistinctness of many laminae, particularly in litho-units A and B meant that errors, perhaps sizeable errors, would render the determinations of little value. Resampling using "frozen-finger" corers (Swain, 1973) is considered necessary.

Considering the hummocky drift down-valley of Tom na Dobhain to be of Loch Lomond Readvance age, attempts were made to locate a site within the kettled terrain. Site 2 (fig. 4.1: N.S. 04938890) is a shallow (2.54 m) kettle-hole containing the following lithostratigraphy:

145 - 0 cm : very dusky red (10 R 2.5/2) wood-peat.

237 - 145 cm : 7.5 YR 3/2 dark brown fen-peat.

243 - 237 cm : peaty gyttja.

254 - 243 cm : 5 Y 6/3 pale olive coarse to fine sands.

Pollen analyses of the basal 10 cm (excluding the sand-unit) recorded high Alnus (11%), Betula (20%, decreasing to 15%) and Corylus (rising from 10 to 15%), with high Calluna (11%) and associated Ericaceae, but no Empetrum, Juniperus or Rumex. Grasses and sedges totalled 35%, and Sphagnum (5%) was recorded, with a few grains of Fraxinus. The stratigraphy is clearly post-glacial, and may date from just after the regional appearance of Corylus, given low (1% T.L.P.) values for Quercus (it is argued in sect. 4.4 that the Alnus rise cannot be relied upon in a relative chronology). The site contains no pre-Loch Lomond Stadial sediment, but in not commencing at the early postglacial Rumex rise the value of the site in terms of glacial chronology is questionable.

The evidence for the dating of the moraines can strictly only relate to the valley system of the Strath nan Lub, and cannot be applied to other valleys, such as Glendaruel. In chapter 8 this site and the results of the investigations at Lon Glas (sect. 4.3) will be combined with other considerations in a reconstruction of stadial glacier patterns in the region.

4.3 LON GLAS (g.r. NM 878015 : lat. 56°09'20" N. long. 5°25" W).

4.3.i Site Location and Geomorphic Setting.

The major peat-accumulation of Lon Glas (c. 3700 m^2) lies in a north-flowing valley at the S.W. end of the Awe Valley (fig. 1.3). The Clachandubh Burn (fig. 4.5a) drains to Loch Ederline, a large kettle-hole, and thence N.E. to Loch Awe, lying north of the watershed at Glennan (NM 860017). Formerly all drainage is believed to have exited through the gorge at Eurach (NM 850010) and thence to Crinan Bay (chap. 1.5.ii; fig. 1.3).

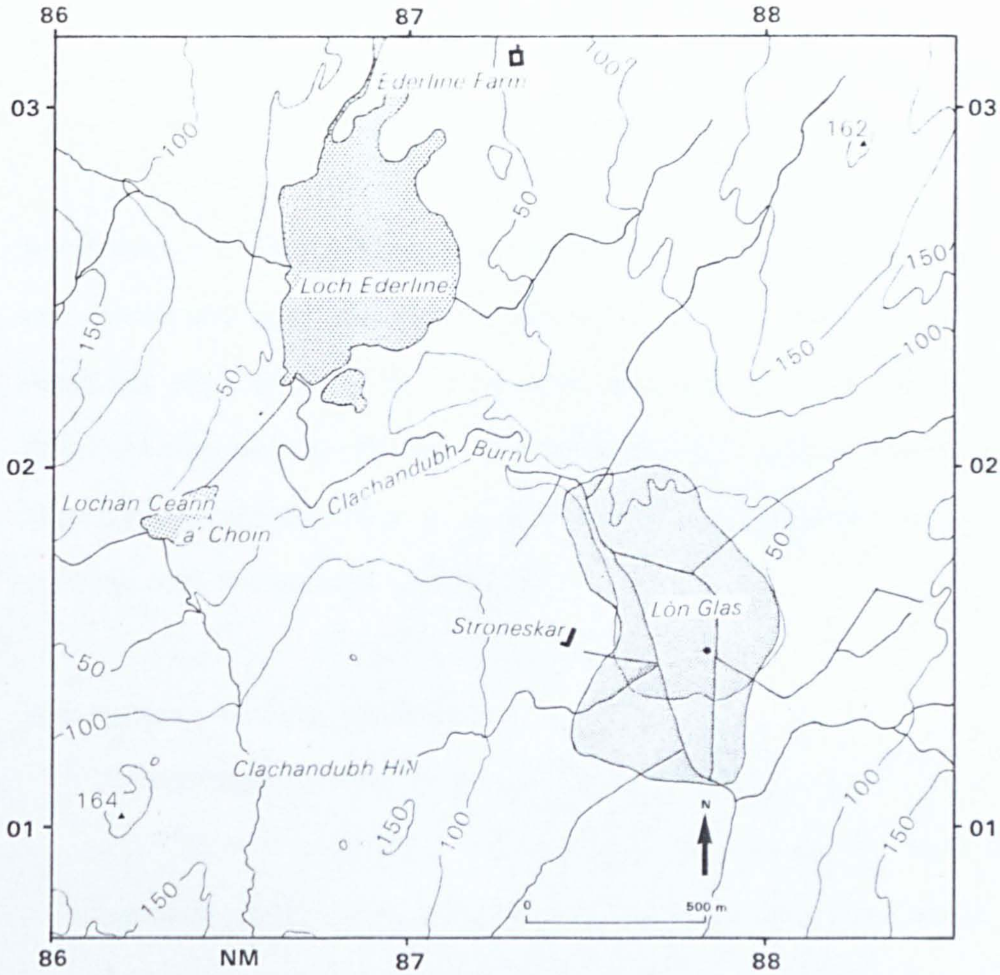
Though lying in a through-valley Lon Glas is not a valley-fen but the site of an old lake-basin, dammed by an extensive sequence of kames and kame terraces, portrayed on fig. 4.5.b (Gray and Sutherland, 1977). On fig 4.5.b terrace K6 has not been drawn further south-east than depicted as it disappears beneath surficial peat. These terraces are graded to a sea-level "at or below 9 - 10 m O.D." (Gray and Sutherland,1977; p. 38). As at Glendaruel, a phase of high sea-level activity (c. 36 m O.D.) is recognized, 1 km up-valley of which a fall of sea-level of 26.0 m is recorded by the terraces of this second ice-front. This second (9 - 10 m O.D.) ice-front "was not necessarily a slightly later stage in the retreat of the Eurach ice-front" (p. 38).

It is the possibility of dating this second ice-position that is the principal interest of the pollen site. Gray and Sutherland (1977) examined the site, recording 3.5 m of grey clay at the base of the stratigraphy, but no tripartite lithostratigraphical subdivision typical of Lateglacial sediments (e.g., Sissons et. al., 1973). On their fig.1 (p.34) the site is considered to show a "Flandrian stratigraphy only".

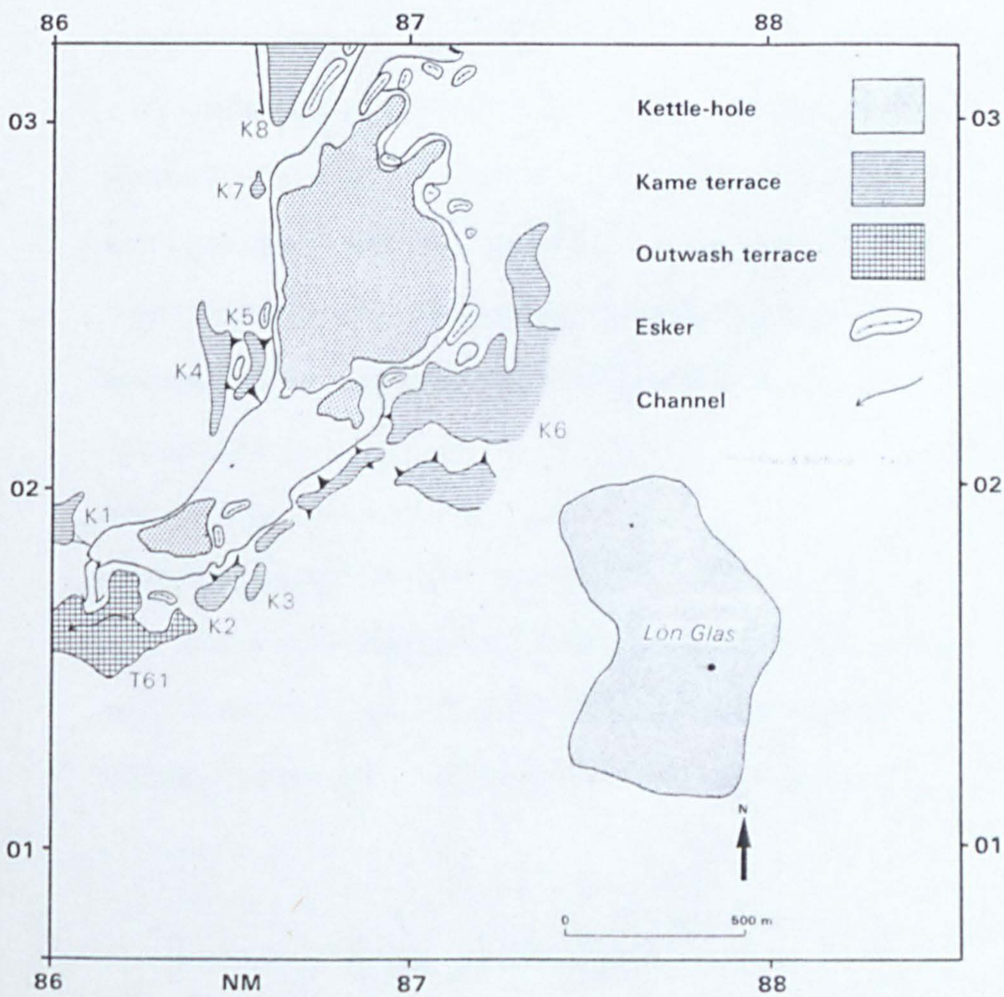
4.3.ii Sampling.

Two sequences of cores (a - g; 1 - 4; fig. 4.6) were collected on separate occasions with a combination of 60 cm piston corers, 50 cm and 1.0 m Russian corers and a power-corer. Gaps between cores in both sequences are due to the extreme difficulty of sampling the very stiff

Fig. 4.5: Lòn Glas a) Site location



b) Geomorphic setting



sediments. Depth-probing was again very difficult, and was not attempted over the entire bog-surface, so that the sampling site (fig. 4.5a) need not represent the deepest point of the valley-floor. The lithostratigraphies can be broadly correlated (fig. 4.6) and agree with that described by Gray and Sutherland (1977).

4.3.iii Generalized Lithostratigraphy

LITHOSTRATIGRAPHIC UNIT A : 1130 - 1093 cm.

5Y 5/2 olive gray silty clay, decreasing in silt upward: basal 15 cm auger sampled, impenetrable below 1130 cm ;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT B : 1093 - 974.5 cm.

predominantly silty clay, often unlaminated (core 3) and gray (5 Y 5/1), but also darker (2.5 Y 4/0 dark gray) and showing fine laminations (<1 mm), usually contorted and frequently indistinct, determined by textural contrasts between silt and clay sub-units;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT C_1: 974.5 - 970 cm.

2.5 Y 4/0 dark gray silty clay with horizontal, very fine (<< 1 mm) laminations distinguished on colour differences, silts appearing darker; silt content reduced from underlying unit but still concentrated in certain sub-units; boundaries between all sub-units sharp, laminae thinning upward; transitional boundary to

LITHOSTRATIGRAPHIC UNIT C_2: 970 - 967 cm.

as unit C_1, but with distorted laminae; transitional boundary to

LITHOSTRATIGRAPHIC UNIT D : 967 - 959 cm.

2.5 Y 5/0 gray pure clay; transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 959 - 884 cm.

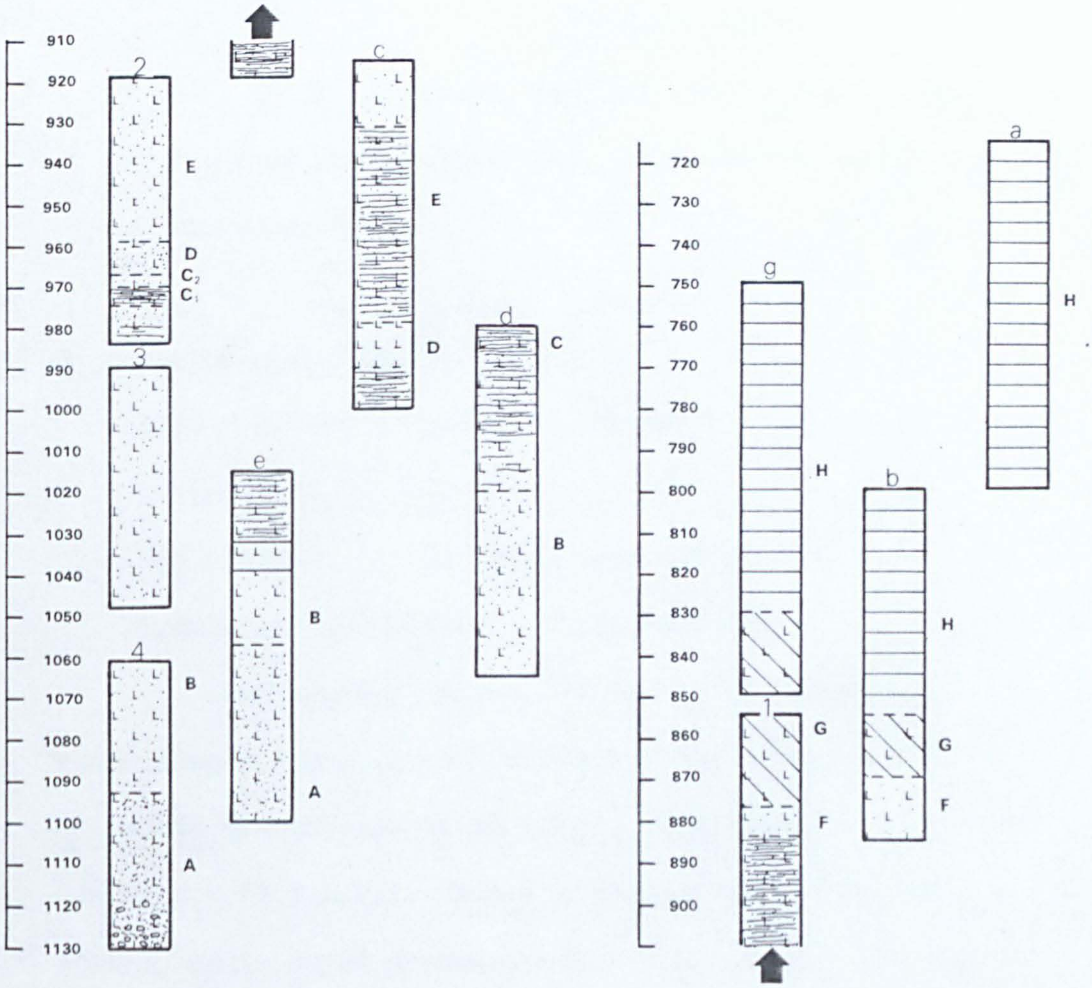
2.5 Y 4/0 dark gray silty clay, homogeneous in some cores, although laminae can be seen indistinctly in these, sharply laminated in other cores, varying in thickness from very finely laminated to quite coarsely (up to 1.4 cm) banded, without any discernible fining-upward sequence; boundaries sharp or transitional, occasionally wavy; laminae distinguished on texture and colour, being at their clearest 2.5 Y 2/0 black silt/silty clay and 5Y 5/1 gray almost pure clay, but graded between these extremes; transitional boundary to

LITHOSTRATIGRAPHIC UNIT F : 884 - 877 cm.

5 Y 2.5/1 black silty clay, homogeneous except between 920 and 880cm;

transitional boundary to

Fig.4.6: Lòn Glas: Lithostratigraphy



LITHOSTRATIGRAPHIC UNIT G : 877 - 830 cm.

10 YR 3/1 very dark gray minerogenic-rich gyttja; transitional boundary to

LITHOSTRATIGRAPHIC UNIT H : 830 - 715 cm. (not sampled above this).

10 YR 2/1 black, very fine and well-humified fen-peat with abundant but badly deteriorated macrofossils.

4.3.iv Biostratigraphy (figs. 4.7; 4.8)

1130 - 955 cm : Non-Polleniferous.

955 - 910 cm : local p.a. zone LON GLAS 1

Gramineae - Cyperaceae - Chenopodiaceae

Herb pollen exceeds 80% T.L.P. throughout, comprising principally the indicator taxa above, with Artemisia distinctive at 3% T.L.P., Epilobium and Dryas (one spectrum = 6% T.L.P.). Rumex is low, as are trees and shrubs, while dwarf shrubs are low also, but Ericaceae and deteriorated tetrad grains are characteristic.

Deterioration is high, dominated by crumpled and split grains. Pollen concentration is uniformly exceedingly low.

910 - 902 cm : local p.a. zone LON GLAS 2

Gramineae - Cyperaceae - *Rumex*

Chenopodiaceae values drop dramatically, *Artemisia* less so. *Rumex* expands to 13% T.L.P., and Ranunculaceae undiff. appear for the first time. *Pinus* values expand, as do those of *Salix*, while dwarf shrub percentages are lower, as are those of Gramineae.

While total pollen concentration rises consistently, total deterioration is slightly reduced.

902 - 882 cm : local p.a. zone LON GLAS 3

Juniperus - *Salix*

this zone is subdivided thus:

(a) 902 - 890 cm.

Juniper values rise to 41% T.L.P. accompanied by a slight expansion of Ericaceae. Herbs are still prominent, but decline to 61% T.L.P. at the upper sub-zone boundary, although *Filipendula* begins to increase and *Rumex* is still strongly represented. Pollen concentration rises markedly at the top of the sub-zone.

(b) 890 - 882 cm.

Betula begins to expand now, and *Salix* rises to 16% T.L.P., while *Juniperus*, after peaking at 44% starts to decline in value. Dwarf shrubs are of little importance, as are most herb taxa except Filipendula.

Deterioration declines still further, and so do pollen concentration values.

882 - 855 cm : local p.a. zone LON GLAS 4

Betula - Filipendula - Salix

Birch is now dominant at maximal 40% T.L.P., with Salix still strong, although Juniperus is now only 5% T.L.P. (average), and of herbs only grasses, sedges, Compositae Liguliflorae, Crataegus-type and Filipendula are consistently present.

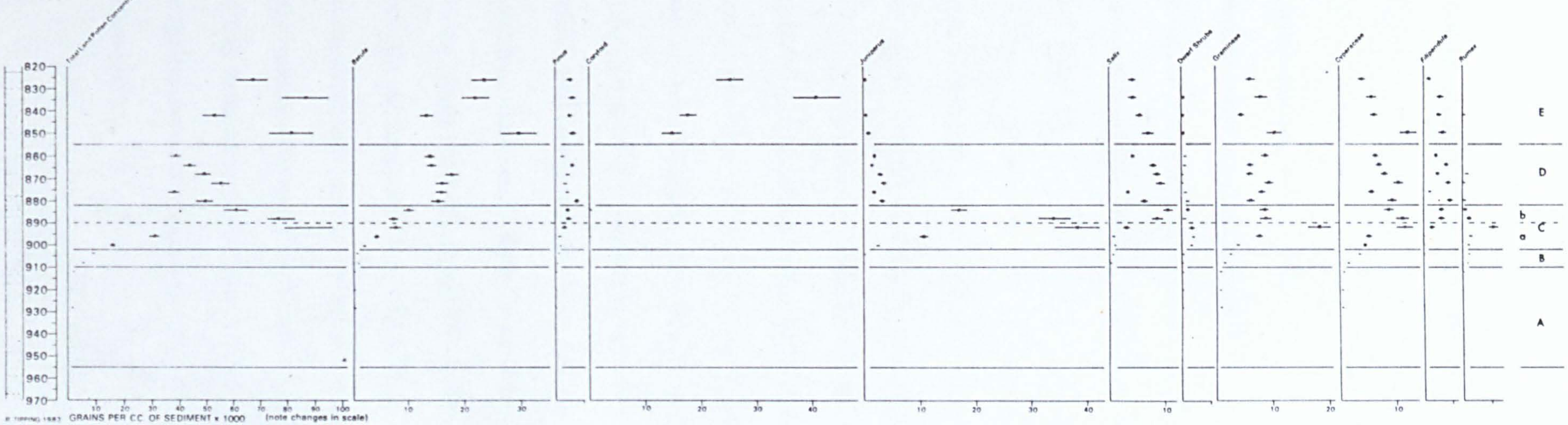
Total deterioration is a constant 30% T.L.P. and indeterminable grains and pollen concentration is also consistent at c. 40 - 45000 grains per cm^3, the lowest since zone 2.

855 - 820 cm : local p.a. zone LON GLAS 5

Coryloid - Betula

Betula is still strongly represented, but all other taxa are statistically suppressed by the expansion of coryloid pollen to 46% T.L.P. Pollen concentration is very erratic but higher than the preceding zone. Deterioration

Fig. 4.8 LÓN GLAS POLLEN CONCENTRATION DIAGRAM



values are increased through higher amounts of corroded pollen.

4.3.v. Geomorphic Significance.

The arguments employed here are similar to those employed at Na Lona Min (sect. 4.2.iv), and it is thought that this site represents a similar mode of deposition during the Loch Lomond Stadial.

(a) Palynological Results

Local p.a. zone Lon Glas 1 bears a very close resemblance to the basal assemblage zone of Na Lona Min, and its stadial age seems likely from the vegetational changes seen in zone LG 2, also very comparable with those seen at zone N.L.M. 2. Total pollen concentration is very low in zone 1, indicating that, as suspected at Na Lona Min, pollen productivity is low, and sedimentation rates very high. At this site the Rumex expansion is seen from the pollen concentration diagram (fig. 4.8) to be largely a statistical artefact of Rumex over-representation, but the increases in Juniperus, Salix and grassland herbs in zone 2 make it likely that the zone 1/2 boundary indicates the change from stadial to postglacial conditions, as does the appearance of Ranunculaceae.

The relation of Chenopodiaceae and Artemisia within stadial sediments (chap. 3) is better seen here than at Na Lona Min. Differences are also seen in the increased importance of Dryas, with Thalictrum, indicating a form of calciphilous heath (Iversen, 1954). The consistently recorded occurrence of Anthemis/Bidens type is not seen at Lon Glas. The ericaceous pollen-types recorded in low percentages in this basal pollen zone at Lon Glas are not thought representative of local vegetation. The calcareous soils and solifluctial conditions would be deleterious to Empetrum and Ericaceae growth (chap. 3). The majority of all tetrad grains were heavily crumpled (66% of tetrad grains), whereas well-preserved grains amounted to only 30%. Pollen concentration values are very low in p.a. zone 1, particularly when it is considered that these were calculated on the combined numbers of dwarf shrub grains. The catchment itself remained ice-free through the stadial, to judge from the glaciological reconstruction, and these ericaceous grains probably came from the reworking of interstadial soils.

(b) Sedimentological analyses

The arguments employed at Na Lona Min seem well-suited to the sediments at Lon Glas. The darker

Munsell colors related to higher silt content seems to accord with Na Lona Min, and the lack of mafic rock-types in the catchment might imply an introduced source for these minerals. Similarly, the mode of sedimentation implied by the couplets is that suggested for Na Lona Min, of density-graded silt units separated by intervals of suspension-load settling.

The absence of laminae in certain cores may be a result of the diffuse character of some boundaries, suggesting graded deposition or thorough bioturbation (Smith, 1959), or, more likely, through the extrusion of piston cores. Litho-unit A appears to represent one major graded silt unit, above which couplets of Subgroup II a/b (Ashley, 1975) are seen (litho-unit B) and eventually in litho-unit C micro-laminations of Subgroup II a, so that the fining-upward sequence is reproduced here. Litho-unit D appears indicative of quiescent sedimentation, before a return to turbidity-current deposition is seen in the Subgroup II b and Group III couplets of litho-units E and F, signalling an increased sedimentation rate at the end of the laminated sequence and coinciding with the development of grassland assemblages in local p.a. zone Lon Glas 2.

There seems little doubt that the conclusions reached at Na Lona Min can apply to Lon Glas also. The bio- and lithostratigraphic sequences accord in most details, and it is proposed that in the south-western Awe valley the kame-terrace sequence graded to low sea-levels is of Loch Lomond Stadial age. This argument is developed in chapter 6, where pollen sequences within the Awe valley are discussed, and in chap. 8 when the evidence is assembled in an overall consideration of the environmental history of the region.

4.4 THE POSTGLACIAL VEGETATIONAL SUCCESSION

It was mentioned at the end of chapter 3 that Na Lona Min and Lon Glas show much more clearly the sequence of vegetational changes in the postglacial period than do Pulpit Hill or Loch Barnluasgan, due to their much faster sedimentation rates. The principal components of the succession, from *Rumex* to *Empetrum*, *Juniperus* and *Betula* have been mentioned in chapter 3, and in the summary to this section will be reconsidered when the driving mechanisms controlling the sequence are discussed. First, other features of the succession at these sites are discussed.

Within the stadial sediments at Na Lona Min and Lon Glas little need be commented on not dealt with in chap. 3. The low representation of *Artemisia* at these sites is in contrast to

Pulpit Hill and Loch Barnluasgan, and other sites in the south-west Highlands (sect. 3.5 E), and in view of the correlation between snow-precipitation and Artemisia growth.(Birks & Matthewes, 1978) it is tempting to infer the presence of a considerable amount of snow in these catchments, and to relate this to the glaciers present in the catchments

The recognition of Betula nana-type grains at both sites from the postglacial sequence onwards may indicate that the dwarf birch was not present around the basins during the late-stadial, and was established only in the earliest post-glacial. This would be in contrast to the findings of Andersen (1980) and Prentice (1981), who on statistical considerations found that Betula nana contributed the majority of birch grains in the stadial. At these two sites, however, it may be that all birch grains recorded before zones NLM 2 and Lon Glas 2 were from long-distance sources.

At Na Lona Min the pine percentage curve (fig. 4.3) shows a curious oscillating pattern of peaks (zones 3,5) and troughs. The concentration values show no such fluctuations, however, and smoothly increase, as they do at Lon Glas (fig. 4.8), and environmental changes, such as fluctuating circulation-patterns (cf. Nichols et. al., 1978) are not considered a more likely explanation for the oscillations than simple statistical fluctuations (Davis and Deevey, 1964). As at the full Lateglacial sites pine is not thought present in the region at any time covered by the pollen diagrams. Fredskild (1973) reports values of 18% T.L.P. from Greenland as being exotic. The gradual rise in concentration probably depicts the approach of pine forest to the Scottish mainland from south-east England (Godwin, 1975) and, as adjudged from radiocarbon-dated profiles, from north-west Scotland (Birks, 1980 unpub.) also (cf. Huntley & Birks, 1982).

Empetrum is seen clearly to rise prior to Juniperus at Na Lona Min, supporting the regional pollen zonation of Lowe and Walker (1980) (chap. 1) on Rannoch Moor. Persson's (1964) suggestion that Empetrum cannot grow without nitrogen-fixation from mycorrhiza is interesting in the appearance in zones NLM 2 and 3 of Urtica-type pollen, Urtica being an indicator of nitrogenous soils. The pollen has been used as an edaphic indicator in the early postglacial by Florin (1979), but Birks (1973) states it to be a common non-local component in treeless vegetation.

From the percentage-based diagram of Lon Glas (fig. 4.7) no Empetrum peak following the expansion of Rumex is seen. Partly this may be the result of the statistical suppression of Empetrum by Juniperus, as on the pollen concentration diagram (fig. 4.8) Juniperus is not seen to expand markedly until the beginning of zone 3. Below this a very limited increase in total dwarf shrub values is seen, such that the succession is upheld at this site, but here the expansion is in ericaceous shrubs. Sites in the study area (chap. 3, this chap., chap. 6) show considerable variations in the representation of the dwarf shrubs which are not satisfactorily explained by statistical artefacts or differing sedimentation rates (note the comparability in sediment thickness between Na Lona Min, Lon Glas and nearly all sites discussed in chap. 6). In Wales and Ireland *Empetrum* is of little significance in the post-glacial (Moore, 1970, 1972; Handa and Moore, 1976; Simpkins, 1974; Lowe, 1981; Walker, 1982; Craig, 1978; Singh, 1970; Mitchell, 1976). Large areas of southern western Britain, thus, have only limited establishment of *Empetrum*, and Brown's (1977) assertion that *Empetrum* is an oceanicity indicator is at best a generalization. In this respect it would be interesting to establish the postglacial succession on the Outer Isles, but Birks and Madsens's (1979) site on Lewis extends only to 9140 +/- 140 B.P., at which time, despite the absence of tree-cover, *Empetrum* and *Juniperus* had apparently not established a "climax" vegetation, tall-herb communities being characteristic of the Flandrian.

Empetrum being represented more strongly at Na Lona Min than Lon Glas, soil chemical factors cannot be seen to determine % representation, since because of their similar bedrock, geochemical contrasts, such as strongly calcareous soils, could not affect Empetrum growth. Competition from pre-existing communities is felt unlikely. From what can be deduced from pollen spectra the grassland and bare-ground communities of the Rumex-phase would have provided sufficient space for seedling establishment at all sites. Aspect and slope are not crucial for development (Anderson et. al., 1966) given the probable absence of solifluction (Dahl, 1956). Whether differences between subspecies are being recorded is unknown. Jessen (1949) suggests that E.nigrum pollen can be separated from that of E.hermaphroditum on size characteristics, but the author agrees with Reynaud (1976) in contesting this criterion. E.hermaphroditum is more common on wetter substrates than the dry, sandy soils colonized by E.nigrum, and Hagerup (1951) reports that it is self-pollinating, with, accordingly extremely limited dispersal, whereas E.nigrum is unisexual and is spread by insects principally, or by wind. Empetrum is widely reported as being under-represented, particularly in lake-muds (Birks, 1973; Pennington, 1980) but no estimates of dispersal between ssp. are known to the author.

The character of the dwarf-shrub heath varies between sites also. An almost pure Empetrum-heath seems to be recorded at Na Lona Min, while at Lon Glas and Loch Barnluasgan the Ericales are better represented, despite having inferior dispersal ranges to Empetrum (Fredskild, 1967). In Greenland at the present day

Vaccinium is most closely associated with Empetrum, together with Loiseleuria (Fredskild, 1973). The latter is known in macrofossil form from Lateglacial deposits at Corstorphine and Nant Ffrancon (Godwin, 1975), and is particularly common on the Scottish west coast today (Fitter, 1978). Alternatively, when Empetrum is poorly represented species of Erica may be present. At many sites the Ericaceae are seen to expand after Empetrum and with Juniperus, and from present-day plant assemblages may be attributed to Vaccinium, a juniper-Vaccinium community being widely recognized (Huntley, 1981; Gilbert, 1980; Poore and McVean, 1958) in Scotland today.

The appearance of Calluna pollen at very low percentages in isolated spectra early in the postglacial in several diagrams need not imply local growth (Birks, 1973). The markedly more consistent occurrence of ling following the dwarf-shrub expansion (e.g., Lon Glas: zone 4; Na Lona Min: zone 4 and 5: several sites in chap. 6) is more likely to indicate its presence in the vegetation. Calluna under most normal conditions will successfully compete against other heathers, and is less demanding in soil conditions, moisture content etc., so has a considerable competitive advantage (Gimingham, 1972). Its delayed expansion is, therefore, likely to imply "extreme" conditions favouring one or other of the heathers. Aridity is thought not to be indicated given the more successful germination after drought of Calluna

(Bannister, 1964) and the environmental changes for the early post glacial proposed in chap. 3, and it may be that _Calluna_ was restricted from areas near the basins by high local watertables, these regions perhaps supporting _Erica_ _tetralix_.

The appearance of _Caltha_-type grains, very likely _C.palustris_ (Godwin, 1975) in this earliest part of the postglacial succession at Pulpit Hill, and distinctly at Na Lona Min, indicates a marsh or lake-edge fen, with _Galium_, other _Ranunculus_ spp. and species of _Typha_. The presence of _T.latifolia_ implies a mean temperature exceeding 14^{o}C. (Iversen, 1954).

Plantago major/media rises consistently earlier than _P.maritima_, not only in this period but also in the interstadial succession. Both _P.maritima_ and _P.media_ are grassland species, and would grow together in species-rich neutral grasslands, but _P.major_ is shade-intolerant (Iversen, 1954), the seeds strongly so, and open communities are implied where _P.major_ is found, and this species may be responsible for the early appearance of Plantaginaceae prior to the development of large expanses of grassland. It seems likely that _P.maritima_ was located in similar communities to those inferred for the interstadial (chap.3).

The increase in ferns at Lon Glas accords with the interpretations placed on it at Pulpit Hill and Loch Barnluasgan, of some form of damp fern-meadow (chap. 3), but at Na Lona Min it occurs with Juniperus, suggesting the development of fern-rich juniper scrub (Juniperus - Thelypteris nodum of McVean and Ratcliffe, 1962), probably on the more alkaline soils, juniper avoiding acid soils below pH 4.5. Clearly there is no single interpretation to the expansions of these taxa.

At Na Lona Min Dryopteris and Polypodiaceae undiff. show a pattern of alternating high and low values, consistently high for Dryopteris when Polypodiaceae are poorly represented and vice versa, bearing a strong correlation with the date each level was prepared and counted (sect, 4.2.ii: fig. 4.3), with low percentages for Dryopteris in later counts. Mis-identification is not thought likely given the distinctiveness of the pollen-types. Deterioration was not determined on taxa outside the pollen sum, but the simplest explanation must be that in the months between counts Dryopteris grains lost their characteristic perines and thus resembled the bean-shaped Polypodiaceae/Filicales. The exact mechanism is unknown, but may involve fungal attack (though not recorded, Polypodiaceae grains showed high perforation-type corrosion).

The post-glacial Salix expansion consistently follows the main Juniperus phase. This consistency does not extend to all diagrams examined, however, and it cannot be relied upon in relative dating (cf. chap. 5). Discussion of species-identification of *Salix* at Pulpit Hill (chap. 3) concentrated on arctic forms present at the earliest colonization stage, and the same species are not likely to be responsible for this later expansion. Jessen (1949) considered three species to be important at this stage, *Salix caprea*, *S.cinerea* and *S.aurita*. All are wetland dwellers, and some bias might be introduced as Jessen sampled lakes and peat-bogs where these species would deposit macrofossils. Shrub willows are also common in sheltered localities with juniper, dominant being *S.myrsinites*, *S.repens* and *S.aurita*, plus hybrids of these (Poore and McVean, 1958). These authors note that *Salix* expands at the expense of *Juniperus* on wetter sites. At both Na Lona Min and Lon Glas, as at other sites, juniper declines dramatically with the expansion of the willow grains, and this response may not be solely statistical. Concordant with the *Salix* expansion is that of *Betula*, considered to be exclusively tree-birch, and shading may have suppressed juniper growth on drier sites.

Birch with willow growing in the canopy layer, with continuing high concentration values of Gramineae is typical of open birch-woods in Scotland today (McVean and Ratcliffe, 1962), where "Grasses are often the most prominent plants" (p. 16). A comment should be made on Pennington's (1977 a) assessment of local birch growth from pollen concentration values, employed in chap.3. It was pointed out that with differing catchment areas and pollen input characteristics comparisons of pollen concentration data are valueless. At the sites discussed in this chapter T.L.P. concentration figures differ enormously, and the actual concentration values for birch also differ. Comparisons of post-glacial vegetational changes using pollen concentration data are of little use, and are not attempted here.

Birch is not considered to have formed closed woodland at either site at any time prior to the rise of hazel. Although Corylus prefers calcareous soils at the present day, with the lack of competition in the Flandrian edaphic controls were probably few, and co-dominance in closed woodland (c. 90% T.L.P.) with birch seems likely over the region. Salix appears from the pollen concentration data to initially compete successfully, but is likely to have been rapidly ousted from the canopy by hazel. The low occurrence of Salix pollen in these spectra at all sites may be from shrubs beneath the birch-hazel canopy or from fen-willows.

Birks (1972) discussed the migration of birch into northern Britain in the Flandrian, suggesting a migration rate of 1 km /yr based on available radiocarbon dates and likely stadial refugia. Goudie (1977) gives a value of 0.2 km /yr , and these contrasts demonstrate the difficulties of reconstructing migration rates.

As Webb (1966) has stressed, the concept of migration by wave-like "fronts", advancing principally from seeds emitted only an average distance from the parent, cannot explain the remarkably rapid Flandrian migration rates, even given that Betula has the most-efficient seed dispersal of all British trees (Webb, 1966). He places much emphasis on random, far-travelled seeding events whereby seeds travel much further than average, by strong winds, for instance, from which isolated colonies expand and gradually coalesce. One implication of this is that radiocarbon dates for the rational limit of birch (cf. Smith and Pilcher, 1973) need show no trend, contrary to the patterns elucidated by Huntley and Birks (1982) and in Scandinavia by Birks and Saarnisto (1975). Demonstration of this proposal of Webbs' might come from conspicuously early radiocarbon dates. However, inevitably the validity of a radiocarbon date is generally assessed by comparison with other sites, and anomalous dates are often questioned, and the tendency must always be to induce a consistency between dates and, perhaps, a bogus synchroneity.

H. H. Birks (1972) has also proposed that dormant birch seeds might have survived the stadial to expand when soil conditions matured sufficiently, (generally this means an organic-rich top soil), and she suggests this delay in soil maturation can explain the perceived delay between climatic amelioration in the earliest postglacial and C14 dates for the birch expansion. Assessing soil development from the carbon and nitrogen analyses, it was considered (chap. 3) that sufficient maturity was attained well before the regional expansion of birch, and it is thought the principal reason for the delay in Betula development is its migration from stadial refugia.

Deacon (1974) has argued for Loch Lomond Stadial refugia of Corylus in western Scotland, the evidence coming from "early" C14 dates on the hazel expansion, and the appearance of Corylus earlier in the interglacial biostratigraphic sequence than in other interglacials. Her views have been supported by Rymer (1974, 1977) at Drimnagall, where Corylus appears to rise with Juniperus, and Moore (1972) on similar evidence in Wales, where he proposed a stadial refugium off Cardiganshire in the present Irish Sea.

Moore's ideas have been questioned on radiocarbon dating evidence by Lowe (1981), and it is argued in chap. 5 (sect. 3) that Moore's sites are affected by slow sedimentation rates, and such problems are suspected at Drimnagall (Rymer, 1977).

In her paper Deacon (1974) assembled 51 radiocarbon dates from western Europe, and appears to question the validity of none. Thus she accepts both the date of 8650 +/- 150 B.P. (Q - 958) from Loch Meodal and that from Lochan Coir a Gharbhainn of

9482 +/- 150 B.P. (Q - 960), both on Skye (Birks, 1973), 25 km. apart. These contrasting dates with an 800 year difference cannot both be valid, given the high dispersal of hazel pollen. Criticisms will be levelled at other sites used by Deacon (1974), such as Roddan's Port (Morrison and Stephens, 1965) in chapter 5 (sect. 5.3). Both Birks (1973) and Pennington (1977a) agree that *Corylus* was not present in Britain during the Lateglacial Interstadial, and refugia in the stadial are thus seen to have no source of seeds.

In western Scotland there are now several dates, (listed in Robinson(1977), Lowe (1982) and Walker and Lowe (1982)) which suggest a markedly later date than the 9700 B.P. proposed by Birks (1977). Lowe's (1981) correlation of radiocarbon dates from Wales leads him to suggest "a remarkable degree of synchroneity for this phenomenon in S.W. Britain." (p. 211), and similar views of widespread colonization are proposed for western Scotland by Walker and Lowe (1982) "shortly after 9000 B.P." (p. 558), and this view is seen as more reasonable in the light of a reassessment of the C14 data.

At Na Lona Min the expanding *Corylus* percentages are interrupted by increases in sedges and *Pinus*, together with marked expansions in *Isoetes*, *Lemna* and *Nymphaea*, Polypodiaceae and *Sphagnum*, and the change in sediment to minerogenic clay makes it apparent that a temporary pool or slow-flowing stream developed over the practically-infilled bog-surface: its areal extent was not determined. The absence of organic sediment and appearance of minerogenic material some distance (200 m.) from the nearest bedrock source suggests flowing water, and given the hostility of Isoetes to silting conditions (Godwin, 1975) it is assumed the sedimentation rate to have been quite slow.

Corylus percentages are also reduced by the rise of the mixed oak-forest components of Quercus and Ulmus. Where recorded in the pollen diagrams in this study, their appearance seems to be practically synchronous. Birks (1980; unpub.) has obtained a date of 6555 +/- 65 B.P. for what is regarded as the local appearance of oak and elm at Donner's (1957) site of Oban 1 a.

South of the study area Alnus appears 500 years later than oak (at Loch Cill on Aonghais; Peglar, in Birks, 1980; unpub.),7500 B.P. compared with 8000 B.P. for oak. Its synchronous expansion at Oban and Salen (fig. 1.5) can be compared with Na Lona Min, where alder appears after the expansion of the mixed-oak-forest. Alnus' rise at this site is interesting in its appearance immediately following a period of temporary flooding, and this may suggest the rise in water-level was not merely of a local nature. Alder is well-represented at the second site analysed at Na Lona Min, (sect. 4.2.v.) this time apparently prior to the expansion of Quercus in the region.

Alnus has the second most efficient seed-dispersal, by wind, of British trees (Webb, 1966), and many authors are now reporting the establishment early in the Flandrian of local colonies as far apart as Hornsea, Humberside at 9500 B.P. (Beckett, 1981), Knapdale at Drimnagall (Rymer, 1974) where "there is convincing evidence for local growth of alder ... from at least 7985 B.P." (Birks, 1977; p. 126), eastern Scotland (Gunson, 1975), and possibly MacPherson's (1978) site of Feagour Channel, although here contamination by the use of a Hiller corer may have occurred. At Bigholm Burn (Moar, 1969a) a peat-section showed a small alder peak at 9470 +/- 170 B.P., while in the study area Donner's (1957) sites of Oban 1, 2 and 3 all show short-lived expansions up to 20% A.P., concordant with the Corylus rise. Beckett (1981) makes the point that such local expansions occur only in favoured habitats, damp, open areas, often replacing Salix (McVean, 1956 a; b), and need bear no relation to the trees' regional expansion. Smith and Pilcher (1973), whilst deducing a general trend of colonization across Britain and Ireland, concede that extreme variability in the timing of Alnus' rational limit is the rule, and as such may provide valuable evidence in support of Webb's (1966) hypothesis of Flandrian plant migration processes discussed earlier. This problem of alder development is referred to briefly in chap. 6.

Comparison of the biostratigraphy of the sites discussed so far with the postglacial sites on and near Rannoch Moor by Walker and Lowe (1976 - 1981) in fig. 4.9 shows good agreement, despite differences in bedrock, altitude, aspect and catchment characteristics. Walker and Lowe (1977) proposed a regional pollen zonation scheme, R-zones (for Rannoch), and it seems reasonable to extend this to include the south-west Scottish Highlands in general.

Throughout the above discussion it is often assumed, if not directly proposed that the biostratigraphic sequence occurs in clearly recognized successional stages, rather than by an imperceptible plant-by-plant change (Gleason, 1926). Succession in tundra ecosystems is poorly understood (Johnson, 1969), but work on the colonization of recently deglaciated ground (Wager, 1938; Cooper, 1939; Bliss, 1956, 1958; Crocker and Dickson, 1957; Stork, 1963; Viereck, 1966; Persson, 1964; Lawrence _et. al._, 1967; Elven and Ryvarden, 1975; Matthews, 1978) has clarified the process. Most successional models are based on the concept of climax theory (Clements, 1916; Churchill and Hansen, 1958), but the recognition of such climax communities is questioned today in the difficulty of defining ecological stability in such communities (Horn, 1975; Harper, 1977). Despite the support from pollen analysis of Gleason's (1926) theory of phyto-sociology (Faegri, 1963; Watts, 1973), discrete plant communities continue to be defined (McVean and Ratcliffe, 1962; Birks, 1973), and

Fig. 4.9 **Correlation of pollen assemblage zones between Rannoch Moor and the study area**

	RANNOCH MOOR (Walker & Lowe, 1977) R-ZONE	MOLLANDS (modified from Lowe, 1978, 1982) LOCAL P.A. ZONE	PULPIT HILL (this study) LOCAL P.A. ZONE	NA LONA MIN (this study) LOCAL P.A. ZONE
EARLY POSTGLACIAL (no synchroneity inferred)	R-4 *Betula-Corylus*	Mo-d *Betula-Corylus*	PH-8 *Betula-Coryloid*	NLM-5 *Betula-Coryloid*
		Mo-c *Betula*		
	R-3 *Betula-Juniperus*		PH-7 *Betula-Juniperus-Filipendula*	
	R-2 *Juniperus-Betula*	Mo-b *Juniperus-Betula*		NLM-4 *Juniperus-Betula-Filipendula-Plantago maritima*
			PH-6 Gramineae-*Empetrum-Juniperus*	NLM-3 *Empetrum-Juniperus*
	R-1 *Empetrum*			
		Mo-a *Rumex-Empetrum-Salix*	PH-5 Gramineae-Ranunculaceae	NLM-2 *Rumex*-Gramineae-Ranunculaceae

Matthews (1978) states that his investigations supported "to a limited extent, the classical workers in succession ... who recognize stages in succession rather than a relatively continuous vegetational development" (p. 173).

Palaeo-ecologists have concerned themselves little with problems of vegetational dynamics or population biology, Watts (1973) emphasizing the restricted data-base from which to draw conclusions. Yet by the nature of their approach to zonation palynologists recognize distinct assemblages of pollen-types changing through time. As has been seen, there are remarkable comparisons between the early post-glacial succession and that recorded from deglaciated regions at the present day. The cause of the former sequence has commonly been assumed to be climatically governed, by ameliorating temperature, and yet the same successional stages are today proceeding under a climate which appears to have deteriorated from the 1930's (Lamb, 1977), and this lack of a clear climatic driving mechanism has led to an emphasis in these studies on soil maturation as the controlling factor.

The three taxa under principal consideration, _Rumex_, _Empetrum_ and _Juniperus_, are all thought to have survived the Loch Lomond Stadial within Scotland, if not the catchments of the sites discussed. _Rumex_ probably survived in depauperate form, much as it does in the arctic today (Wager, 1938); on fjaeldmarks growth is exceedingly slow. Juniperus is believed to have survived in nana-form under winter snow-cover (Iversen, 1954), while, although the presence of Empetrum through the stadial is unclear (chap. 3) there are few environmental restrictions to its survival (McVean and Ratcliffe, 1962; Bell and Tallis, 1973), probably on quartz-rich acid bedrock on low slopes, bearing in mind its antipathy to solifluction. It will be seen in chap. 6 that postglacial successions are very similar at sites outside Loch Lomond Readvance limits, (correctly secondary successions since a type of vegetation existed through the stadial), and within the limits of the Readvance, (primary successions on bare, freshly deglaciated ground). The reason for this close comparability must be the severely debilitating effect on vegetation and soils of the Loch Lomond Stadial climate, which nullified any edaphic or vegetational differences.

Generally, as has been seen in chaps. 3 and 4, the floristic succession in the Lateglacial and early Flandrian is a poor indicator of climate in any detailed sense, and the majority of taxa are "complacent" in this respect. In chap. 3 it was suggested that Rumex might respond with the increasing oceanicity of this period. Bliss (1956) has suggested that very low soil and air temperatures discourage its expansion, and whatever the exact reason, the expansion of Rumex is likely to have had a climatic cause. *Empetrum*, on the other hand, clearly relies on soil development before it can expand, and no climatic influence, other than sufficient precipitation to encourage leaching, can be discerned.

The reasons for the change of growth-form of *Juniperus* from dwarf to shrub form are not often discussed. In chap. 3 it was suggested that exposure was the key factor. Gilbert (1980) notes that high wind-speeds can reduce the average height of bushes from 3.5 - 4.0 m in sheltered areas to 0.6 - 1.5 m. The importance of exposure is confirmed by Fredskild's (1973) observation that *J.communis* (always dwarf-form in Greenland) increases in numbers and pollen productivity away from the coast.

What effect the rapid postglacial climatic expansion, deduced from, for instance, coleopteran studies (Coope, 1977), had on the pace of the vegetational succession is very difficult to model, and is discussed in chap. 6. The consistency of the sequence, from *Rumex* to *Empetrum* and *Juniperus* forms the basis of the argument elaborated in chap. 5, concerned with the prospects of establishing a relative chronology using these taxa to demonstrate the occupation of the Awe valley by Loch Lomond Stadial glaciers.

Fig. 4.3

NA LONA MIN POLLEN PERCENTAGE DIAGRAM

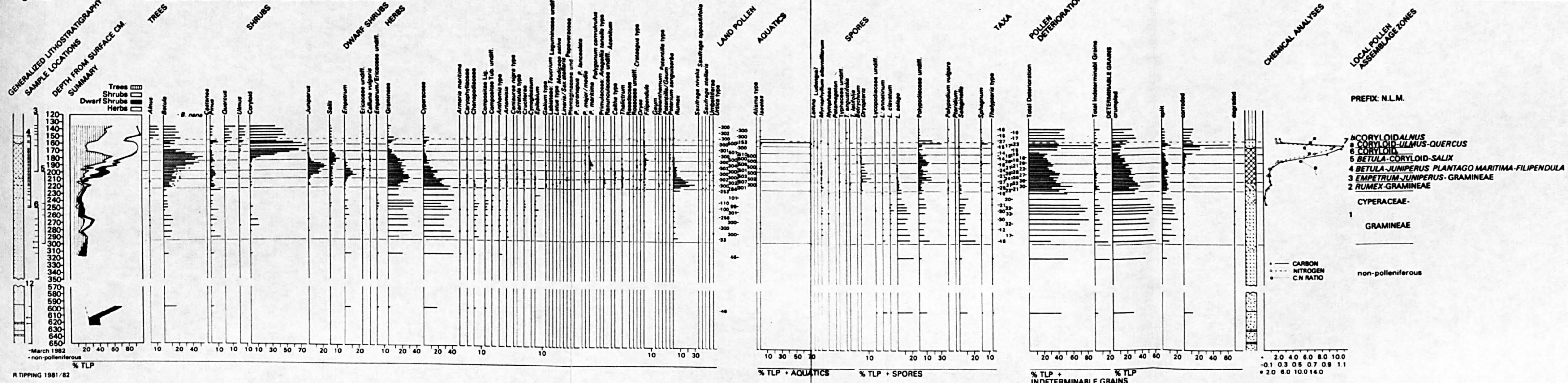
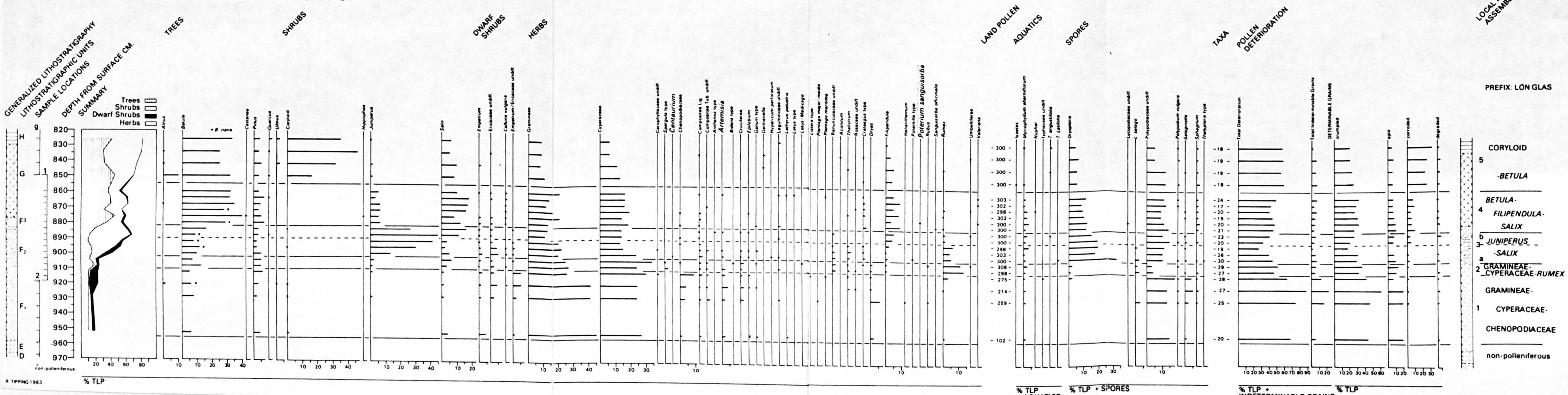


Fig. 4.7

LÓN GLAS POLLEN PERCENTAGE DIAGRAM



CHAPTER FIVE

EARLY POSTGLACIAL POLLEN SUCCESSIONS AND THE PROSPECTS FOR A BIOSTRATIGRAPHICALLY DETERMINED DEGLACIAL CHRONOLOGY

5.1 INTRODUCTION

From the review in chapter 1 of the geomorphological investigations it is apparent that a degree of uncertainty exists concerning the extent of Loch Lomond Readvance glaciers in the Awe Valley (fig 5.1).

In attempting to establish a relative chronology for the deposits Gray (1975) and Gray and Sutherland (1977) examined the lithostratigraphies of several basins in the area (fig 5.1). The results suggested that all the sites upvalley of Ford contained post-glacial sediments only, implying on Donner's (1957) premise that they lay within the Loch Lomond Readvance limits. However, Gray (1975) points out that in "denoting an individual site as 'postglacial' one is arguing on the basis of negative evidence" (p.229), and he goes on to detail several problems with such a simplistic interpretation:

(a) ice may have lingered in the kettle-hole for much of the Lateglacial period, preventing the accumulation of sediments of this age.

(b) hydrological conditions may have militated against Late-glacial sedimentation.

(c) the deepest parts of the kettle-hole may not have been located.

A further possibility is that periglacial activity during the Loch Lomond Stadial resulted in an impenetrable layer of, for instance, coarse sand and/or gravel.

Gray (1975) recommends the sampling of many sites within a region to reinforce the conclusions drawn from single sites. It seems apparent that Sutherland (pers. comm.) may regard the postglacial lithostratigraphies in the Awe valley as of suspect validity in considering the moraine at Kilchrenan (chap.1; fig 5.1) as a terminal feature of the Loch Lomond Readvance. Other geomorphologists view similar evidence with scepticism. Sissons (1982a), for instance, disregarded twenty postglacial stratigraphies from small kettle-holes, cored in search of a full Lateglacial sequence, in suggesting the deposits of Achnasheen to be of Wester Ross Readvance age. Whether such dismissals of the data are justified is considered later (sect.5.3). This follows a brief outline of a palynologically based test of the significance of postglacial sites within the context of the Awe valley (sect.5.2). Previous approaches to this problem are analysed in section 5.4, from which discussion a more rigorous strategy is constructed (sect.5.5), applied to the Awe valley in chapter 6.

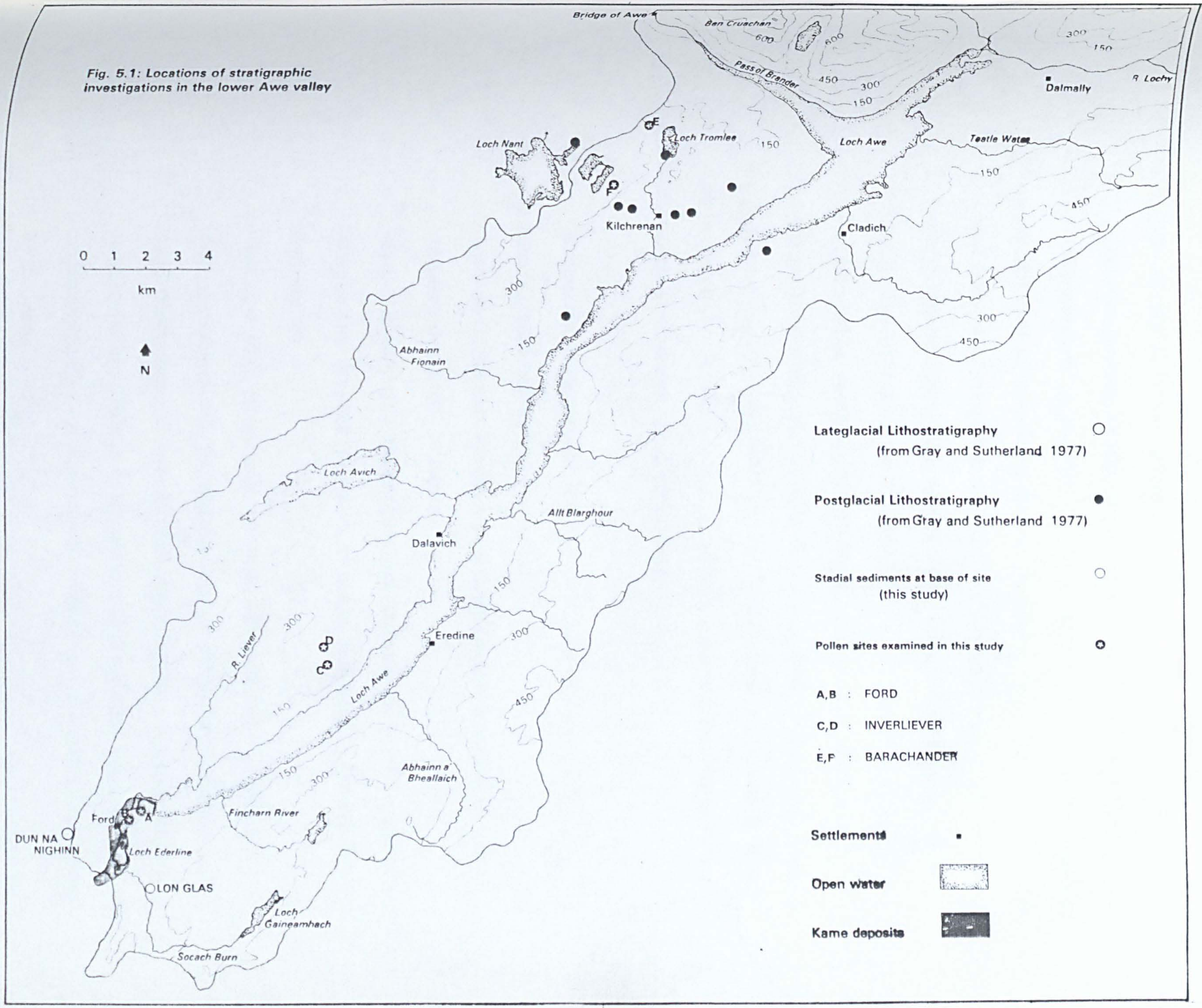


Fig. 5.1: Locations of stratigraphic investigations in the lower Awe valley

5.2 OUTLINE OF THE PROPOSED INVESTIGATION

The consistency of the postglacial vegetation succession has been demonstrated in chapter 4. It is proposed that palynological investigations of the earliest sediments at sites within suspected glacial limits of the Loch Lomond Readvance will show successively younger biostratigraphical assemblages up-valley of the glacial limit, in the direction of ice-retreat. The hypothesis is in principle similar to that constructed by Donner (1951) to determine the extent of Younger Dryas glaciers in Finland, and applied by him in Scotland (1957), in that one is assuming that the occupation of ground by glacier ice delayed sedimentation, reflected in the pollen stratigraphy.

There are a number of assumptions inherent in this hypothesis, outlined as follows:

i. that the earliest deposited sediments are located in the deepest parts of a basin;

ii. that the sampling techniques are sufficiently stringent to locate the deepest point of a basin and retain the earliest sediments;

iii. that the site accurately records the sequence of environmental changes in the region, and is not affected by localized disturbances such as delayed melt-out of dead-ice in kettle-holes, hiatuses in sedimentation, lack of preservation of material due to unsuitable hydrological conditions (Gray, 1975) etc.;

iv. that the sequence of pollen-stratigraphical changes is readily discernible, and is consistent between sites;

v. that each taxon is synchronous in its expansion in a region, and

vi. that ice retreat proceeds by uniform, systematic frontal retreat.

5.3 DISCUSSION OF THE ASSUMPTIONS

i. The earliest sediments are located in the deepest parts of a basin.

Chapter 2 (sect.3) discusses this point, wherein the observations of Davis (1973) and Lehman (1975) are seen to support this assumption. Nichols (1967b) suggested that ice grounding on shallow lake-floors may distort the litho-stratigraphy, but the horizontal laminations recorded at several sites in the present study (chap.6) probably preclude this.

ii. The sampling techniques are sufficiently stringent to locate the deepest point of a basin, and retain the earliest sediments.

Chapter 2 (sect.3) describes the method of probing employed. The piston corer has also been described in section 2.3.

iii. The site accurately portrays the sequence of environmental changes in the region, and is not affected by local disturbances.

(a) delayed melt-out of ice in kettle-holes:- the possibility of ice persisting in kettle-holes long after regional deglaciation is one commonly quoted, the major reference being that of Porter and Carson (1971). In this the authors date by the C14 method trees enclosed in a Valders Till diamicton in Alaska, and obtain results too young for the known date of the Valders Readvance. They surmise in the absence of obvious errors in the dates that the trees were growing on dead-ice which disintegrated perhaps as much as 1400 years after ice of Valders age retreated. The authors point out that the climate throughout this period was similar to present-day Alaska, but this climate is at considerable variance with climatic reconstructions for Britain following the retreat of the Main Devensian ice-sheet (Coope, 1977). Temperatures as high or higher than at present(Coope, 1977) would militate against the survival of dead-ice through the Lateglacial interstadial.

Ostrem (1965) reported ice-cored moraines from Scandinavia as being thousands of years old, but there are doubts concerning the validity of his radiocarbon dates, and he concedes errors of over 1000 years. At only one locality did the maximum summer temperature exceed 5^{o}C, at Isfallsglacieren, and here Ostrem considers ice-melt to have occurred. He considers that over 1.5 m of drift is required to insulate buried ice. Sampling of the sites described in chapter 6 failed to reveal any diamictic sediment at the base of profiles.

Consequently these studies can in no way be said to describe conditions pertaining to the Lateglacial interstadial in north-west Europe, and dead-ice lingering throughout this period is considered unlikely. It is undoubtedly a problem in the time-period immediately following the Loch Lomond Stadial (sect.4iii), but the absence of Lateglacial sediments in sites beyond stadial limits for this reason is improbable.

(b) unsuitable hydrological conditions:-

hiatuses in sedimentation caused by the failure of basins to retain sediment or water necessary to preserve sediment, through low water-tables or free-drainage through sandy substrates, have been blamed in part for the absence of Lateglacial sediments at Achnasheen (Sissons, 1982a). This may well be a factor in regions of kame-deposition as at Achnasheen or Ford (chap.6), but is questioned in bedrock-floored basins, providing depth-probing has clearly demonstrated the enclosed nature of the basin. Providing soil-development progresses, slope-wash will supply clay to a basin, the thickness dependent on catchment size, slope steepness and the rate of soil development. Thus although Walker and Lowe (1981) identify a hiatus at their site of Clashgour 2 where the earliest postglacial sediments are absent, pollen preservation was possible by the Juniperus expansion, c.800 years after deglaciation (sect.5.3), at a site of low topographic expression, and if this rate of sediment infilling is typical it is unlikely that Lateglacial sediments would have failed to accumulate for the reasons proposed.

(c) impenetrable sand and gravel layers:-

This is considered by Sissons (1982a) to be partly responsible for the absence of Lateglacial stratigraphies at Achnasheen. It is thought from the experiences of this author that such layers at depth can clearly be distinguished from the presence of bedrock: in chapter 6, at Ford and at Barachander I a sand layer was indicated by the gradual resistance to penetration during depth-probing and sampling, while at all other sites the unyielding presence of bedrock was recognized.

iv The sequence of pollen-spectral changes is readily discernible, and is consistent between sites.

The ease with which a clear and complete pollen sequence can be distinguished depends partly on the ability to extract pollen from the basal, usually minerogenic sediment (chap.2; sect.4), and the rate of sedimentation, discussed in chapters 3 and 4.

Regional consistency has been demonstrated in chapter 4, where it is suggested that the succession at all sites was "driven" by similar environmental processes, climatic and edaphic, and in which no evidence of early post-glacial climatic revertences, such as the Piottino Oscillation of Behre (1967) can be recognized.

Pollen records relate solely to the basin from which they are derived, and need not represent regional changes, although the discussion in chapter 2.2 (Site Selection) indicates that the sites used in this study are likely to reflect regional vegetational changes. The absence of pollen spectra dominated by Rumex at the base of Walker and Lowe's Rannoch Moor sites has been explained by J.J. Lowe (pers. comm.) as a result of delayed sedimentation at each site, thus suggesting that these sites need not be typical of the area as a whole. Later in this chapter (sects.4,5) it is proposed that a possible solution to this restriction would be to increase the number of sites examined, whereby anomalous basins can be recognized. The problem may persist, however; Lowe and Walker examined eight sites on the Moor itself.

With particular regard to the deglacial chronology hypothesis under consideration, an apparent paradox arises with the proposal (sect.5.2) that initial colonizers of bare ground, e.g., Rumex, will be absent at certain pollen sites. The same problem arises with other investigations (see sect.5.4) yet in these the results have been seen to accord with the hypothesis outlined above.

An explanation of this problem may relate to processes of plant migration onto freshly deglaciated ground, and to pollen productivity characteristics. At the onset of glacial retreat sites outside and immediately inside glacial termini record the same vegetational and palynological changes, but with improving climatic and edaphic conditions later deglaciated sites, although possibly playing host to early colonizers, would receive pollen from more mature communities down-valley, which would tend to "swamp" the local components. This reconstruction is supported by the studies of Persson (1964), Elven and Ryvarden (1975) and Matthews (1978).

v Each taxon is synchronous in its appearance in a region.

Discussions on the synchroneity of the postglacial peaks of Rumex, Empetrum and Juniperus are few. In the following discussion consideration is given to radiocarbon determinations believed to date directly or approximately peaks of Empetrum (section B; Table 5.3; fig 5.3) and Juniperus (section A; Table 5.1; 5.2; fig 5.2). The Rumex peak invariably lies in minerogenic sediment. Attention is paid to particular problems and dates, but it should be noted that comments on the validity of all dates in Tables 5.1 and 5.3 are based on similarly detailed analyses: space precludes a discussion in depth of all dates.

JUNIPERUS

Smith and Pilcher (1973) quote six dates in their discussion of the juniper peak. Of these, however, three can be criticized or have already been criticized for inaccuracies. It is arguable, for instance, whether Smith and Pilcher are justified in quoting the C14 date of 10490 +/- 160 B.P. (I - 3598) from Blelham Bog (Pennington and Bonny, 1970) when in "Radiocarbon" the latter authors suggest the date to be perhaps 3-500 years too old (in Buckley and Willis, 1970). Similarly, the date from Roddan's Port (Morrison and Stephens, 1965) of 10130 +/- 170 B.P. (Q - 371) has been questioned by Dresser (1970). In Appendix IV of Morrison and Stephens (1965) Godwin and Willis consider that the Phragmites peat assayed was not susceptible to hard-water error, but being semi-aquatic it is hard to see why this plant should be exempt from such errors. The entire series of 14 dates shows problems of hard-water error (dates Q-361, 364, 369 and 365), and date-inversions are common. Q-371 itself lies in a sequence of dates (Q-370, 371, 368) which clearly trend towards date-inversions (although their standard deviations overlap). In addition, the length of time between sampling (1957) and assay (1963) is not ideal pre-treatment, and it would seem these dates cannot be relied upon with the implied dangers of fungal growth introducing "younging" errors.

This consequently leaves three dates: from Bigholm Burn (Moar, 1969a) Smith and Pilcher (1973) take two dates, 9590 +/- 170 B.P. and 9470 +/- 170 B.P. (Q-697), the latter slightly higher in the lithostratigraphy but both bracketing the same event. On the pollen diagram the juniper and birch maxima occur on the same level, and it is clear that the low sedimentation rate has blurred the biostratigraphical definition of the site.

The date of 9660 +/- 105 B.P. (UB-298 D) from Slieve Gallion in Co. Tyrone (Pilcher, 1973) clearly records the rational limit of Juniperus rather than the peak, which by interpolation lies nearer 9200 B.P. A 2 cm slice of reed-peat was removed from a monolith, and this date lies in an internally consistent series. Considerable reliance can be placed on this date as a result of these exemplary methods. Pilcher (1973) considers that juniper expanded at 9600 B.P., and maintained itself as a dominant until the delayed colonization of birch in these uplands. Pilcher then argues that the Juniperus expansion was non-synchronous across Ireland in view of the date at Sluggan Bog of 9160 +/- 130 B.P. (UB-244) for the peak. This date is also considered valid here, coming from a set of internally consistent dates. As the two dates overlap at one standard deviation there is little evidence for Smith & Pilcher's suspected diachroneity, and the authors withhold judgment on the interpretation of the few dates available to them.

Interestingly, some authors have implied synchroneity in discussions on possible early migrations of forest trees. Bartley (1966) and Moore (1972) relate apparently early peaks of birch and hazel with Juniperus, and in using the juniper peak as a temporal "control" on tree migration imply its synchroneity. Moore (1972) uses this argument in proposing the early presence of Corylus in Cardiganshire. In the absence of C14 dates these speculations cannot be relied upon, however (chap. 4; sect.4).

In his 1977 paper, Moore argues instead that the _Juniperus_ peaks at sites in Wales represent purely local stands, and are diachronous in time. This is itself a considerable change in emphasis from a paper written in 1976 (Handa and Moore, 1976) in which, using four dates from the basal organic deposits of three Welsh pingos investigated by Handa and Moore, plus information from six other sites (of which four, Blelham Bog, Roddan's Port, Slieve Gallion and Bigholm Burn are discussed by Smith and Pilcher, 1973), the suggestion of non-synchroneity is much more tentatively expressed. Moore (1977) therefore places much reliance on the dates obtained by Watson (Shotton _et_. _al_., 1973, 1974, 1975) from several Welsh pingos (Watson, 1971). The 7 dates reported in "Radiocarbon" do not, however, present a consistent pattern, those subjected to alkali pre-treatment showing distinct differences between the residue and the humate extract. Those not treated may well be contaminated by younger carbon, and it is unlikely that the very young date of 9380 +/- 340 B.P. (BIRM-368) is reliable. In addition the standard deviations are unacceptably high given the 4 - 6 cm thick samples collected. In any event, the dates from the pollen-analysed sites do not relate directly to the _Juniperus_ peaks at these sites (Handa and Moore, 1976), but are basal dates for the onset of organic-rich sedimentation at each site.

Dates on the postglacial pollen peaks of *Juniperus* published since 1973 are often directly related to the *Juniperus* peak by improved sampling techniques. These approaches have meant that more confidence can probably be placed on many of the dates to be discussed below.

Fig 5.2 details the range of 40 dates, in terms of the standard deviations supplied with the date (a mean date is not presented as the C14 age can occur anywhere between the end-points of the standard deviations, and these themselves only give a 66% probability of it being an accurate date; Harkness, 1975) and the sediment and sediment thickness of the 40 dates known to the author produced since 1970 to the time of writing (August 1983). The date from Lairigmor 2 (Walker and Lowe, 1981) of 11300 +/- 245 B.P. (GU- 1083) is considered in serious error, and will not be used. Also excluded are those dates quoted by Smith and Pilcher (1973) and Handa and Moore (1976), but criticized above. Not all the dates relate to the *Juniperus* peak, however, some dates relating to the initial rise or decline in pollen values. Where indicated on the pollen diagrams or in comments in "Radiocarbon" (see Table 5.1) the position of the peak, which is the phase most commonly dated, is shown in relation to the date illustrated, giving an indication of the relationship of the date in question to the stratigraphic point of interest (fig. 5.2).

Some general points can be made first. As mentioned above, the majority of the dates (25/40) refer to the _Juniperus_ peak. Interestingly, however, 4/10 of the older dates (numbers 30 - 40) are considered to be from material predating the peak although a similar sequence of post-peak dates is not seen in the younger dates, dates 1 - 10. Initially, a linear regression analysis was performed for sample thickness against the standard deviation for the 40 dates. This was shown to be significant at 95% probability, demonstrating the value in improved precision of taking thinner sediment slices for radiocarbon assay.

Before a palaeoecological interpretation can be placed on the C14 assays considerations of their reliability must be made. Reasons for the rejection of some dates are given in Table 5.1, and the assessment followed the approach taken for the dates of Smith and Pilcher (1973) and Handa and Moore (1976).

A general criticism concerns the comments on dates published in "Radiocarbon". Very rarely is information on bedrock, carbon content or weight of material supplied; when bulk sampling is employed this should be mentioned, and the means of correlation, litho- or biostratigraphic, discussed (cf. Lowe and Walker, 1981); δC13 values should be provided

TABLE 5.1

C^{14} DETERMINATIONS ON POSTGLACIAL *JUNIPERUS* 'PEAKS'

TABLE No	SITE NAME	SEDIMENT	THICKNESS OF SAMPLE (cm)	DATE C^{14} YEARS B.P.	LABORATORY No	PRINCIPAL REFERENCES	RADIOCARBON REFERENCE (where known)	ASSESSMENT OF VALIDITY AND COMMENTS
1	TYNDRUM	organic mud	4	*8040* ± 50	SRR 1416	LOWE and WALKER (1980,1981)		groundwater contamination
2	TYNDRUM	gyttja	3	8130 ± 40	SRR 1417	LOWE and WALKER (1980,1981)		suspected dates discarded
3	TYNDRUM	silty gyttja	3	*8340* ± 160	BIRM 856	LOWE and WALKER (1980,1981)		(Lowe and Walker 1980)
4	LOCHAN COIR A' GHARBHAINN	fine detritus mud	3	*8650* ± 150	Q 958	BIRKS H.J.B. (1973)	14(1),239-46	post dates *Juniperus* peak (see date 9) date discarded
5	CORROUR 2	fine detritus gyttja	3	*8920* ± 80	SRR 1418	WALKER and LOWE (1979) LOWE and WALKER (1980)		Related dates at sites inverted date discarded
6	BLACKNESS	gyttja peat	1.5	*9140* ± 105	Hv 5648	WALKER (1975) LOWE and WALKER (1977)		groundwater contamination suspected (Walker 1975) date discarded
7	RANNOCH STATION 2	telmatic peat	4	*9152* ± 95	SRR 1073	WALKER and LOWE (1979) LOWE and WALKER (1980)		date inverted with SRR 1072 discarded
8	LOCH CUITHIR	diatomaceous gyttja	10	*9400* ± 210	HEL 502	VASARI (1977)		date 20 (below) is closer to *Juniperus* peak this date discarded
9	LOCHAN COIR A' GHARBHAINN	fine detritus mud	3	*9420* ± 150	Q-957	BIRKS H.J.B. (1973)	14(1),239-46	groundwater contamination suspected discarded
10	LOCH ASSYNT	moss rich silts sands	5	*9430* ± 150	Q-1280	BIRKS H.H. in BIRKS,H.J.B. (1980)	23(1)81-93	internally consistent series considered valid
11	CORROUR 2	gyttja	3	*9440* ± 310	BIRM 855	WALKER and LOWE (1979) LOWE and WALKER (1980)	—	reversal with date 23 (below) high C value discarded
12	LOCH SCIONASCAIG	gyttja	5?	*9474* ± 160		PENNINGTON *et al* (1972) BIRKS H.J.B. (1980)	—	internally consistent series considered valid
13	COIRE CLACHACH	gyttja	5	*9500* ± 70	SRR 1596	WALKER and LOWE (1982)	—	although SRR 1597 discordant other dates agree considered valid
14	RED MOSS	fine detritus mud	5	*9508* ± 200	Q 925	HIBBERT *et al* (1971)	12(2),593	reversal of 200 years with date Q 924 date discarded
15	BELLE LAKE	gyttja	10	*9600* ± 135	D 112	CRAIG (1978)	16(1),6-9	internally consistent series considered valid
16	SLUGGAN BOG	reedy detritus mud	2	*9610* ± 130	UB-444	SMITH and PILCHER (1973)	13(2),454-56	internally consistent series considered valid
17	LOCH CILL CHRIOSD	gyttja	5	*9655* ±150	Q-956	BIRKS H.J.B. (1973)	14(1),239-46	no error suspected from principal reference considered valid
18	TORNESS	gyttja	2	*9660* ± 140	SRR 1797	WALKER and LOWE (1982)	—	internally consistent series considered valid
19	SLIEVE GALLION	reed peat	2	*9660* ± 105	UB 298 D	PILCHER (1973)	13(1),113-14	internally consistent series considered valid
20	LOCH CUITHIR	clay gyttja diatomaceous gyttja	10	*9660* ± 250	HEL 503	VASARI (1977)	—	see date 8 considered valid
21	CLASHGOUR 1	silty organic mud	2.5	*9730* ± 180	Gu-1101	LOWE and WALKER (1980)	—	2 dates from site in accord considered valid
22	ABERNETHY FOREST	fine detritus silty mud	8	*9740* ± 170	Q 1268	BIRKS H.H. and MATTHEWES (1978)	23(1),81-93	internally consistent series considered valid
23	CORROUR 2	organic lake mud	3	*9800* ± 160	BIRM 854	WALKER and LOWE (1979) LOWE and WALKER (1980)	—	date inverted compared to date 11 (above) date discarded
24	LOCH KINORD	gyttja	10	*9820* ± 250	HEL-421	VASARI (1977)	—	post dates *Juniperus* peak but considered valid
25	KINGSHOUSE 2	organic lake mud	3	*9910* ± 200	BIRM 724	LOWE and WALKER (1976,1980) WALKER and LOWE (1977)	—	younger of 2 dates preferred due to C value considered valid
26	NANT FFRANCON	gyttja/mud	11	*9920* ± 220	Q-890 bis	HIBBERT and SWITSUR (1976)	15(1),156-64	slow sedimentation rate, with high *Betula* but considered valid
27	LOCH CLEAT	gyttja	7	*9990* ± 130	SRR 940	WILLIAMS (unpub. Ph.D thesis 1977)	23(2),252-304	high C value but belonging to internally consistent series considered valid
28	MUIR PARK RESR (DRYMEN)	clay gyttja/gyttja	16	*10010* ± 230	HEL 162	VASARI (1977)	—	may pre-date *Juniperus* peak but included in S.D. considered valid
29	LOCH SALEN	silt	6	*10090* ± 100	SRR 1186	WILLIAMS in BIRKS,H.J.B. (1980)	23(2),252-304	early postglacial series consistent considered valid
30	RANNOCH STATION 2	organic lake mud	3	*10160* ± 200	BIRM 859	WALKER and LOWE (1979) LOWE and WALKER (1980)	—	dates from site seem old but considered valid in absence of contrary evidence
31	LOCHAN DOILEAD	clay/gyttja	7	*10200* ± 150	SRR 773	WILLIAMS (unpub. Ph.D thesis 1977)	23(2),252-304	internally consistent series considered valid
32	COOLTEEN	gyttja	10	*10210* ± 110	D-108	CRAIG (1978)	16(1),6-9	internally consistent series considered valid
33	CAM LOCH	gyttja	10	*10230* ± 190	SRR-247	PENNINGTON (1975)	21(2),203-56	very high C value (—19.0) date discarded
34	AMULREE 2	peat	1.5	*10270* ± 100	Hv-9643	LOWE and WALKER (1977)	—	date below this (Hv 9644) suspect this date also discarded
35	CROSE MERE	silty fine detritus mud	8	*10312* ± 210	Q-1240	BEALES (1980)	17(1),35-51	internally consistent series considered valid
36	LOCH ASHIK	gyttja	5	*10330* ± 80	SRR 813	WILLIAMS (unpub. Ph.D thesis 1977)	23(2),252-304	dates seem old but are internally consistent considered valid
37	DIN MOSS	fine detritus mud	4	*10340* ± 200	Q-1078	HIBBERT and SWITSUR 1976	—	internally consistent series considered valid
38	TYNASPIRIT 2	peat	1.5	*10420* ± 160	Hv-4985	LOWE and WALKER 1977	—	hard water error suspected (principal ref) date discarded
39	MOLLANDS	fine detritus peat	1.5	*10480* ± 150	Hv-5646	LOWE and WALKER 1977 LOWE (1978,1982)	—	as date 38
40	AN DRUM, ERIBOLL	clay	10	*10650* ± 110	SRR-783	BIRKS H.H. in BIRKS H.J.B (1980)	23(2),252-304	hard water error possible (Radiocarbon ref) date discarded

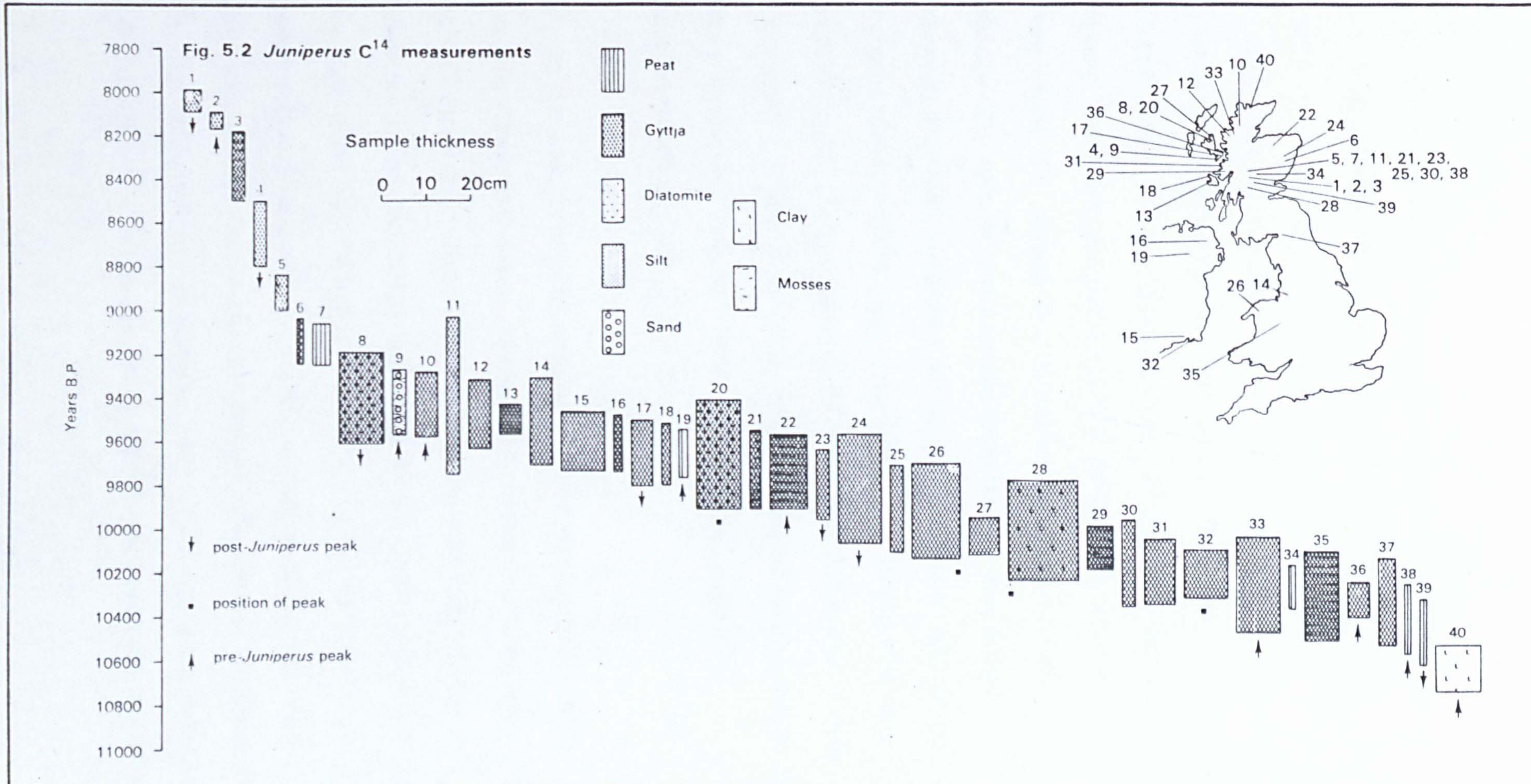


Fig. 5.2 *Juniperus* C^{14} measurements
Years B P
Sample thickness
0 10 20cm
Peat
Gyttja
Diatomite
Clay
Silt
Mosses
Sand
post-*Juniperus* peak
position of peak
pre-*Juniperus* peak

as the rule rather than the exception, and a more objective attitude to the possibilities of error is needed.

Of the 40 dates, 17 are rejected as untrustworthy or as not depicting the peak with confidence. Certain sites are included despite their general range of dates at several horizons appearing consistently old in varying sediment types; dates 30, 36 and 37. Other sites are included although the lack of information supplied by the author either in the main reference or in "Radiocarbon" allows no interpretation; objectively this should not imply the date is acceptable, but in the absence of data to the contrary this is assumed. 23 dates are thus taken as valid measurements of either the rise, peak or decline in <u>Juniperus</u> pollen percentages at 23 sites.

It is seen from the revised list of dates (Table 5.2) that the discarded dates concentrate at both ends of the series (fig 5.2). This improves the consistency of the remaining dates markedly, but these still show a range of ages from 9280 B.P. (higher S.D. of date 10) to 10540 B.P. (lower S.D. of date 37). Linear regression analyses were performed on the data base (23 dates) against (1) altitude, (2) latitude, and (3) longitude. For these the mean date of each sample was used except at sites dating sediment prior to or post-*Juniperus* peak, in which cases the higher and lower standard deviations on the dates were used respectively. Likewise, for dates 26 and 28, the lower and higher standard deviations respectively are quoted as the considerable thickness of sediment renders the C14 dates obtained similar in bias to dates from thinner slices of pre- and post-peak sediment (Table 5.2). Altitudes are taken from the main reference in each case, or from the appropriate O.S. 1: 50,000 scale map, as are the latitudes and longitudes of each site (Table 5.2).

In each test the product moment correlation coefficient r failed at 95% probability. These results do not necessarily imply that Pilcher's (1973) arguments for diachroneity are wrong. They do, however, suggest that none of the principal geographical factors which could correlate with climatically or edaphically-controlled delay succeed in explaining the variation in the dates. From an equation (13) in Warner (1975) it is found that the extreme dates (8 and 37) can be regarded as two separate "events", but no clear division is found between adjacent dates, so that no separation can be made within the series. Synchroneity cannot be assumed from these data, but the many difficulties inherent in radiocarbon

TABLE 5.2

VALID *JUNIPERUS* C^{14} DETERMINATIONS

SITE No (TABLE 5.1)	C^{14} DATE USED (B.P.)	ALTITUDE (metres O.D.)	LATITUDE (°N)	LONGITUDE (°W)
10	9280□	c.90	58°10′	5°04′
12	9474	c.75	58°03′	5°10′
13	9500	200	56°24′	5°51′
15	9600	33	52°11′	7°02′
16	9610	c.170	54°47′	6°16′
17	9655	20	57°12′	5°58′
18	9660	110	56°26′	5°48′
19	9660	430	54°45′	6°45′
20	9660	180	57°33′	6°14′
21	9730	200	56°32′	4°52′
22	9530□	221	56°14′	3°43′
24	10070■	175	57°05′	2°55′
25	9910	308	56°39′	4°48′
26	10140■	198	53°08′	4°03′
27	9990	c.150	57°41′	6°20′
28	9780□	c.220	56°05′	4°25′
29	10090	c.85	56°43′	5°47′
30	10160	c.290	56°41′	4°34′
31	10200	c.35	56°59′	5°48′
32	10210	c.50	52°21′	6°36′
35	10312	90	52°52′	3°51′
36	10250	40	57°15′	5°49′
37	10340	170	55°34′	2°18′

■ Lower S.D used

□ Higher S.D used

dating (chap.3; this section) may mean that proof of synchroneity demands too much from the data. Given these uncertainties over C14 determinations, clear demonstration of synchroneity is, perhaps, not to be expected.

Of particular note in Table 5.2 and fig 5.2 is the consistency of many of the dates in relation to the time-period between 9600 - 9800 B.P. This age-band passes through 15 of the 23 valid dates. As an approximation, therefore, it is considered that the majority of valid dates suggest (and no stronger given the limitations of the evidence), that the *Juniperus* expansion may have been synchronous on a broad scale.

EMPETRUM

Since Smith and Pilcher's (1973) study the refined C14 dating techniques have enabled dates to be obtained on the *Empetrum* peak at several sites (Table 5.3; fig 5.3).

It is disturbing to note the pronounced differences between dates 2 and 7 (Table 5.3) from the same site, Abernethy Forest, collected by different workers and processed at different laboratories. Vasari (1977) considered that other, older dates he collected from this site showed hard- water error, but discounted this problem with the date in question (HEL-422) in the good agreement with date 3 (Table 5.3) from the nearby site of Loch of Park. The sediment description in Birks and Matthewes (1978) for date Q-1268 suggests a low carbon content (see fig 5.3), but this has not affected the results, the Cambridge laboratories' date having a smaller standard deviation than Helsinki's (Vasari, 1977). Groundwater contamination is thought unlikely to affect Birks and Matthewes'(1978) date as overlying sediments produce dates in good agreement with similar horizons at other sites. It is tempting to propose that inter-laboratory bias (International Study Group,1982) is responsible for the differences, but such errors are not clearly delineated at present. The dates remain enigmatic, and cannot be explained on the data available. They are a significant testament to the uncertainties and questions that remain in radiocarbon dating, and endorse the views on the difficulties of proving synchroneity developed in this section (above). On consideration of the other dates (fig 5.3) it is felt date 2 is anomalous, for reasons unknown, and is discarded from the analyses.

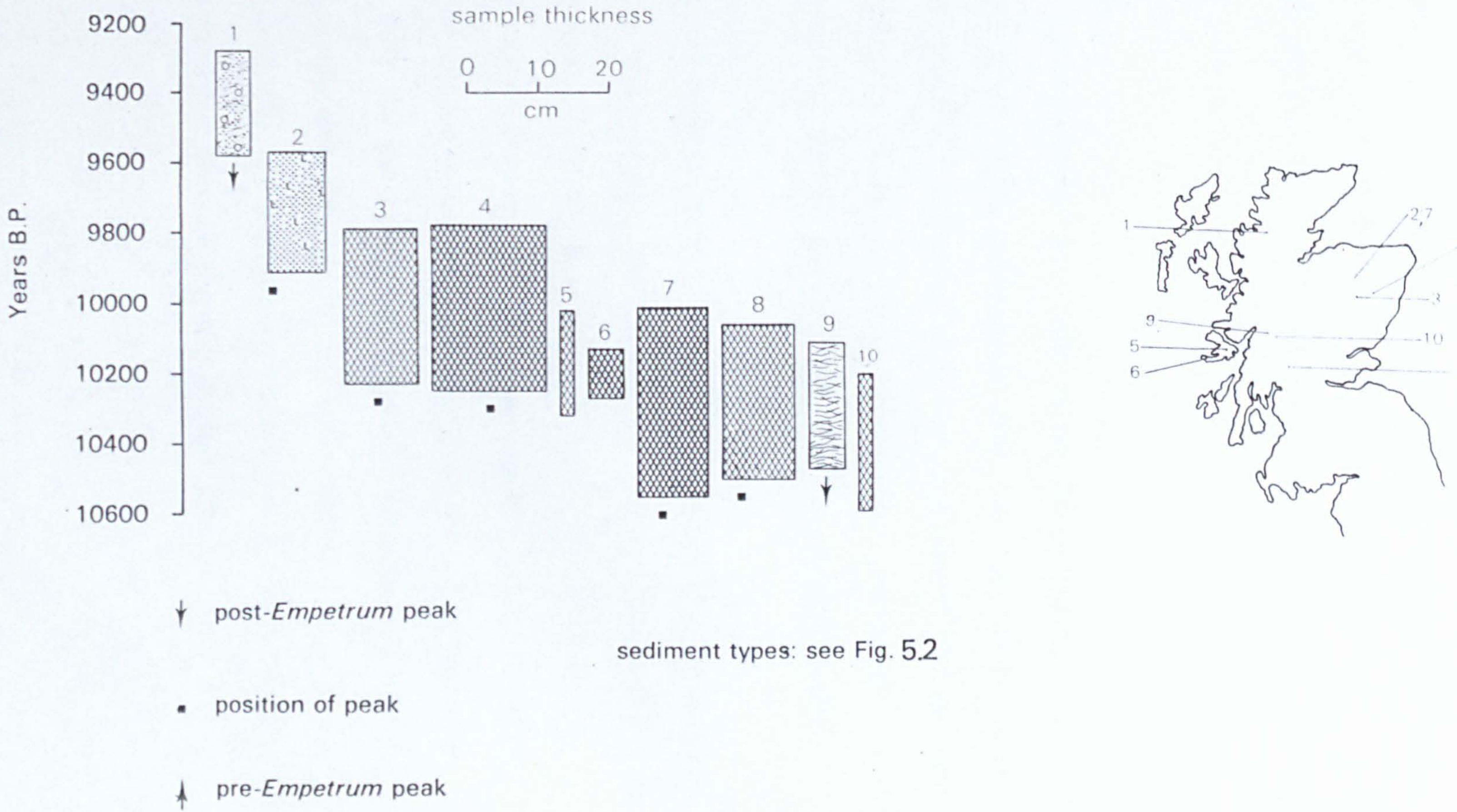
Dates 1 and 2 (Table 5.3) clearly post-date the _Empetrum_ peak (and indeed were used in the above section relating to _Juniperus_), and their validity is uncertain (see Table 5.3). The remaining seven "valid" dates were tested to see whether

TABLE 5.3

C^{14} DETERMINATIONS ON POSTGLACIAL *EMPETRUM* 'PEAKS'

TABLE No	SITE NAME	SEDIMENT	SAMPLE THICKNESS (cm)	DATE C^{14} YEARS B.P.	LAB No	MAIN REFERENCES	'RADIOCARBON' REFERENCE (where known)	ASSESSMENT OF VALIDITY & COMMENTS
1	LOCH ASSYNT	moss-rich silts/sands	5	9430 ± 150	Q-1280	BIRKS,H.H; in Birks,H.J.B(1980)	23 (1);81-93	not specific to *'Empetrum'* peak; date already used in fig 7 4
2	ABERNETHY FOREST	fine detritus silty mud	8	9740 ±170	Q-1268	BIRKS,H.H and MATTHEWES(1978)	23 (1);81-93	date discarded (see text)
3	LOCH KINORD	gyttja	10	10010±220	HEL-420	VASARI(1977)	—	considered valid
4	MUIR PARK(DRYMEN)	clay gyttja/gyttja	16	10010 ± 230	HEL-162	VASARI(1977)	—	as date 1 (above)
5	TORNESS	gyttja	2	10170 ± 150	SRR-1797	WALKER and LOWE(1982)	—	considered valid
6	LOCH AN T-SUIDHE	gyttja	5	10200 ±70	SRR-1801	WALKER and LOWE(1982)	—	considered valid
7	ABERNETHY	gyttja	10	10230 ±220	HEL-422	VASARI(1977)	—	considered valid, but note date 2 (above;see text)
8	LOCH OF PARK	clay gyttja/gyttja	10	10280±220	HEL-416	VASARI(1977)	—	considered valid
9	KINGSHOUSE 2	moss fragments	5	10290 ±180	BIRM-722	LOWE and WALKER(1976,1980)	—	date = average of two dates; (1980 ref.);considered valid
10	RANNOCH STATION 2	organic lake mud	2	10390 ± 200	BIRM-858	LOWE and WALKER(1980) WALKER and LOWE(1979)	—	considered valid

Fig. 5.3 *Empetrum* C^{14} measurements



the age-range represented significantly different "events" (Warner, 1975), using dates 6 and 8, which resulted in the view that the dates represent one synchronous event with an average and standard deviation (calculated from the 14 standard deviations of the samples) of 10,215 +/- 229 years B.P.

SUMMARY

It is considered that radiocarbon dates relating to the Gramineae-*Rumex* pollen assemblage zone are unreliable as the vast majority are concerned more with the age of the earliest organic deposits formed in the post-glacial, which will vary between sites, rather than with the pollen stratigraphy.

It has been argued that the C14 dates available suggest that both the *Empetrum* and *Juniperus* peaks are synchronous on a large scale. It has also been demonstrated that many factors affect the accuracy of a radiocarbon date, many of which one can only speculate on. Consequently it might be argued that the data base has inherent inaccuracies which undermine the reliability of the conclusions. This is appreciated, but as a first approximation the results suggest broad synchroneities in the early post-glacial pollen record.

f Ice-retreat proceeds by uniform, systematic frontal retreat.

Evidence from Loch Lomond Stadial deposits and present-day glaciers will here be presented to demonstrate that this behaviour was unlikely to have occurred, and that ice-thinning was as significant as frontal retreat.

It has long been thought on the basis of the absence of morphological features indicating glacio-equilibrial conditions (i.e., retreat moraines) within stadial ice-limits in Scotland that ice-retreat was by "widespread stagnation of the ice" (Sissons, 1976; p.107). Retreat stages within terminal limits are known from North Wales (Gray, 1982) and the Southern Uplands of Scotland (Cornish, 1981), but are almost unknown further north. The essentially in situ decay is believed to have been triggered by the climatic amelioration before 10,000 B.P., and was probably rapid, Weideck (1968) proposing that 20 years is a maximal response time for glaciers to respond to a climatic impetus regardless of type or magnitude of glacier. The distribution of hummocky moraine is believed to indicate this decay (Sissons, 1976), although much work remains to be done to establish the exact origins of this undoubtedly polygenetic landform, and in understanding the glaciological significance of its distribution (cf. Hodgson, 1982).

Bergquist (1979) has modelled the thinning of an ice-sheet by melting, although his provisional study was acknowledged to be limited by its failure to incorporate assumptions concerning ice-flow within glaciers. Assuming an elliptic profile for the ice-sheet he demonstrated that melting in response to increasing temperature reduces an ice-dome of 1500 m maximum thickness to 1200 m in 500 years. Given the time-scales known for the end of the Loch Lomond Stadial it is likely that temperature changes were much more extreme at that time. Significantly, however, ice-front recession was markedly faster than overall thinning at the earliest phase of deglaciation, so that frontal retreat in 500 years was approximately 80 km. The concept of an elliptic profile is doubted for stadial glaciers (see chap. 6.6), however, and it is likely that valley glaciers had a more slab-like profile (Schilling and Hollin, 1981). As a result thinning may have had more dramatic effects than in Bergquist's (1979) model.

Models of deglaciation are few for Younger Dryas glaciers except in the most generalized sense. Hillefors (1979) attempted to relate in detail the mode of deglaciation to topographic influences for a part of the west coast of Sweden, with fjord-like valleys similar to western Scotland. Here he described the plateau-like watersheds as undergoing thinning of the ice first, with residual ice flowing laterally down-slope into the valleys. The plateaux are now characterized by rock-cored drumlins (rare in Scotland) and irregular ablation till.

It seems unlikely that ice-retreat was as orderly as has been supposed in section 3. What is unknown is whether rapid down-wasting led to the exposure of land to plant colonization within the decaying ice-mass. The patchy distribution of hummocky moraine suggests that areas of the Rannoch ice-cap and associated valley glaciers decayed *in situ* as dead-ice masses while, perhaps, within narrow valleys ice retreated in a more orthodox fashion bolstered by ice flowing from the plateaux, but this situation is hypothetical. It remains a major problem in the successful application of a deglacial chronology.

5.4 PREVIOUS APPROACHES

Three previous investigations will be discussed, those of (a) Pennington (1978), (b) MacPherson (1978) and Lowe and Walker (1981). Attention will be paid to the major problems involved in such research in an effort to clarify the procedures and refinements demanded by the nature of the study, and listed in section 5.5.

(a) Pennington (1978) was perhaps the first researcher to consider the glaciological implications behind post-glacial pollen successions, in suggesting time-transgressive melt-out of small valley and corrie glaciers in the English Lake District. She had intimated a similar idea in a paper written in 1970.

Pennington (1978) records the basal pollen assemblage zones for 14 corrie lakes and 3 infilled peat-basins, and arranges them in a relative time-dependent order: Artemisia - Gramineae - Rumex - Empetrum - Juniperus (subdivided into base, middle and top) - Betula p.a. zones. It is assumed that these zones are synchronous in the region, though no evidence is supplied to demonstrate this. The Loch Lomond Readvance terminal limits used are those of Marr (1916) and Manley (1959). Her interpretation of the results is straightforward, with the sites marked by an Artemisia peak at their bases representing ice-decay earlier than at other sites.

There are, unfortunately, several limitations in the study associated with (i) sampling techniques, (ii) ecological interpretation, and (iii) the correspondence between her sites (1978) and the reconstructions of the Stadial glaciers in the Lake District published by Sissons in 1980(a).

(i) Sampling Techniques

Only three of her sites, Bleawater Moss, Wolf Crags Moss and Langdale Combe (analysed by Walker, 1965) are from terrestrial peat-basins. All others are lake-basins, and it is regarded as considerably more difficult to locate the area of deepest sediments from a boat. Likewise, sampling from a boat using free-fall samplers results in problems of penetration of stiff sediment. Often the basal sediments may not be penetrated or recovered using this method, and this may be behind the problems admitted by Pennington (1964) at the site of Blind Tarn on the Old Man of Coniston range, where the basal deposits analysed were only of Godwin zone VII. The site was not included in her 1978 study, although Blea Water, which dates from Godwin zone V is discussed. Here, seven mutually consistent cores were retrieved, yet a laterally continuous sand layer, common in upland sites (Donner, 1962) would render the same result. It could be argued that similar problems occur on terrestrial sites, but considerably more options are open to investigators in sampling such sites, such as power-corers etc.

The majority of pollen diagrams discussed by Pennington (1978) are unpublished (or are unreferenced in her 1978 paper). At Goatswater, adjacent to Blind Tarn, Pennington (1964) reported a lack of fine sediment from the tarn-floor (enterprisingly at this site a diver was employed) except on a large mound, interpreted as a moraine, where a total thickness of 1.0 m of sediment was sampled. Deposition on such areas is often irregular, hiatuses are common with sequences condensed (hence the 1.0 m core), and this site at least is of questionable usefulness.

(ii) Ecological Interpretations

The site of Goatswater can usefully be discussed here also. It is considered (Pennington, 1978) that ice withdrew from this upland basin during or at the end of the Loch Lomond Stadial in its showing an Artemisia peak at the base. The entire Flandrian sequence is, however, compressed into 60 cm (the lower 40 cm of clay were thought non-polleniferous), and this basal "zone" (one level), as well as showing high Artemisia features a Juniperus maximum and abundant Betula.

A clearer example of the problems of interpreting the order of succession in sediments with slow rates of accumulation is seen at Walker's (1965) site of Langdale Combe, reproduced in full by Pennington (1970). Walker regarded the basal zone as of Godwin zone IV - V. Pennington (1978) considered the site as having an *Artemisia* assemblage at the base. Calculated on an arboreal pollen sum, the basal 8 cm (4 levels) show a maximum of 3% for *Artemisia*. These spectra are dominated by *Rumex* (c30% maximum at base), Gramineae (80 - 140%), and *Empetrum* (24% peak). *Juniperus* rises to 250% A.P. in level 6, and Pennington's zonation may not be operable if objective zonation methods (Gordon and Birks, 1974; Pennington and Sackin, 1975) are applied. The presence of *Artemisia* may be taken to justify her zonation, but it should be appreciated that taxa may have persisted in the pollen rain long after their first appearance, particularly in the high ground of Langdale, while *Empetrum* and *Juniperus* were colonizing the lowlands. The dominant percentage values are considered most relevant to this type of study. As a rule, the pollen stratigraphy should show clear evidence of one pollen assemblage zone to the exclusion of higher, overlying zones. This cannot be demonstrated at either Goatswater or Langdale Combe. Sites showing markedly slow sedimentation rates should be avoided wherever possible.

(iii) The mapping of Sissons (1980a)

Remapping the extent of the Loch Lomond Readvance in the Lake District, Sissons (1980a) points out that two of Pennington's (1978) sites, Grisedale Tarn and Levers Tarn, lie well outside his terminal limits, and to these should be added Bleawater Moss in Haweswater. Sissons (1980a) assumes that coarse minerogenic bands had prevented the sampling of Lateglacial deposits at these sites. Further in his discussion he employs the same argument for the deposits at Keppelcove Tarn, within the stadial limits of Sissons (1980a), as late melt-out inferred by Pennington (1978) is felt by Sissons to be inconsistent with the size and aspect of the glacier which occupied the basin. The invocation of this argument here and at Achnasheen (sect.5.1) shows the utmost importance of knowing that the bedrock floor has been met with.

(b) In trying to establish a relative chronology for the major shore-lines of the Glen Roy - Loch Laggan proglacial lake, MacPherson (1978) examined four sites palynologically, emphasizing the basal spectra from each site. Problems of sampling are immediately apparent with the operation of a Hiller sampler which with its 10 cm tip cannot sample the basal sediments, although MacPherson (1978) is aware of this deficiency. More seriously, at her An Dubh Lochan site MacPherson was forced to sample from the edge of a lochan, from where it cannot be proved the deepest point had been located.

(c) Lowe and Walker's work (1981) involved the correlation biostratigraphically of three sites; Mollands, near Callander (Lowe, 1978), Tyndrum, 30 km W.N.W. of Mollands (Lowe and Walker, 1981), and Kingshouse 2 (Lowe and Walker, 1976; Walker and Lowe, 1977), one of nine sites investigated on or near Rannoch Moor (Lowe and Walker, 1976, 1980, 1981; Walker and Lowe, 1977, 1979, 1980a,b, 1981). Kingshouse 2 itself is some 25 km N.W. of Tyndrum. They conclude that "Mollands shows the most detailed early Postglacial biostratigraphic record, Tyndrum the next, and Kingshouse 2 the least detailed," (Lowe and Walker, 1981; p.292). They argue that, although all sites are kettle-holes, delayed melt-out of ice is unlikely due to the consistent pollen-stratigraphic correlation between sites. This is in essence untestable from one site without supporting evidence from adjacent basins. One cannot demonstrate that delayed melt-out could not account for the sequence Lowe and Walker show.

Two points emerge from this discussion. Firstly, the selection of basins known to be formed by dead-ice (Flint, 1957; Price, 1973; Embleton and King, 1975) should be avoided , and in particular sites within hummocky moraine, which may imply in-situ ice-decay (but see Hodgson, 1982),in work of this kind. Secondly, the pattern of events is best reconstructed from many sites as Gray (1975) stated. For example, regional deglaciation could be thought more successfully demonstrated from the consistency of the basal Empetrum zone at many sites on Rannoch Moor rather than to isolate one site among them.

Since that publication Lowe and Walker (pers. comm.) have proposed subdividing their originally defined R-p.a. zones in a way similar to Pennington's treatment (1978) of her Juniperus p.a. zones, basing their subdivision on rising, maximal or declining values for key pollen curves. Their intention is to discern a more finely detailed chronology. Ecologically this appears sound. Colonizing species occupy a new niche in low numbers, expand to a peak and, particularly with apophytes (Faegri, 1963) or r-strategists (MacArthur and Wilson, 1967), decline with increasing competition. The weakness with the proposal is in the reliability of interpreting this from percentage-based pollen diagrams. Rising and falling curves can be explained by other reasons. Such zonation procedures are best illustrated from pollen influx rather than percentage-based diagrams.

In summary, many points pertain to the location, sampling and interpretation of early postglacial sites which will be considered when devising a strategy for the present study.

One important difference distinguishes the present study from these previous investigations. In the latter the limits of Loch Lomond Readvance glaciers were thought reasonably well-known. In the present work the hypothesis is to be applied as a test in its own right in the absence of decisive morphological evidence.

5.5 A STRATEGY FOR TESTING THE DEGLACIAL CHRONOLOGY HYPOTHESIS

From the above discussions certain assumptions appear valid, while others remain uncertain. Many problems can be avoided by carefully designed procedures for both sampling and analysis, and it is the purpose of this final section to detail the strategy adopted in the Awe valley (chap.6).

SAMPLING

1 Infilled terrestrial basins are selected so that it is possible to probe the entire surface at close intervals.

2 Pairs of such basins are chosen, lying within 1 km of each other, preferably lying parallel to the presumed direction of ice-retreat; each pair of basins is considered as one locality, and sites designated I and II respectively.

Gray (1975) proposed that many basins should be examined in an area, but pollen analysis is time-consuming, and it is felt as a compromise that two basins per locality provide a sufficient number. The number of localities will depend upon the detail of the investigation and the size of the region to be examined. In this study, three localities (fig 5.1) are located along the length of Loch Awe.

The advantage of using pairs of basins lies in the increased probability that what is being recorded is more likely to relate to regional deglaciation rather than to local factors such as late melt-out of dead-ice. It is thought unlikely that sediments from two independent basins (the independence is important; many sites close to Barachander I (chap.6) were rejected through the belief that one large block of dead-ice could have influenced sedimentation in several basins) with very similar basal pollen stratigraphies would be influenced by dead-ice, as this would require ice melting out at the same time in two places, and this coincidence is considered improbable.

It would be advantageous for the sites at one locality to be on different rock-types to distinguish between local and regional pollen rain as does Jacobsen (1979), but in the study area this was not possible. Basins need not be of similar dimensions, but this is useful as some pollen-entrainment characteristics are related to basin size (Davis, M.B., 1973; Pennington, 1979). In this catchment size can also be important (cf. chaps.3,4), and so it is convenient to deal with uniformly-sized basins. The basins in the study were all small, average 150 - 200 m diameter, but large enough to receive a predominantly regional pollen influx in treeless conditions (Berglund, 1979).

3 The basins selected should, wherever possible, lie on a non-drift substrate. Livingstone et. al. (1958) described the problems involved in ascertaining the depth to substrate in arctic lakes on drift, and similar difficulties are reported from the study area in chapter 2. Bedrock basins allow much more confidence in the successful probing of basins, and at sites on the Dalradian bedrock of the region probing was met with an unyielding "clunk" when the floor of the basin had been struck. Also, it is felt that such basins are less likely to contain dead-ice than kettle-holes, for which it is a requirement of their formation.

4 Initially, care must be taken to ensure the prospective site is an enclosed basin, and with detailed probing at 10m , 5 m , and finally 2 m intervals the deepest point of the basin is established. This is crucial. Of 21 lake-basins in the study area on Dalradian strata examined by Murray and Pullar (1910), 11 were described as simple, i.e., a simple outline and contouring with one area clearly the deepest, while almost as many, 10, were complex, having two basins separated by a rock-bar. Such subdued features are very likely given the strong lineation of the region's lithology, and probing over the entire basin is essential.

5 At the deepest point the basal sediments are sampled with a modified Abbey piston corer (chap.2). Using this the successful retrieval of the basal sediments is assured. Only at one site, subsequently abandoned, was sampling foiled by semi-liquid clay, but it is acknowledged that at many sites this may be a problem.

PREPARATION

6 The chemical preparation techniques (chap.2) are regarded as rigorous enough to make counting of what would otherwise be "non-polleniferous" sediment possible. The basal sediments can accordingly be analysed, which has not been the case in earlier studies (Pennington, 1964, 1978).

The definition of non-polleniferous sediment is that in chapter 2.

INTERPRETATION

7 After counting to 300 T.L.P. (chap.2), zonation is by visual estimation. The basal pollen assemblage zone can be confidently related to the R-zonation of Walker and Lowe (1977; chap.4) when it can be shown to be present to the exclusion of overlying R-zone characteristics (cf. Pennington, 1978). If one site at a locality records older sediment than the adjacent site the older age is taken as that relevant to deglaciation.

The writer is aware that improvements could be made, including the C14 dating of biostratigraphic horizons at each locality (although at many sites in chap.6 the key levels are within minerogenic sediment), and the adoption throughout of pollen concentration techniques (not possible in the limited time available). The approach outlined above is considered more rigorous and constructive in accounting for the assumptions inherent in the hypothesis than previous attempts. The test of the hypothesis is appraised in the next chapter.

CHAPTER 6

EARLY POSTGLACIAL POLLEN SEQUENCES IN THE AWE VALLEY.

1. INTRODUCTION

The purpose of this chapter is to detail the litho - and biostratigraphies of each of six sites from the three localites in the Awe valley illustrated in fig. 5.1, with particular attention being paid to evidence relating to the deglacial chronology hypothesis, to discuss the significance of the records to the hypothesis of deglacial chronology outlined in the preceding chapter, and finally to consider the different interpretations for late-Devensian glaciation in the Awe valley expressed by previous workers (chap. 1, sect. 5) in the light of the palynological evidence.

2. DESCRIPTION OF THE SITES.

2A. LOCALITY ONE : FORD

Fig. 5.1 gives the position of this locality at the south-west end of Loch Awe, while fig. 6.1 shows the setting in more detail.

i) Geomorphic Setting.

The sites (Ford I, Ford II) lie close to Loch Awe within a series of kame terraces, which in turn lie on bedrock of middle Dalradian meta-sediments, conglomerates, sandstones and silty slates with occasional thick limestone bands.

The kame terrace sequence has been described and mapped most recently by Gray and Sutherland (1977). The pollen sites are situated in two kettle-holes, bedrock basins not being located in this area, but as the fluvioglacial sediments are the most conspicuous features of past glaciation pollen sites on these would provide at least a minimal limiting date for the terraces. Both sites are on the lowest, youngest suite of terraces mapped, graded to a sea-level "at or below 9 - 10 m O.D." (Gray and Sutherland, 1977; p. 38).

ii) FORD I (g.r NM 877039; lat. 5°25'20" N, long 56°11'37" W).

(a) Site Location and Description

The peat-infilled surface of the kettle-hole lies at 40 m O.D., some 15 m below the level of terrace fragments K 17, 18, 19 and 20 (Gray and Sutherland, 1977) at approx. 55 m O.D., and 4 m above the present level of the loch. A spring marked on fig. 6.1a is invariably dry due to the permeable sands of the kame terraces, and no stream enters the basin. With the sides of the kettle-hole sloping extremely steeply the catchment of the basin is limited, app. 3,770 m^2; the surface area of the

Fig. 6.1: Ford

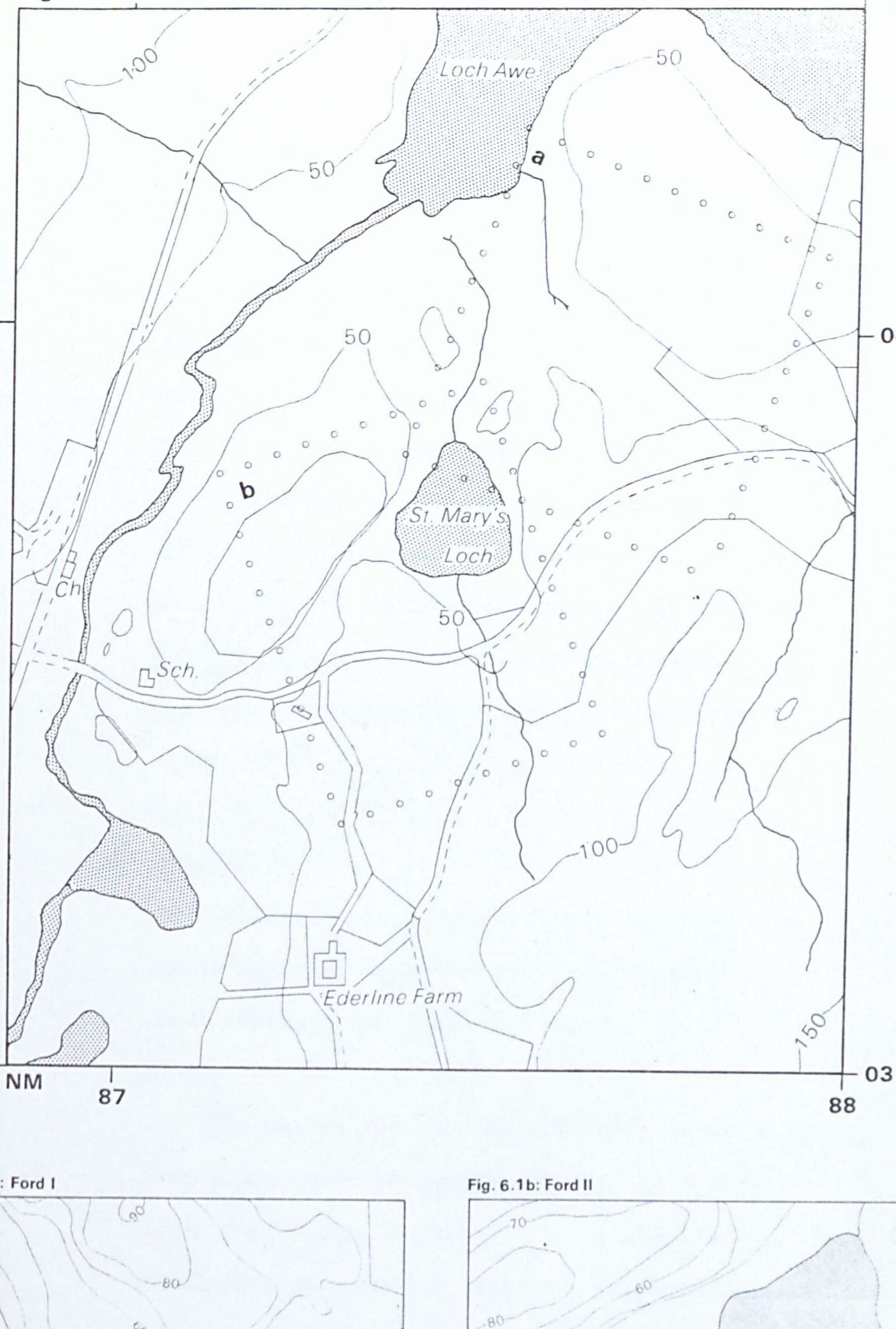


Fig. 6.1a: Ford I

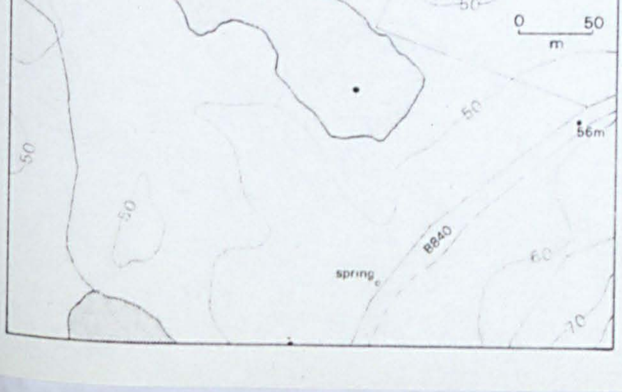
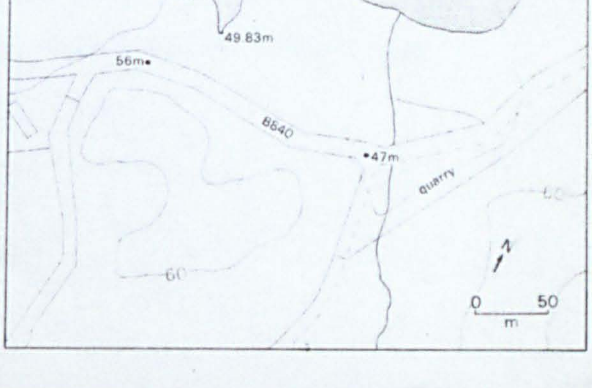


Fig. 6.1b: Ford II



peat-surface is 865 m^2.

Kame sediments, coarse sands with occasional cobbles, surround and floor the basin except for a small, oak-wooded knoll on Dalradian strata to the N.E. (fig. 6.1a). The slopes south of the B 840 are also in bedrock, covered with Forestry Commission fir and spruce plantations. The peat-surface has been partly drained, and is being colonized by clumps of *Erica tetralix*, with various grasses, *Juncus*, *Caltha palustris* and *Drosera rotundifolia* in the damper areas.

(b) Sampling

Detailed probing (chap. 5; sect. 6) revealed a double basin, a shallow bar coinciding with the constriction of the basin shown in fig. 6.1a.

The deepest area was established as being in the more southerly of the basins (fig. 6.1a), 6.21 m below the surface. Seven piston-core samples were obtained in July 1980, with core 8 augmenting the lithostratigraphic detail in November 1980. Four cores were used in the construction of the pollen diagram (fig. 6.2). All piston cores suffered some degree of compression on extrusion, ranging from 10% (core 5) to 27% (core 6). This was corrected for using the method of calculation detailed in chap. 2, and the revised core lithologies are portrayed in fig. 6.2. Core 8 shows a thinner development of certain lithostratigraphic units due to lateral differences in sedimentation, it having been sampled a small distance from the original site. The sediments were extremely stiff, and could not be sampled by Russian corer, and such difficulties meant that core overlaps were not uniform, even allowing for differential core-compression corrections. Sampling to a base of non-lithified material might lead to doubts that the basal deposits were sampled (see also Livingstone et. al., 1958), but probing with stout metal rods, including determined hammering, failed to penetrate deeper than the material sampled in core 6.

(c) Generalized Lithostratigraphy

LITHOSTRATIGRAPHIC UNIT A : 621 - 605.5 cm below surface.

An alternating sequence of thinly banded clays and fine sands, from the base upwards:

	SEDIMENT	THICKNESS (cm)	MUNSELL COLOR
	organic? mud	1.0	2.5 Y 4/2
	clay with organic traces	3.5	not recorded
	sandy clay	1.0	not recorded
	clayey sand	1.0	not recorded
	sand with organic traces	2.5	not recorded
	grey/fawn clay	0.5	not recorded
	clay	0.5	not recorded
	sand	0.75	5 Y 6/3
	clay	0.5	2.5 Y 6/0
	laminated sands and clays	0.5	5 Y 7/2
	clay	0.5	5 Y 5/1
BASE	fine sands	2.5	5 Y 7/2

occasional mica-schist pebbles are present. All boundaries are sharp.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT B : 605.5 - 587 cm.

Faintly laminated (0.1 cm) coarse silty clay with rounded and frosted silt and fine sand grains (magnification x 20), 2.5 Y 8/2 white, and 5 Y 3/1 very dark gray gyttja containing whole and crumpled (unidentified) seeds and leaves. The laminations in some cores are blurred through bioturbation or disturbance during sampling, but generally, although the light laminae maintain constant thicknesses, the darker organic bands thicken upward and merge with the overlying lithostratigraphic unit C. Boundaries are sharply defined, but at the top there is a transitional boundary to

LITHOSTRATIGRAPHIC UNIT C : 587 - 580 cm.

Fine-grained gyttja-peat, 5 YR 2.5/2 dark reddish brown, with unidentified macrofossils and admixed silt:

transitional boundary to

LITHOSTRATIGRAPHIC UNIT D : 580 - 540 cm.

coarse, matted Eriophorum peat:

transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 540 - 530 cm. (not sampled above this)

Fen-peat, few macrofossils and high degree of humification.

(d) Biostratigraphy (fig. 6.2)

621 - 617 cm.

Non-polleniferous.

617 - 605 cm : local p.a.z. FORD I A

Gramineae - Rumex - Dwarf Shrubs

Herb values at 70% T.L.P. are at their highest in the diagram, dominated by Rumex (maximum 20% T.L.P. at the basal spectrum, declining upward) and the grasses with values consistently over 30% T.L.P. The dwarf shrubs of Empetrum, Ericaceae undiff. and undetermined ericaceous tetrad grains attain a peak of 12% T.L.P. towards the top of the zone. Tree pollen is represented by consistent values of Betula (10%) and Pinus, the latter declining from a peak in the earliest spectrum. Also prominent are Compositae Liguliflorae, and Galium, with rising curves for Cruciferae, Dryopteris and Polypodiaceae. Lycopodium annotinum is restricted to this zone. The aquatics are poorly represented.

Pollen abundance (grains per traverse) is higher than at other sites in this chapter (see below) but is lower than in overlying zones. Deterioration values are not noticeably higher in this zone, but crumpled and split grains are important, and degraded grains are prominent.

605 - 599 cm : local p.a.z. FORD I B.

Juniperus - Gramineae

Tree pollen values rise through this zone at the expense of those of dwarf shrubs and herbs, notably *Rumex* and Gramineae. *Betula* values attain 30% T.L.P. at the end of the zone, and *Juniperus* is prominent, expanding from 14% to 29% T.L.P. Cruciferae continue to expand, as does *Filipendula*, while *Dryopteris* and Polypodiaceae achieve their highest proportions. *Typha latifolia* registers consistent values for the first time. Little variation is seen in the pollen abundance or deterioration values.

599 - 585 cm : local p.a.z. FORD I C

Betula - *Salix* - *Filipendula*

Tree pollen values, almost exclusively of *Betula*, rise to 60% T.L.P. The empirical limit of *Corylus* (coryloid grains) occurs at the base of the zone, but the rational limit is probably not reached until the overlying zone D. *Juniperus* declines quite rapidly, while *Salix* is prominently, if erratically, represented. Several of the herb taxa are no longer recorded, including Compositae and Chenopodiaceae, and in addition several more are present as isolated, single grains only, such as Galium and Poterium. Conversely, the pollen curves of Rosaceae, Crataegus type and Filipendula, Plantaginaceae and Saxifragaceae all expand. Typha is again the only aquatic of note.

Pollen abundance increases, but again there is little change in deterioration.

585 - 574 cm : local p.a.z. FORD I D.

Coryloid - Betula

The increase in values of Corylus from 20 - 71% T.L.P. in 4 cm dominates the zone, although birch figures prominently but erratically. No Ericales are recorded, and Juniperus is now unimportant. Salix values are lowered markedly, and spores and aquatics are also sparsely represented. Pollen grains per traverse are highest in this and the next zone.

574 - 567 cm : local p.a.z. FORD I E.

Coryloid - Ulmus

Birch percentages drop from 45% to maintain steady values at around 22% T.L.P. Corylus totally dominates the spectra with values over 55% T.L.P. _Salix_ maintains its proportions, as do the grasses, while Cyperaceae rise slightly. Elm pollen is recorded consistently for the first time.

567 - 530 cm : local p.a.z. FORD I F

Coryloid - _Ulmus_ - _Quercus_

Quercus appears in contiguous spectra, with _Ulmus_ increasing gradually through the zone. Other taxa show little change.

(e) Interpretations.

The basal sediments suggest in their horizontal banding that they are water-lain, although aquatic indicators are absent from the pollen and spore record. Although organic traces are present biological productivity is presumed to be low given the lack of organic sediments and poorly polleniferous spectra.

The sands and pebbles of litho-unit A are closely comparable to the kame material on the slopes of the basin, and the light and dark laminae of litho-unit B might also relate to, perhaps, seasonal melting of permafrost soils, but given the frosted appearance and apparent sorting of mineral grains in this unit, loess deposition might be a more likely explanation, periods of deposition being intermittent, and possibly quite rapid in the absence of gyttja within the minerogenic bands.

Little need be said concerning the vegetational development at this site. That local vegetational succession is being recorded throughout the sequence is supported by the low regional components, e.g., Pinus, above the bottommost level. Palynological changes are very closely comparable to those described in chapter 4, and at this site the presence of a basal Rumex zone should be noted.

The Corylus rise is particularly dramatic at this site, as is its sustained prominence. This may be associated with an increasing sedimentation rate with the closure of the lake and a cover of fen-peat, finally Eriophorum-peat, particularly when the coarseness of Eriophorum-peat is borne in mind. The small catchment would supply only a limited amount of minerogenic material to the lake, and organic deposition may well have exceeded that of the minerogenic litho-units.

iii) FORD II (g.r NM 87350365; lat. $5^{\circ}25'37''$ N, long. $56^{\circ}10'$ $43''$ W)

(a) Site Location and Description

The site (fig. 6.1b) is a very small and shallow (3.20 m) kettle-hole surrounded on three sides by kame material of terrace fragment F_1 (Gray and Sutherland, 1977), underlain by kame sands also, while the southern edge is in impermeable Dalradian strata. The site lies within the same suite of terraces as Ford I, and is only 450 m to the south-east (fig. 6.1), at an altitude of c. 50 m O.D. The catchment of Ford II is only 1050 m^2, relief very low at c. 7.0 m from peat-surface to the highest point of the kame terrace.

(b) Sampling

Depth-probing located the deepest point (fig. 6.1b) as extending 3.20 m below the peat-surface. One piston core (fig. 6.3) sampled the basal sediments, which on extrusion were measured to be 10 cm longer than the 60 cm piston chamber, principally through flowage of litho-unit B (sect. c). Bedding may be distorted, but at 273 cm a horizontal clay band appears not to have been disturbed.

Countable pollen was obtained from the basal sediments, but during the construction of a provisional, skeletal (100 T.L.P.) diagram marked inconsistencies were noted between this and the adjacent site of Ford I. These will be clarified in the discussion below, but it should be borne in mind that the pollen diagram (fig. 6.3) is based on a sum of 100 T.L.P. only.

(c) Lithostratigraphy.

LITHOSTRATIGRAPHIC UNIT A : 320 - 308 cm.

Very stiff light brownish gray (2.5 Y 6/2) clay with few sub-angular to rounded stones and sand grains, of varied composition, including vein, crystal and rose quartz, abundant muscovite, rock fragments of granite, schists, tourmalinized granite and basalt, concentrated at the base of the unit. Macrofossil material is limited to a few unrecognizable leaf fragments and wood remains.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT B : 308 - 273 cm.

a coarsening-upward sequence from predominantly clayey sediment between 308 - 296 cm , resembling unit A, to an increasingly sandy and silty component, with occasional stones, 10 YR 5/2 grayish brown.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT C : 273 - 271.5 cm.

almost pure clay, light brownish gray (2.5 Y 6/2), with some sand,

sharp boundary to

LITHOSTRATIGRAPHIC UNIT D : 271.5 - 250 cm.

2.5 Y 4/2 dark grayish brown coarse-medium sand with clay, silt and occasional stones.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT E : 250 - 245 cm (not sampled above this).

Fine structureless peat (10 YR 2/2 dark brown) with high macrofossil content, a few Coleopteran remains and occasional inwashed element of coarse-medium sand.

(d) Biostratigraphy

320 - 308 cm : local p.a.z. FORD II A

Betula - *Salix* - Gramineae

Birch exceeds 25% at the base of the site, with *Alnus* present and coryloid grains exceeding 20% T.L.P. Exclusive to this zone are *Juniperus*, *Salix* (with the exception of one level in p.a.z. B), the dwarf shrubs, and *Artemisia*, *Filipendula*, *Mentha* type, *Poterium sanguisorba* and Ranunculaceae. Aquatics are poorly represented throughout, and are not found in local p.a.z. B: neither are Lycopodiaceae, although Polypodiaceae undifferentiated and *Polypodium vulgare*, and *Thelypteris*-type spores rise to prominence above the zone boundary.

308 - 265 cm : local p.a.z. FORD II B

Coryloid - *Alnus*

Coryloid grains expand to over 80% T.L.P. *Alnus* assumes considerable importance, with pine, oak and elm present in increasing amounts up-core.

(e) Interpretations.

The low pollen sums of levels 316 - 320 cm render these spectra of uncertain significance.

However, it is still apparent from local p.a.z. A that comparisons with Ford I can only be made above local p.a.z. Ford I C (fig. 6.13). Empetrum and Rumex are not recorded in any count, and Juniperus is not prominent. If these basal pollen spectra are of long-distance origin the pollen sequence might be expected to show an apparent revertence as local communities expanded, but in the change to hazel dominance it is likely the pollen diagram (fig. 6.3) depicts a local and contemporaneous vegetation.

The absence of the characteristic postglacial succession from Rumex to Juniperus has to be explained by some form of delayed sedimentation.

Being a kettle-hole occupation by dead-ice (Porter and Carson,1971) might be thought responsible. It having been proposed that ice is unlikely to have persisted from the Main Devensian (chap. 5; sect. C), dead-ice occupation of the kettle-hole would imply formation of the kame terraces in the Loch Lomond Stadial. Supporting evidence comes predominantly from the sedimentological record . Biostratigraphic evidence is sparse, and the presence of Lycopodium selago, and one grain of L.clavatum suggests but by no means demonstrates snow-patch conditions (McVean and Ratcliffe, 1962) in the absence of Lycopodium alpinum and Selaginella selaginoides.

Litho-units A and B show a coarsening-upward sequence. Such a sequence is unexpected in a lacustrine environment. It could be suggested that the basal clays have a subglacial origin, being essentially rock-flour, while the overlying sands are derived from lithomorphic soils delayed in their development by ice.

A further clue may lie in the pronounced difference in pollen abundance between the clays and overlying sands, anomalous if it is assumed both litho-units had similar origins in slope-wash. Despite the likelihood of differing sedimentation rates the marked increases in pollen abundance, (considering the increasing coarseness of sediment which generally renders the preparation technique less useful, lowering pollen abundance), may imply different origins for the two litho-units.

One major objection to the suggestion of dead-ice occupation of the kettle-hole must be the capacity for a relatively small and isolated block of ice to survive an ameliorating climate for perhaps 1000 years after ice-retreat. No evidence of diamictic sediment was located at the base of the sequence, believed essential to the preservation of dead-ice (Ostrem, 1965; sect. 5c), and this must be a major obstacle to the acceptance of the hypothesis.

Proposals that slope-wash processes are responsible for the sediments find difficulties in explaining the coarsening upward sequence. It could be argued, however, that the kettle-hole remained free-draining until a layer of impermeable clay retained water, sediment and pollen. Yet Ford I, on the same sand deposits, retained sediment from the earliest postglacial. The evidence, such as it is, is insufficient to draw any firm conclusions on this matter.

The site is of little use in testing the deglacial chronology hypothesis, and the site of Ford I is taken as indicative of the Ford region.

In chap. 4 the early appearance of Alnus in Scotland was discussed, and there is strong evidence of alder arriving at the site of Ford II with hazel and before oak and elm. No Alnus pollen was recorded at Ford I, which is difficult to explain, even given the limited dispersal of the pollen (Livingstone, 1968). Restricted dispersal may arise through a high trunk-space component (Tauber, 1965) in the hazel-birch woodland, but equally the percentage representation of Alnus may come from one tree growing directly on the moist peat-surface, a favoured habitat (McVean, 1956 b). The difficulties of inferring vegetational representativity from the pollen record are clearly emphasized in the analysis of sites very close to one another as here, at Ford I, Ford II and Lon Glas (chap. 4).

2B. LOCALITY TWO : INVERLIEVER

i) Geomorphic Setting.

The plateau between Lochs Awe and Avich contains many infilled basins, and two of these close to Loch Awe were selected from aerial photo-reconnaissance for inclusion in the study (fig. 5.1). Pollen sites are unavailable on the steep southern sides of the loch, But Inverliever Forest lies well within the watershed (fig. 5.1). only 0.5 km from the waters' edge, with streams flowing into the loch.

Glacial deposits are represented by thin veneers of till on the Dalradian bedrock, and no major glacio-geomorphic features are known in the immediate vicinity of the sites. Around Barmaddy (g.r. 955122) subdued till hummocks surrounding blanket peat up to 3 m deep were noted during reconnaissance.

ii) INVERLIEVER I (g.r. 93400845; lat. $5^{\circ}20'$ N; long. 56° 14'30"W.)

(a) Site Location and Description.

The site is an unnamed bog and pool near the small valley of Bealachan Sgorach (fig. 6.4.a) lying directly on Upper Dalradian schistose (epidioritic, chloritic, talc) bedrock. The resistant bands of epidioritic schist in the meta-sedimentary sequence form glacially-scoured ridges between which the basins are found.

The peat-bog examined lies in a subdued basin, the maximum height of the drainage divide being only c. 3 - 4 m above the bog-surface (fig. 6.4a). The

Fig. 6.4: Inverliever

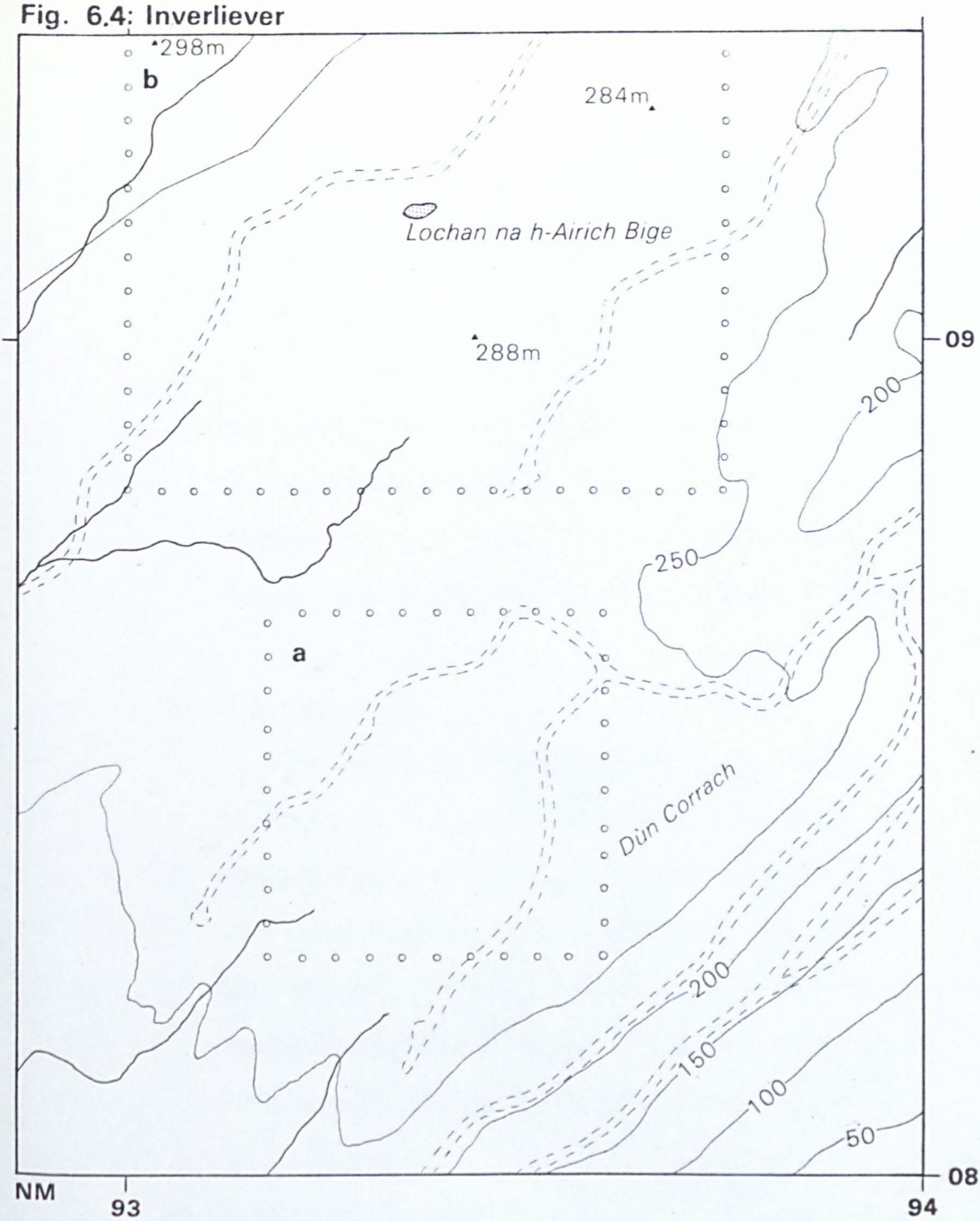


Fig. 6.4 a: Inverliever I

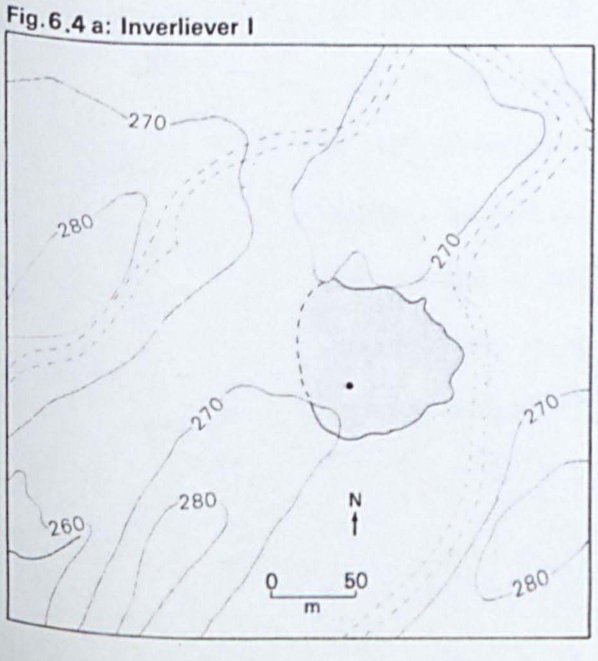
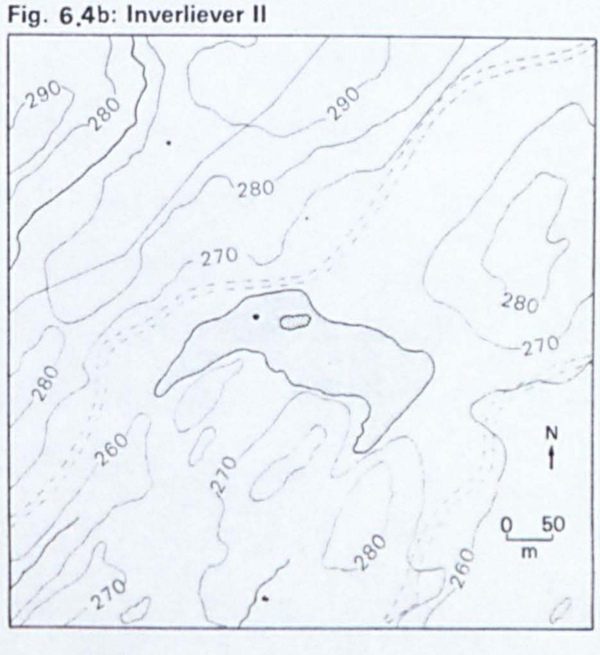


Fig. 6.4b: Inverliever II



catchment is limited due to this, and is only slightly larger than the basinal area of 617 m^2 , at 747 m^2. It is roughly circular, and although the plan (fig. 6.4a) shows no rim to the N.W., detailed depth-probing confirmed only a very shallow depth to bedrock (2.5 m) across this area, with a shallow outlet to Bealachan Sgorach beneath blanket-peat.

(b) Sampling.

The sampling site is located at the deepest part of a simple basinal structure. One piston core sampled the basal deposits successfully, the length of core (fig. 6.5) of 48 cm being foreshortened through compression and the fact that bedrock was reached before the chamber was filled. A 50 cm Russian core confirmed the lithostratigraphy.

(c) Generalized Lithostratigraphy.

LITHOSTRATIGRAPHIC UNIT A : 925 - 914 cm.

Coarse gravelly clay (5 Y 5/1 gray) comprising a varied suite of schists, phyllites, gabbroic-like rocks, vesicular basalts and hornblende-rich metamorphics but no clastic rocks, rounded to subrounded, with angular stones very rare: the stones decrease in number, though not in size, upward.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT B : 914 - 907 cm.

as above, but with the coarse component very much reduced.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT C : 907 - 904 cm.

almost pure clay (5 Y 5/1 gray) with some sand, containing a few badly-preserved and indeterminable moss-fragments and seed-cases.

transitional boundary over 2 cm to

LITHOSTRATIGRAPHIC UNIT D : 904 - 881 cm.

uniform gyttja (7.5 YR 3/2 dark brown) with high macrofossil content including the following mosses:

897 cm :	Rhacomitrium fasciculare	(1 stem) good preservation.
896 cm :	Bryum spp.	(1 stem) very good preservation.
893 cm :	R. fasciculare	(3 stems) good preservation.

Rhacomitrium spp. (1 stem) bad preservation.

sand grains, quartz and phyllitic, are present but rare.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 881 - 859 cm (not sampled above this).

fine peaty gyttja (10 YR 2/2 dark brown), with few macrofossils preserved.

(d) Biostratigraphy.

925 - 910 cm : local p.a.z INV I A

Empetrum - Ericaceae undiff. - *Salix*

Despite high *Betula* values (max. 30% T.L.P.) the inconsistency of the curve does not warrant its inclusion as a zone-indicator. As at other sites (this chapter; FORD I, II) the *Pinus* curve declines from a peak in the basal spectrum. Coryloid grains and *Juniperus* are also erratically represented, but the dwarf shrubs are prominent throughout, *Empetrum* being present at values around 10% T.L.P. *Calluna vulgaris* is not represented.

Gramineae dominate in this and in all zones prior to local p.a.z INV I E. Many open-ground herbs, Chenopodiaceae, Compositae and, to a lesser extent, Caryophyllaceae and Epilobium are recorded, although Rumex is relatively subdued (< 5% T.L.P.) in this zone. Selaginella selaginoides is represented by a continuous curve, and Sphagnum is conspicuous, as are Lycopodiaceae, L. clavatum and L. selago. With the exception of one count of 27% T.L.P. + spores, Polypodiaceae maintain values of 15% T.L.P. + spores.

Pollen abundance is generally very low, but with two anomalously high levels, while pollen deterioration averages under 10% T.L.P. and indeterminable grains, despite the coarseness of the sediment, of which the indeterminable tetrad grains of Ericaceae contribute the major portion.

910 - 902 cm : local p.a.z INV I B.

Pinus - Cyperaceae - Rumex

Pinus shows a consistent increase in values, while the dwarf shrubs in general decline, the exception being Ericaceae undiff., which maintains low percentages. The sedges show a distinct increase at the beginning of the zone, and with the rise in Rumex is the characteristic feature of this zone.

Artemisia is, with the exception of one level, continuously recognized, with a peak of 3%. Other herbs do not show a similar response except Compositae Tubuliflorae undiff.,and most are only inconsistently depicted on fig 6.5. *Filipendula* suffers a temporary setback from its strong contribution to the pollen counts at the end of the previous zone. *Thalictrum* establishes itself, as does *Saxifraga stellaris* and *Urtica*-type pollen.

Changes among aquatic taxa are few, but *Myriophyllum*, almost exclusively *M. alterniflorum*, makes a significant improvement in values. The ferns have low values temporarily, but soon recover. Pollen grains per traverse increase in all levels upwards, while total deterioration declines.

902 - 896 cm : local p.a.z INV I C.
Juniperus - Ericaceae undiff. - *Filipendula*

Changes within the arboreal component are limited to a decrease in pine percentages. Juniper and heather values rise, while other shrubs are either unchanged or decline (the spectrum at 901 cm . is anomalous for *Empetrum* in this zone), and although Cyperaceae fail to sustain their importance, Gramineae expand in this and the next zone. Artemisia, together with the bare-ground herbs previously significant, Chenopodiaceae and Ranunculaceae, are not represented in the pollen rain. Rumex continues to approach values of 7% T.L.P., Filipendula increases, and Crataegus-type pollen is recorded consistently for the first time.

Myriophyllum values reach a maximum at the lower boundary of the zone. Lycopodium alpinum is restricted to this zone, and the Polypodiaceae curve is seen to recover from low values in local p.a.z B. Pollen abundance continues to improve, and changes in total deterioration are minimal.

896 - 874 cm : local p.a.z INV I D.

Betula - Salix - Gramineae

The values for birch are virtually doubled (15 - 29% T.L.P.) in only 3 cm , and eventually peak at 40% T.L.P. Coryloid grains increase only at the upper boundary of the zone, but Salix, from an early expansion, is consistently present from 883 cm. Juniper values decline steadily; the inconsistencies seen in the pollen curve are due to the slight variations in percentages between cores (see Sample Locations; fig. 6.5), seen most clearly between 885 and 880 cm , but trends in both cores are consistent: indeed, with most taxa the differences between cores are not immediately apparent.

Several herb-types are sustained in this zone; Compositae, Rumex (1 - 2% T.L.P.) and Ranunculaceae intermittently. With high values for grasses come Crataegus-type grains, Galium, Helianthemum, Plantago major/media and P. maritima, Saxifraga stellaris, Thalictrum and Umbelliferae.

874 - 870 cm : local p.a.z INV I E.

Coryloid - Betula

Corylus (see chap. 3) is dominant in this zone together with Betula. Filipendula also increases, and Salix maintains values averaging 5 - 6% T.L.P., but all other shrubs and herbs decline. Towards the end of the zone Sphagnum expands to 9% T.L.P. + spores. Throughout zones D and E pollen abundance is very high.

(e) Interpretations.

The palynological record reveals several features akin to the site of Ford I discussed previously, and these will be commented on only briefly. The site also shows some unexpected patterns which must be discussed more fully.

The fining-upward sequence in litho-units A and B indicate a lacustrine environment, with the varied lithologies and rounded nature of stones in the basal unit suggesting erosion of till mantling the catchment slopes.

In chapter 5 it was anticipated that pollen sites some distance behind Loch Lomond Readvance glacial termini might show at their base an Empetrum (Dwarf shrub) zone, and that Rumex would not be recorded in significant amounts. The sequence at Inverliever I does not support this construct as Rumex rises after the basal Empetrum zone in an apparent successional revertence.

Without pollen concentration data little can perhaps be made of the earliest pollen spectra with regard to their predominantly local or regional origin. The measure of pollen abundance adopted can only be an approximate measure, and is affected by the success of the preparation technique, so that comparisons between sand and clay units are suspect. Many open-ground herbs are known to be over-represented (chaps. 3, 4), but viewed as an assemblage the taxa recorded in local p.a.z A accord with a role on freshly deglaciated ground (Matthews, 1978). *Rumex*, with its pronounced over-representation (Birks, 1973; Markgraf, 1980) appears not to have been growing locally at this period, which accords with the suggestion in chap. 3.2 vii of slightly delayed colonization to new bare ground.

There are elements of contamination in the basal pollen zone also (Coryloid, *Quercus*, *Ulmus* and *Alnus*) and probably of regional pollen (willow, birch), whose percentages vary either through statistical distortions or from non-uniform aeolian deposition.

The principal question must be whether the *Empetrum* and Ericaceae undiff. pollen represents a regional or extra-local source, or is growing within the catchment prior to the *Rumex* expansion. The edaphic controls on the growth of ericaceous shrubs (chap. 4) strongly suggest that *Empetrum* growth at this early stage would be anomalous, and the almost "universal" pattern of *Empetrum* expanding after a

Rumex - dominated phase would also seem to endorse this view (chap. 5).

Pollen production in *Empetrum* is reported to be low to moderate (Birks, 1972). Dispersal is also thought to be limited, (Birks, 1972; Pennington, 1980), and the pollen is under-represented in the present-day Scottish pollen rain (Birks, 1973), in Greenland (Pennington, 1980) and Scandinavia (Prentice, 1978). Rymer, (1973), however, states the pollen to be slightly over-represented in Icelandic moss polstors, and in the Canadian arctic Davis (1980) reports Ericales pollen as contributing a small (c. 5% T.L.P.) component to the regional pollen "rain", and extra-local dispersal in areas of low pollen influx is likely.

It seems reasonable to conclude that *Empetrum* and the Ericales were probably growing on slightly older ground, perhaps only a few hundred metres from Inverliever I, as it does today at Storbreen (Matthews, 1978), close enough to the pollen site to contribute pollen from this extra-local source (*sensu* Jacobsen and Bradshaw, 1981) at a time of very low pollen influx.

Given an extra-local source for the dwarf shrubs, their representation in the pollen "rain" would be expected to decline as local plant assemblages developed, as they do in local p.a.z B, to be replaced by *Rumex*, now growing with the pioneer herbs, which persist into this zone. Thus the increases in *Rumex* and *Artemisia* are not seen as indicative of a short-lived climatic recession, but of local vegetational expansions reducing the importance of external pollen sources.

The proposed pattern of vegetational succession (chap. 5) anticipates that *Empetrum* should succeed *Rumex* at each site. A peak of *Empetrum* at the base of local p.a.z C in only one spectrum cannot be relied upon greatly in any interpretation. The Ericaceae rise to 10% T.L.P., however, before and during the *Juniperus* rise. This variability between dwarf shrub species has been noted in chap. 4. The dwarf shrubs are then suppressed by the rise of juniper during and immediately after the *Rumex*-phase. This pattern can be interpreted in two ways:

(a) regionally generated Juniperus pollen reduced the importance in the pollen spectra of local Empetrum/Ericaceae.

(b) Juniperus passed the climatic/edaphic threshold which had restricted its growth (Iversen, 1954; chaps, 3, 4) so that it could expand locally and regionally before the dwarf shrubs could become established. A corollary of this suggestion would be that the early postglacial peak of Empetrum (chaps. 4, 5) is determined by environmental suppression of juniper rather than the competitive abilities of the crowberry.

Little can be made of this problem at this site, but the point is returned to in sect. 6.3.

iii) INVERLIEVER II (g.r. NM 934092 lat. 5°20' N; long. 56°13'53" W)

(a) Site Location and Description.

Lochan na-h Airich Bige is today little more than an infilled peat-bog, the present lochan being virtually overgrown with Juncus (fig. 6.4b). The basin lies in an irregularly shaped hollow within

Dalradian bedrock of practically identical lithologies to Inverliever I. Till is not mapped in the immediate vicinity of the basin.

Lying only 750 m to the north of Inverliever I (fig. 6.4), the catchment is much larger, at c. 5680 m^2, though the basin is only marginally more extensive; 677 m^2, and the peat-surface lies some 26 m below the highest point of the catchment, which reaches 288 m O.D.

(b) Sampling.

The peat-surface declines in height from the east to south-west, where a small stream exits through the blanket-peat and dense Forestry Commission spruce trees. Depth-probing was difficult in this dense growth, but depth determinations in the 25 m before difficulties were encountered consistently shallowed, and as the slopes of the catchment narrow in this area (fig. 6.4b) it is thought assured that the deepest part of the basin has been located at the point indicated on fig. 6.4b, at a depth of 11.25 m.

One piston core only was required in the counting to reach the distinctive Corylus rise. Compression in this core amounted to 15%.

(c) Lithostratigraphy.

LITHOSTRATIGRAPHIC UNIT A : 1125 - 1114 cm.

very fine gray (5 Y 5/1) clay, stoneless and without macrofossil remains.

sharp, uneven boundary to

LITHOSTRATIGRAPHIC UNIT B : 1114 - 1074 cm.

very fine gyttja/organic mud, with muscovite flakes and sub-rounded to sub-angular quartz grains present throughout. Moist Munsell colors change upward from 10 YR 4/2 dark grayish brown (1114 - 1111 cm) to 7.5 YR 3/2 dark brown (1111 - 1086 cm) and eventually to 10 YR 3/1 (very dark gray) between 1086 and 1074 cm. A band of diffuse moss filaments was recorded in the piston core sample between 1104 and 1101 cm , but was not found in an adjacent Russian core. Macrofossils of Characeae cases, twigs and moss fragments (indeterminable) and Coleopteran remains were quite common in this unit.

(d) Biostratigraphy. (fig. 6.6)

1125 - 1120 cm : local p.a.z INV II A

Empetrum (_Empetrum_/Ericaceae undiff.) - Cyperaceae

Tree pollen values are very low at 12% T.L.P., and herb pollen dominates the zone. Nevertheless the dwarf shrubs comprise 17 - 20% T.L.P., with sedges contributing on average 31% T.L.P. Many open-ground herbs are characteristic of this zone; _Artemisia_, Chenopodiaceae, Compositae, _Epilobium_ and Umbelliferae, although _Rumex_ percentages are subdued.

Potamogeton is recorded from the basal spectrum, and _Myriophyllum alterniflorum_ is conspicuous if erratic throughout the lower zones. _Selaginella_ is at its maximum at the base of the sequence, together with _Lycopodium selago_ and _L. clavatum_. Polypodiaceae are also common.

Pollen abundance is low in this zone, but a satisfactory pollen sum was attained. Single, isolated grains of _Alnus_, _Quercus_ and _Ulmus_ suggest some slight contamination.

1120 - 1116 cm : local p.a.z INV II B

Rumex - Cyperaceae

Conspicuous in this zone is the sudden

expansion of Alnus to 12% T.L.P., with a concordant and similarly brief rise in Corylus. Birch increases slightly. Although Ericaceae values are sustained, with the indeterminable Empetrum/Ericaceae undiff. category, Empetrum itself declines to 2% T.L.P. Sedges are dominant, with Gramineae, and most herb taxa of note in local p.a.z INV II A persist, albeit at slightly lower levels in most instances. Filipendula contributes to the pollen rain for the first time, but the herb of principal interest is Rumex, which expands to 12% T.L.P. at the basal level, and, although somewhat erratically represented, is notably more significant than in the underlying zone. Lycopodium selago and Selaginella decline, and Polypodiaceae are poorly represented.

Pollen abundance is slightly higher in this zone, and total deterioration values are as high as zone A.

1116 - 1108 cm : local p.a.z INV II C

Juniperus - Pinus

Alnus grains are not recorded in this zone, and Pinus rises sharply from 1 - 8% T.L.P. in 2 cm , and values are maintained at percentages above 4% throughout. Junipers' is the principal expansion, which reaches 34% T.L.P. Despite this marked increase, birch percentages do not decrease noticeably. Of the dwarf shrubs, only Ericaceae maintain values consistent with those of lower spectra, and although Cyperaceae show reductions, the grasses are high in this zone as in earlier ones. Caryophyllaceae appear, with Crataegus-type pollen, and Thalictrum shows increased percentages. The decline in open-ground herbs noted in local p.a.z B continues, and many of these cease to appear in counts above 1110 cm. Rumex returns it its pre-zone B levels of 2-3% T.L.P.

Potamogeton begins to increase, as do Typhaceae, but Polypodiaceae, and Dryopteris in particular, dominate the zone, with Thelypteris-type pollen present at low values.

Total deterioration values are reduced, though still high at 40% T.L.P. + indeterminable grains. Pollen abundance rises throughout the zone.

1108 - 1097 cm : local p.a.z INV II D

Betula - Gramineae - Salix

Trends within the tree genera are similar to those described below, with values approaching 30% T.L.P., while pine, although recorded at around 5% T.L.P. is less notable. The Juniperus rise is curtailed, and values are below 5% T.L.P., while Salix, which had been rising uniformly throughout zone C establishes itself as the principal shrub at c. 10% T.L.P. Ericaceae decline here, and become inconsistently represented.

Grasses reach their highest percentages (31% T.L.P.), and Cyperaceae are present at 10 - 14%, as in the top spectra of zone C. Few herb species contribute to the diagram, although Filipendula characteristically increases with the grasses. Only Crataegus-type grains, Filipendula, Ranunculaceae, Rumex and Thalictrum are recorded in more than two levels.

Polypodiaceae maintain their values. Dryopteris declines, while Potamogeton grains are common, exceeding 5% T.L.P. + aquatics at one level.

Pollen abundance does not rise in this zone. Deteriorated grains are consistently 50% T.L.P. + indeterminable grains, with, as in all earlier zones, crumpled grains contributing most to the total, with corroded grains important.

1097 - 1083 cm : local p.a.z INV II E

Coryloid - *Betula*

Coryloid (*Corylus*) percentages increase from 2% at 1099 cm to 49% T.L.P. in the final spectrum counted. Other curves on this percentage-based diagram decline, including birch, *Juniperus*, (not recorded above the *Betula* maximum), *Salix* and Gramineae, which still persists at values of 10% T.L.P. Pine values show little change, and *Quercus* and *Ulmus* rise together. *Filipendula* maintains its presence in the pollen rain, and *Poterium sanguisorba* is recorded in every spectrum.

Pollen abundance is highest in this zone, while deterioration values return to the high values of the basal pollen assemblage zone.

(e) Interpretations.

The absence of till from the immediate vicinity of the catchment, and the lack of coarse sediments in the lithostratigraphical record make it likely that the clays of lithostratigraphic unit A are derived solely from the Dalradian rocks around the basin. The absence of sand, despite the sampling site lying close to the basin-edge (fig. 6.4b) indicates that the schists weather to fine clastics only.

The pollen analytical changes mirror to a striking degree those of Inverliever I. Assuming synchroneity of the changes, Inverliever II has a slower overall sedimentation rate, despite having a larger catchment area. The marked similarities suggest that the same pollen recruitment mechanisms and environmental controls, e.g., extra-local Empetrum in the basal zone, determined the sequences at both sites.

The pollen curve for alder is highly erratic, and inconsistencies of this nature make it questionable to consider its local pressence, and contamination is suspected.

Zone Inverliever II C contains the Juniperus expansion, and a Pinus rise similar to one seen at Inverliever I (fig. 6.5), but not mentioned in sect. 2B.ii. In that diagram the increase in pine coincided with the local colonization of Rumex, at Inverliever II it appears to follow it. In occurring in the diagrams above the basal spectra where regional and extra-local pollen would be expected to pre-dominate the expansion of pine is unlikely to be the result of statistical exaggeration, but probably represents an actual increase in the long-distance influx of Pinus pollen (see later; sect. 2c).

2C. LOCALITY THREE : BARACHANDER.

i) Geomorphic Setting.

The low-lying area of land at the north-east end of Loch Awe, around the village of Kilchrenan (fig. 5.1),emerges from the steeply confining valley of Loch Awe, and extends from Kilchrenan to Glen Orchy, beyond Dalmally (fig. 1.3). As can be seen from fig. 1.4, the geology of the region is predominantly of Dalradian strata, (though of considerably greater variety than up-loch), but the overlying O.R.S. basaltic lavas outcrop immediately north of Loch Nant, with the intrusive granites and associated plutonic complex of Ben Cruachan separated from these and the Dalradian by the fault-line of the Pass of Brander.

Although "hummocky moraine" is known from the plateau between Lochs Awe and Fyne, above Braevallich (Gray, pers. comm.), and a "terminal" moraine was mapped by the Geological Survey (Hill et. al., 1905) from Braevallich to Loch Leacann above Loch Fyne, the first distinctive glacial depositional landforms in the Awe valley below Ford are found in this area.

D. G. Sutherland (pers. comm.) has identified a series of short, parallel-ridged moraines broadly perpendicular to the loch around Kilchrenan, lying within a broad morainic strip, which he regards as a terminal feature, trending from the slopes above Shellachan (fig. 6.7) to the farms at Barachander, and rising up the slopes of Cruach Achadh na Craoibhe to Loch on Droighinn; beyond Barachander the line is lost. The delineation of this feature is not clear-cut but diffuse, with isolated drift hummocks lying well outside this line , around Loch Nant (fig. 6.7), for instance. The pollen site of Barachander I to be discussed (sect. 2c; ii) lies immediately within the moraine (fig. 6.7a), while, due to uncertainties in extending the feature on the ground above Barachander Farm, the second site (Barachander II; fig. 6.7b) may or

Fig. 6.7: Barachander

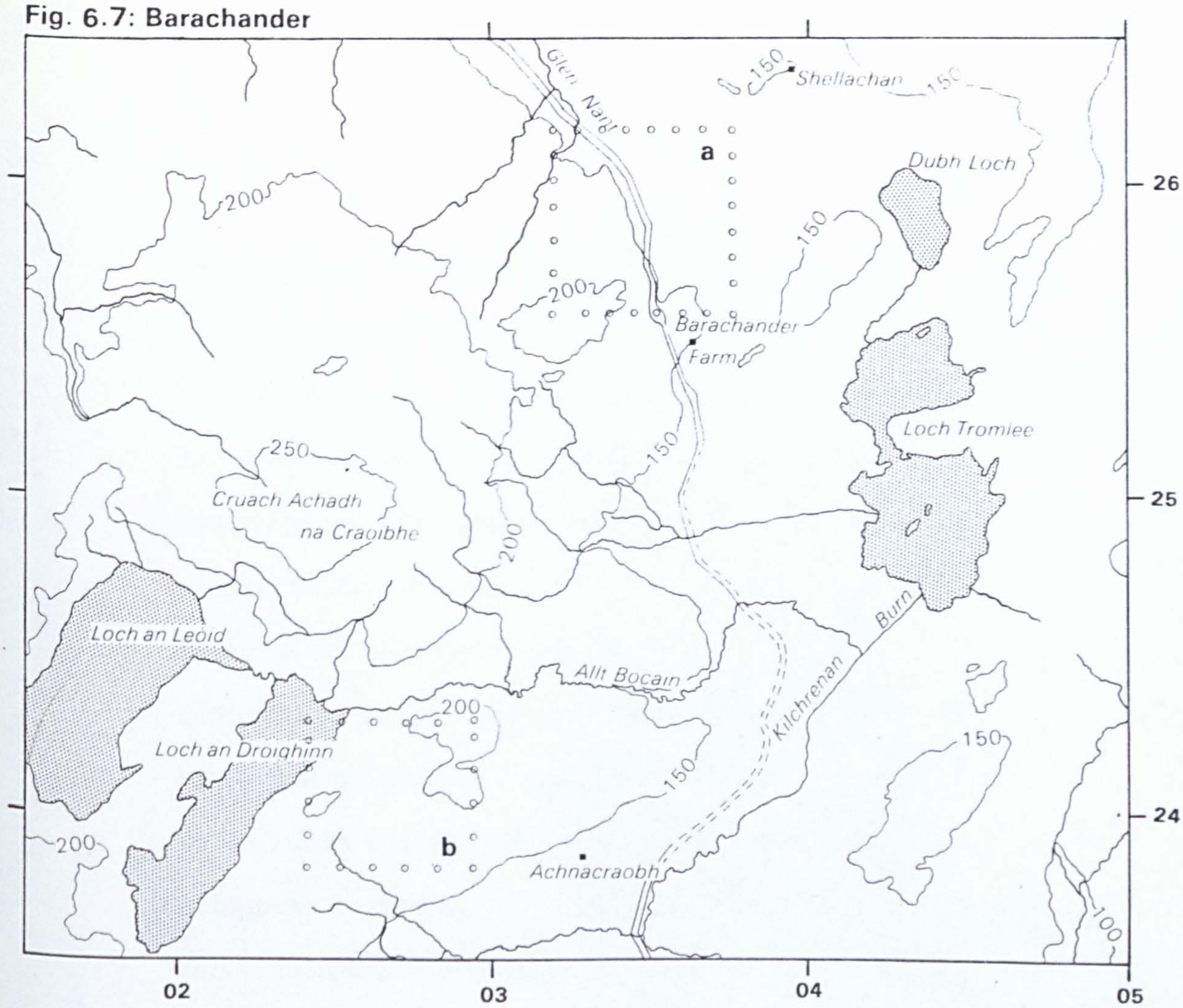


Fig. 6.7a: Barachander I

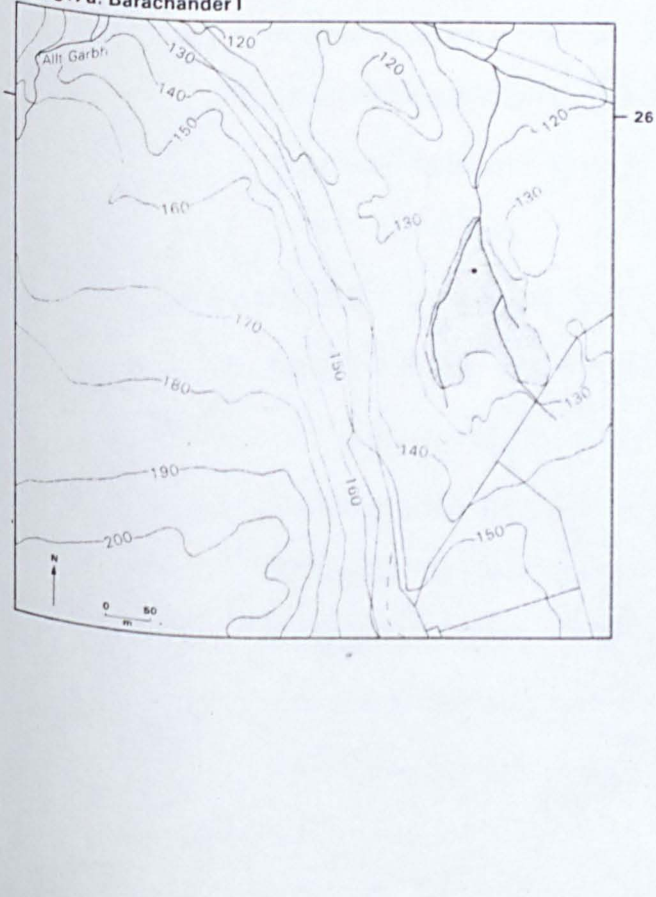
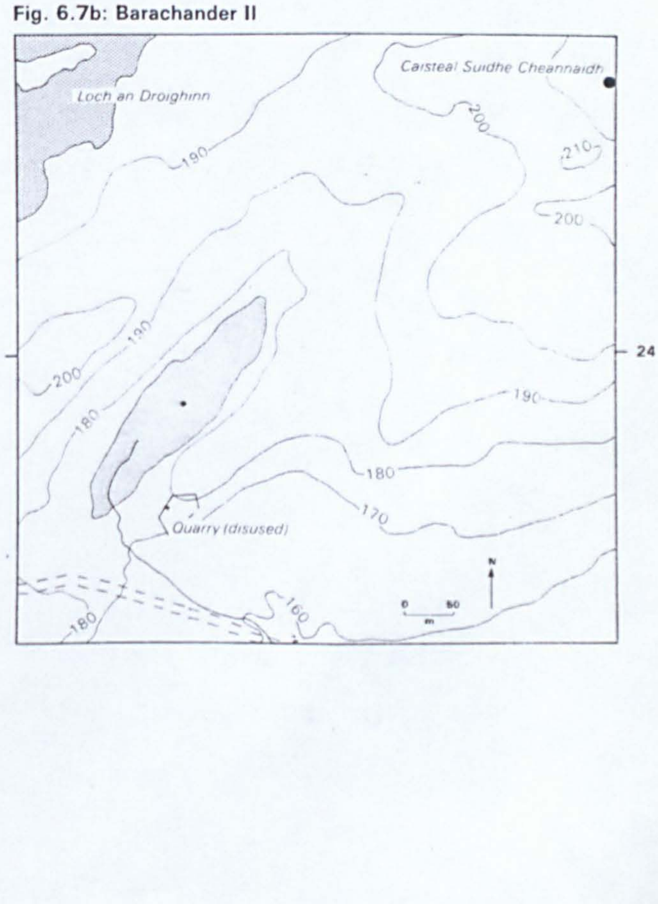


Fig. 6.7b: Barachander II



may not lie within the moraine (Sutherland, pers. comm.).

P. Thorp (pers. comm.) also extends his glacial limit for this region to approximately this locality on the basis of his trimline evidence (Thorp, 1981) from the slopes of Ben Cruachan (fig. 1.3), recording a descent in altitude of the lower limit of frost-shattered bedrock from 520 m on the slopes of Beinn Suidhe (NN 203376) to below 350 m on Meall Copagach (NN 156326) approximately 20 km from Sutherland's morainic ridge, between which evidence is absent. Gray (1972, 1975) considered that at the Loch Lomond Readvance maximum ice from the Awe valley was confluent with the Etive glacier. During deglaciation, however, the glaciers separated, and the Awe glacier laid down two suites of kettled terraces draining from the Pass of Brander to Taynuilt (fig. 1.3).

ii. BARACHANDER I (g.r. NN 035258; lat. 5°11' N, long. 56°23'W).

a) Site Location and Description.

This small basin (bog-surface: 490 m^2), lying partly in Dalradian bedrock but with subdued hummocky drift fringing the basin to the east, is some 26 m below Barachander Farm, at an altitude of 124 m O.D., adjacent to the B 845 road running between Taynuilt and Kilchrenan. Immediately northward the valley of Allt Poll an Dubhaich narrows to the gorge of Glen Nant, but the terrain around the site is hilly but open. (fig. 6.7a).

As described above, the north and north-west sides of the catchment (fig. 6.7a) are confined by a steeply-sloping ridge of glacial drift abutting the O.R.S. lavas at the head of Glen Nant. The shallow out-flowing stream has cut its way between this ridge and the Dalradian bedrock forming the east side of the basin (fig. 6.7a). Barachander Farm also stands on Dalradian meta-sediments.

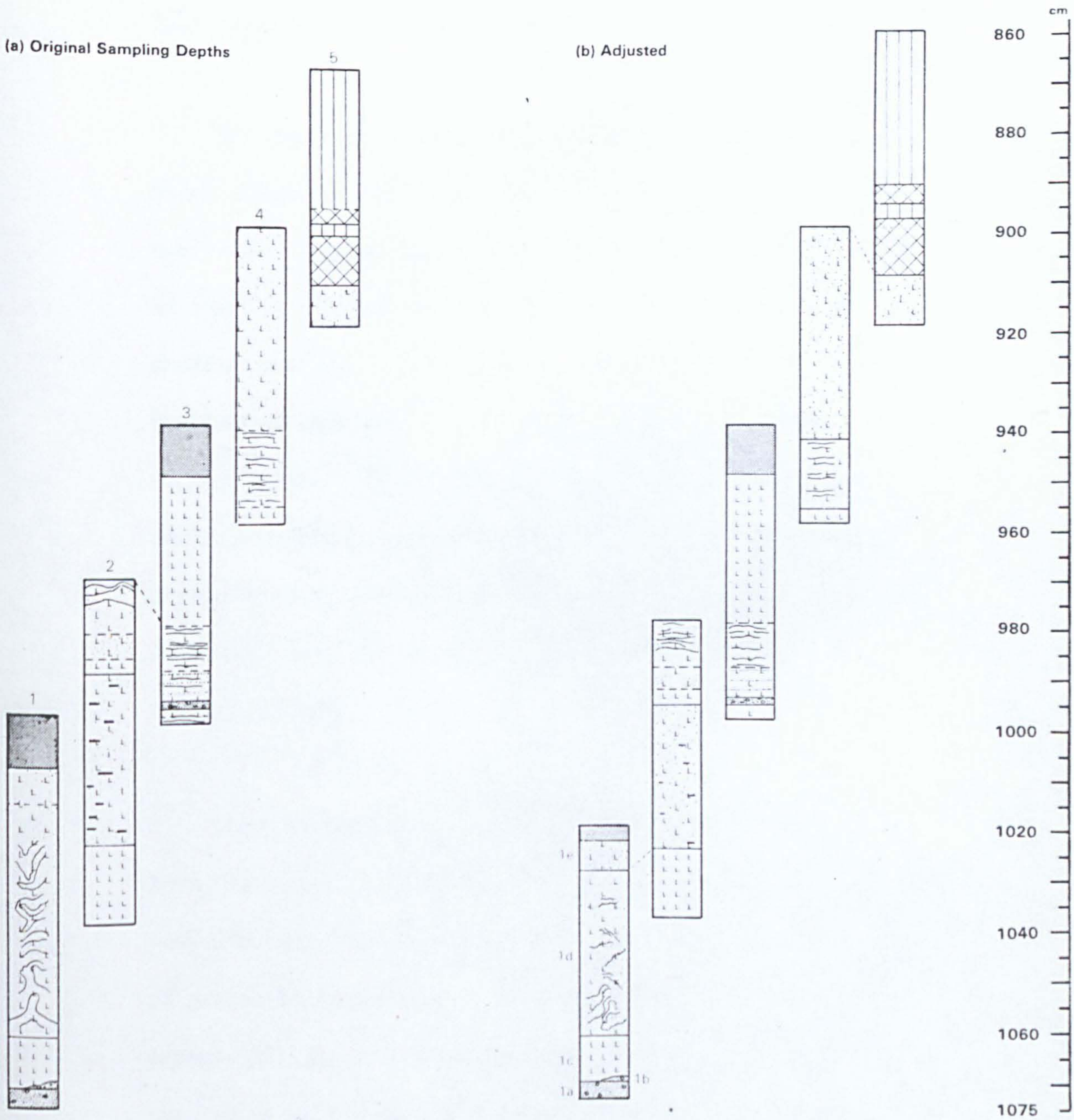
b) Sampling.

The site was located and depth-probed on a 10 m grid in March 1981. The basin floor is quite uneven on a small (1 - 2 m grid) scale, varying in depth by 0.25 - 0.5 m, but on a broad scale the deepest area could successfully be defined, and a sampling site (fig. 6.7a) was located and marked.

Sampling took place in September 1981, using a 60 cm piston corer to obtain the basal sediment. Attempts then and on other visits to use both 1.0 m and 50 cm Russian corers had to be aborted through the failure to penetrate much below 6.0 m. Sampling of upper horizons was, therefore, continued with the piston corer.

Fig. 6.8 shows the five cores obtained, at the depths sampled and thicknesses on extrusion. Three cores (cores 1, 2 and 4) show considerable extension of the samples through flowage, by 28, 15 and 15% repectively. Core 5 shows a 13% compression. Fig. 6.8 also shows the cores adjusted to their probable thicknesses in the basin, but it can be seen that core-correlation problems remain. In cores 1 and 3 the uppermost few cm are occupied entirely by contaminant overlying peat (this may result from the barrel of the corer sliding beyond the piston in soft sediment, thus sampling above the intended depth). Evidence of considerable contortion, probably on extrusion, is found in the distorted laminae of core 1. The major problem is the lack of convincing correlations based on the lithostratigraphies. Biostratigraphical correlation was used to construct the generalized lithostratigraphy in fig. 6.9, the pollen diagram. No overlap is seen between cores 2 and 3, or between cores 4 and 5. The sequence of these cores is thus open to conjecture, but the lowest spectrum of core 5 is likely to be higher in the biostratigraphic sequence than any in core 4, and core 2 is thought to be lower in the succession than the base of core 3. With more success, an

Fig 6.8: Core correlation - BARACHANDER I



adjustment on biostratigraphic grounds of only 2 cm was felt necessary between cores 3 and 4.

Attempts to circumvent these problems by locating other sites in the area resulted in the demonstration that other basins were either occupied by blanket-peat (as at the "inside" site at Na Lona Min; chap. 4), were very shallow and would be likely to lack the biostratigraphic resolution demanded in the study, or could not be sampled successfully. Thus, although it is acknowledged that certain problems are present at the site, conclusions drawn from it can be compared with those from Barachander II (sect. 2 c iii), to eliminate site-specific irregularities.

With regard to laboratory sampling, the sample locations on fig. 6.9 are marked to indicate the date of preparation, 1981 or 1982. In earlier counts the amount of sediment sampled was that usually expected to provide enough pollen to reach the sum of 300 T.L.P. grains. At the depth of 948 cm the sample one cm above (947 cm) was combined to give a reasonable sum (T.L.P. = 98 grains), but in other levels the sediment thickness sampled was 0.5 cm. With this method the lowest polleniferous level was regarded as that at 990 cm. In the autumn of 1982 the cores were re-sampled in order to try to extend this pollen stratigraphy, and amounts of sediment 3 - 4 times that used earlier were prepared, using a very rigorous technique (sieving through 10 μm nylon sieves, 2 hours hot Hf acid treatment with frequent changes of acid to avoid saturation with silica). Despite this half the levels examined proved barren. Such treatment obviously affects the assessment of pollen abundance, but more important is the problem of relating such pollen spectra to contemporaneous vegetation around the site, as is discussed in section e.

c) Lithostratigraphy.

In view of the lack of correlation between the lower most cores (cores 1 and 2) each will be described separately. A generalized lithostratigraphy is given for cores 3, 4 and 5 where biostratigraphic control is provided.

<u>CORE ONE</u>

1a : 1074 - 1069.5 cm.

5 Y 6/1 gray sandy and silty clay, horizontally banded due to grain size differences.

sharp boundary to

1b : 1069.5 - 1067.5 cm.

discontinuous wedge of coarse, black (2.5 Y 2/0) sand.

sharp boundary to

1c : 1067.5 - 1058.5 cm.

very stiff "rubbery" clay, 5 Y 5/1 gray, showing transitional boundary where directly overlying unit 1a.

sharp, possibly erosive, boundary to

1d : 1058.5 - 1024 cm.

fine sand and silty horizon with low clay content, showing exceedingly fine (mm scale) distorted laminae, varying in colour only, between 2.5 Y 3/0 very dark gray to 2.5 Y 4/0 dark gray, not in grain size.

transitional boundary to

1e : 1024 - 1017.5 cm.

homogeneous silt with higher clay content (assessed qualitatively throughout) than unit 1d, 2.5 Y 4/0 dark gray, with laminae absent.

CONTAMINANT : 1017.5 - 1013.5 cm.

CORE TWO

2a : 1038 - 1024 cm.

fine, stoneless, plastic clay, 5 Y 5/1 gray.

sharp boundary to

2b : 1024 - 995 cm.

dark gray, (5 Y 4/1) silt plus clay, with darker mottles/nodules, similar to unit 1d but discontinuous.

sharp boundary to

2c : 995 - 992 cm.

fine, pure clay, 2.5 Y 4/0 dark gray.

gradual boundary to

2d : 992 - 987.5 cm.

as unit 2b;

sharp boundary to

2e : 987.5 - 978 cm.

stiff, silty clay, 2.5 Y 4/0 dark gray, homogeneous in the lower 4.5 cm (987.5 - 983 cm), but with very faint distorted laminae possibly present in upper 5 cm.

GENERALIZED LITHOSTRATIGRAPHY.

LITHOSTRATIGRAPHIC UNIT A : 998- 995 cm.

gray, 2.5 Y 5/0 stiff sandy clay, vaguely horizontally laminated in colour, not in grain size, with a suite of quartz, muscovite and dark mafic minerals.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT B : 995 - 993.5 cm.

fine sandy, silty layer with high clay content, 2.5 Y 5/0 gray, with lenses of fine sand, 2.5 Y 5/0 black.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT C : 993.5 - 987.5 cm.

pure clay, 2.3 Y 5/0 gray, but with prominent, very fine textural and colour-differentiated partings on too fine a scale to be distinguished successfully. Chara oospores were the only organic remains found, and are abundant at 988 cm.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT D : 987.5 - 978.5 cm.

Finely laminated clay, 2.5 Y 5/0 gray, distinguished by dark (organic?) laminations, horizontally banded. The macrofossils retained included Characeae, siliceous skeletons and amorphous concretions of FeS_2 (iron-pyrite), and broken shells.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 978.5 - 950.5 cm.

pure clay, 2.5 Y 5/0 gray, laminations absent but FeS_2 recovered at 952 cm , and occasional stones, principally basaltic, retained.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT F : 950.5 - 939 cm.

as lithostratigraphic unit D;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT G : 939 - 860 cm.

silty clay/clayey silt, predominantly 5 Y 6/3 pale olive, but occasionally mottled (5 Y 4/2 olive gray) and discontinuous horizontal laminations; *Chara* prominent throughout.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT H : 860 - 874.5 cm.

fine peaty gyttja, 10 YR 2/1 black, containing seeds and mosses (undetermined) and few woody fragments.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT I : 874.5 - 871.5 cm.

very coarse sedge peat, 10 YR 2/1 black.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT J : 871.5 - 868.5 cm.

as lithostratigraphic unit H;

transitional boundary to

LITHOSTRATIGRAPHIC UNIT K : 868.5 - 858 cm. (not sampled above this)

as lithostratigraphical unit I.

d) Biostratigraphy.

1074 - 1033 cm.

Non-polleniferous

1033 - 986 cm : local p.a.z BAR I A

Cyperaceae - Betula

Construction

The assemblage zone combines core 2 above 1033 cm., and the lower 12 cm of core 3. On the lithostratigraphical detail (fig. 6.8) the expected overlap is not borne out by the pollen spectra, and in fig. 6.9 the sequences are drawn separately with a gap between cores. The high values for pine in core 3 above 980 cm are not present in core 2, and provide a point above which the latter cannot be correlated. It is thought that the principal taxa failing to correlate successfully, coryloid grains and Cyperaceae, are affected in core 3 by contamination of coryloid grains and hence by statistical variations induced by such inputs (Cyperaceae), so that the consistencies between cores outweigh the inconsistencies, and the two can be regarded as one zone.

Definition

Herb pollen totals are generally very high, exceeding 60% T.L.P., and with tree pollen at 25 - 30% T.L.P., principally birch, with B. nana distinctive, and pine grains present at all levels, shrubs and dwarf shrubs are only inconsistently represented. Corylus is present throughout, as is Alnus (except one level), while at 992 cm is a spectrum extraordinary for the records of single grains of Abies, Fagus, Quercus, and, tentatively, Aesculus.

The number of taxa increase upward (determined by the increasing sum), essentially of herb-types. Cyperaceae percentages exceed those of grasses in this zone, and also common are Caryophyllaceae (5%), Chenopodiaceae (3%), Filipendula (1%) and Rumex in low amounts. Ranunculaceae and Artemisia are inconsistent, but present throughout. The grains of Ailanthus-type are discussed in section e.

The aquatics are poorly represented, and of most note outside the pollen sum are the clubmosses, Lycopodium clavatum and L. selago, with Selaginella selaginoides. Pollen abundance is exceedingly low, and total deterioration quite high (60% T.L.P. + indeterminable grains), although indeterminable grains are usually only 5 - 10% of this sum.

986 - 943 cm : local p.a.z BAR I B.

Pinus - Rumex

Tree pollen values expand to equal those of herbs, of which Pinus is the most not-able contributor (41% T.L.P. peak). Shrub values do not change significantly, Corylus being erratically represented, (see section e) and Hippophäe becoming relatively common. Ericales grains increase towards the zone C boundary.

Gramineae (20% T.L.P. average) now exceed sedges in pollen input to the basin, and most of the herbs already described for zone A are sustained, plus Compositae and Cruciferae, Galium, Crataegus-type, Dryas (1 - 5% T.L.P.) and Filipendula (2%). Rumex values are increased, but inconsistently, an erratic pattern that seems to be a "mirror-image" of the Corylus curve, and a statistical factor might be in operation here. Primulaceae are essentially confined to this zone, and Artemisia declines in importance.

Pollen abundance rises, but the poor "concentration" still is seen in the low sums reached at some levels. The curves of mechanical deterioration correspond to the pollen curve of Pinus (see chap. 7), and total deterioration is still quite high. The spectrum at 954 cm., is clearly anomalous in its high representation of grasses, and the zonation takes no account of this feature with its low sum (98 T.L.P.).

943 - 928 cm : local p.a.z BAR I C

Empetrum - Juniperus

With the decline in pine pollen values to below 5% T.L.P., and with no response seen in the Betula curve the major percentage increases are in the shrubs and dwarf shrub curves. Juniperus achieves 23% T.L.P. at the end of the zone, but expands in zone D, while Empetrum attains a maximal 28% T.L.P., and also declines within the zone.

The majority of the herbs decline or are not represented, though Gramineae values remain unchanged. Contrary to this trend are the curves of Plantago maritima, Epilobium and Filipendula, which continue to rise to 3% T.L.P. After a temporary suppression of values Rumex shows a second peak of 6 - 7% T.L.P. in this zone. Polypodiaceae commence their expansion at this stage to a maximum in zone D.

The pollen zonation is reflected very closely in the curve for total deterioration, wherein a temporary drop in values is produced by a reduction in the amount of crumpling (chap. 7.7). Pollen counts per traverse rise in this zone.

928 - 892 cm : local p.a.z BAR I D.

Juniperus - Salix - Betula

Tree pollen values continue to expand, due exclusively to Betula. Of the shrubs, Juniperus (25 - 30% T.L.P.) and Salix (5% T.L.P.) are prominent. Empetrum percentages remain higher (6% T.L.P.) than in local p.a.zones A and B. Nearly all herb taxa remain quite consistent from the underlying zone, although Rumex drops once more to 2% T.L.P. and less. Polypodiaceae values attain their maximal totals. Total deterioration is lower in this zone than before.

892 - 880 cm : local p.a.z BAR I E.

Coryloid - Betula

Very high peaks of tree-birch to 60% T.L.P. early in the zone give way to Corylus dominance (59% T.L.P.). Practically all other taxa suffer, except Salix which persists at values of 4% T.L.P.

Potamogeton occurs in increasing frequency in the last four spectra of the diagram, and Sphagnum spores appear consistently at the same time.

Total deterioration declines to below 30% T.L.P., with corrosion contributing 4% of this in the uppermost two levels.

e) Interpretations.

Familiarity with the sites discussed previously in this chapter allows the appreciation that the zonation above local p.a.zones BAR I C, D and E has close parallels, (described already), and these need not be commented on in detail. On the other hand, the basal polleniferous spectra need to be discussed more fully, as several interesting differences are seen between this site and those at Ford and Inverliever.

The lithostratigraphy, in the laminae of core la, indicate a lacustrine environment. Even within sediments classed as "clays" considerable amounts of sand and silt were retained, and the sediments are, by and large, poorly sorted, indicating high energy deposition. The laminae, distinguished at the base on grain-size differences, higher on colour contrasts, can be described as rhythmites, as at Na Lona Min and Lon Glas (chap. 4): the absence of laminae in some cores may indicate disturbance of the sediments during sampling. A similar glacial source may be suggested for the rhythmites.

The age of the rhythmitic sequence cannot readily be determined. The sediments are non-polleniferous below 1033 cm , probably through very high sedimentation rates, while above this depth the pollen influx to the basin may have increased to provide countable spectra in view of the unchanging character of the sediments.

The differences in edaphic demands and vegetational dynamics between the Loch Lomond Stadial and freshly deglaciated ground in the earliest post-glacial are likely to be indiscernible. At sites within stadial-age moraines the initial colonizers will be unrecognizable from those plants growing throughout the stadial outside the limits, and at this scale of analysis the designation of the term "stadial" to a pollen assemblage is largely a matter of semantics. Not withstanding this difficulty, it is tentatively considered that the presence of Ranunculaceae undiff. pollen indicates a milder climate than exists in the stadial (cf. chap. 3). The very high rates of sedimentation have emphasized the pioneer phase of colonization, prior to the expansion of Rumex, which, as argued previously, (chap. 3) is not characteristic of this period.

The exceedingly low pollen "concentrations" in the lowermost pollen zone have emphasized several pollen taxa anomalous to the early post-glacial, including Fagus, not native to Scotland (Godwin, 1975) and, tentatively, Aesculus, not native to Britain (Godwin, 1975). Ailanthus-type pollen in significant amounts is disturbing in that similar grains are employed as "exotic markers" in concentration studies at Pulpit Hill and Loch Barnluasgan (chaps. 2, 3). It is, perhaps, possible for the viscous glycerol in which the Ailanthus grains are embedded to survive on the very fine mesh of the 10 μm sieves, and this is thought to be the only likely source of contamination.

Rumex is likely to be present locally from zone B. The principal zone-taxon, Pinus, is represented by values which exceed those of any Flandrian pollen zone in western Scotland. For this reason contamination from overlying sediments is ruled out, and the high percentages are thought to be from long-distance pollen, their importance exaggerated by the very low pollen influx. The dramatic increases, however, are hard to explain on this basis. Examination of the deterioration curve for Pinus (chap. 7) shows that in the ten levels of high pine percentages 29% (S.D = 9%) of grains were broken. Taking the extreme case that all such split grains were counted twice (thought unlikely) the percentages can be "corrected", resulting in a value of 23% T.L.P., still extremely high. Hall (1981) considers pine pollen to increase in relative terms in sediments showing high deterioration values, as in local p.a.z BAR I B, but this need not imply resistance to deterioration (chap. 7) when it is appreciated that losses to the indeterminable category are few in such easily recognized pollen. Over-representation is believed to be caused by sampling at the edge of a lake where pine sacs are thought to be blown and accumulate selectively (Davis and Brubaker, 1973), but in a basin as small as Barachander I this mechanism is probably insignificant. The increase in pollen abundance with the change to litho-unit E (fig. 6.9) is unlikely to explain the increase in Pinus pollen at this time, as the effect would be noted in all taxa. An alternative suggestion is that the increases are real, and represent a change in the dominant circulation patterns over the British Isles. This is discussed in detail in section 4 of this chapter.

Above zone B the succession resembles closely those outlined earlier in this chapter, and in chaps. 4 and 5. There is a clear rise in Empetrum prior to that of Juniperus, and here the crowberry was not suppressed by juniper.

iii) BARACHANDER II (g.r. NN 025239; lat. 5°12' N; long. 56°22' W).

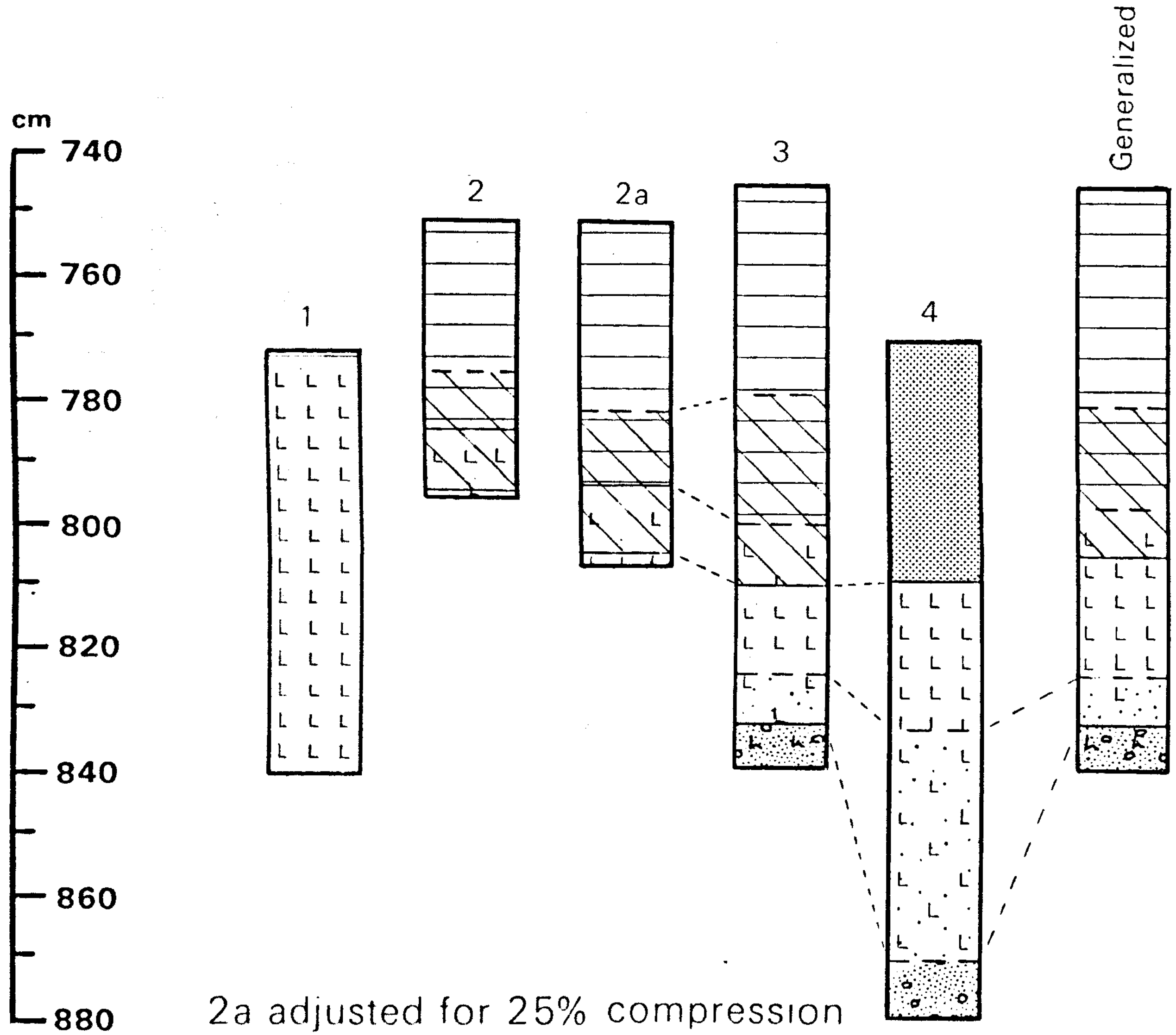
a) Site Location and Description.

The basin (fig. 6.7b) lies entirely within glacially-smoothed Dalradian bedrock, close to the boundary with the Old Red Sandstone lavas (fig. 1.4). The site is aligned S.W. - N.E., parallel to other valleys in the region (fig 6.7), controlled by the strike of resistant beds within the metamorphic complex. Lying at approximately 180 m O.D., the bog-surface slopes gently from 77 m at the N.E. end to 73 m at the S.W., where a rock-bar is seen exposed in a small stream draining the present valley, (fig. 6.7b). The sub-surface topography was established by a linear traverse of depth-probes along the axis of the valley at 10 m intervals, from which a complex, triple basin was suggested, two ridges some 80 m and 120 m up-valley from the rock-bar, lying 3.60 and 3.80 m respectively below the peat-surface, separate basins approx. 6.00 m and 6.20 m deep respectively from that cored for pollen analysis (fig. 6.7b) which reached 8.78 m maximum depth. The areal extent of the catchment is 1375 m , and the size of the basin as delineated by the present bog-surface is 1170 m , though whether this represented the size of basin in the early post-glacial, or whether the basins were separate can only be conjecture.

b) Sampling.

The series of cores recovered is depicted in fig. 6.10. Initial sampling (September 1981) resulted in one core (core 2) displaying a distinct lithostratigraphy (fig. 6.10), but the deeper core 1 showed no overlap and considerable distortion of the semi-fluid clay. In January 1983 two 1.0 m Russian cores were retrieved. Core 3 extended 48 cm deeper than core 1, but heavy contamination rendered it unsuitable for pollen analysis. The lithostratigraphy of this core is similar in all respects to the basal units of core 4, and with lithostratigraphic units A and B proving non-polleniferous (sect. c; fig. 6.11) it is felt that the basal 10 cm , not

Fig. 6.10: Core correlation - BARACHANDER II



2a adjusted for 25% compression

sampled with the Russian corer, would not have proved significant.

Laboratory sampling was undertaken on cores 2 and 4 (core 2 is adjusted in fig. 6.10 for a compression factor of 25%). The successful lithostratigraphic correlation is supported by the overlapping pollen spectra (fig. 6.11). Pollen concentration analyses were carried out on 11 of the 22 levels counted (fig. 6.12).

c) Generalized Lithostratigraphy.

LITHOSTRATIGRAPHIC UNIT A : 838 - 831 cm.

Coarse sandy clay, 2.5 Y 5/0 gray, with few rounded stones, lithologies undetermined.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT B : 831 - 824 cm.

finer, silty clay, 2.5 Y 5/0 gray; no stones or discernible structure.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT C : 824 - 804 cm.

pure clay, stoneless but with abundant macrofossils of *Chara*; 2.5 Y 5/0 gray.

sharp boundary to

LITHOSTRATIGRAPHIC UNIT D : 804 - 796 cm.

2.5 Y 4/2 dark grayish brown silty organic clay, with occasional intermixed sand.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT E : 796 - 779.75 cm.

very fine organic mud with peat, occasional plant stems and sporadic finds of Characeae, varying in colour (due to oxidation) from 5 YR 2.5/2 dark reddish brown to 10 YR 2/1 black.

transitional boundary to

LITHOSTRATIGRAPHIC UNIT F : 779.75 - 744 cm. (not sampled above this).

coarse fen-peat, gyttja content decreasing upward, with horizontal stratification and prominent macrofossil remains including *Chara*; 5 YR 2.5/1 black.

d) Biostratigraphy.

838 - 824 cm : non-polleniferous.

One sample, at 827 cm was examined, proving barren, and in view of the coarsening of sediment down-core it was thought countable samples were unlikely to be obtained below this.

824 - 806.5 cm : local p.a.z BAR II A.

Alnus - Betula - Ericaceae undiff.

The very low totals of land pollen per c.c. of sediment affect the pollen sum obtained, maximum 203 grains T.L.P., and usually lower.

Arboreal pollen is approximately 40% T.L.P., with Alnus (average 8.6% T.L.P.) and Betula (27%) being the major contributors. B.nana was not recorded in this zone. Pinus is inconsistent in the spectra, as is Corylus (coryloid grains), from 3 - 18% T.L.P., while the Ericaceae undiff., together with Calluna vulgaris and deteriorated grains of the Empetrum/Ericaceae undiff. category are strongly represented.

Grasses are the most important herb taxon, with Cyperaceae increasing at the end of the zone. Isolated spectra of Caryophyllaceae and Chenopodiaceae at high values occur at this time also. Polypodiaceae and Sphagnales are prominent.

Total deterioration is highest in this zone, as are values for indeterminable grains. Corrosion and degradation are characteristic of this zone, but crumpled grains contribute the majority of deteriorated grains.

806.5 - 802 cm : local p.a.z BAR II B.

Rumex - Empetrum - Pinus

The level 805 cm continues the trend of low pollen concentration, but with the change in sedimentation at 804 cm a pronounced rise in total pollen concentration is seen, and in all major taxa except Salix. This is only partly reflected in the percentage-based diagram (fig. 8.11), where birch values do not change. Betula nana is now recorded continuously. Alnus and Ericaceae now decline abruptly, while taxa described as erratic in local p.a.z A, Pinus and Corylus are more consistent, albeit at lower percentages. Unlike Ericaceae, Empetrum shows a pronounced increase to peak at 21% T.L.P. The increases in concentration (fig. 6.12) are also poorly expressed in percentages of Gramineae, and in Cyperaceae, which decline from 27% T.L.P. at the base of the zone. Rumex percentages show a marked increase from being unrecorded at level 807 cm to 12% T.L.P. one cm above, but the concentration values for the genus only expand above 803 cm. Notable in this zone are the Compositae, Artemisia, Ranunculaceae and Dryas.

Sphagnum is only recorded at two levels, but Dryopteris rises throughout, and Lycopodium selago is consistently recorded only in this zone. Typha latifolia is characteristic of the lower half of the zone.

802 - 797 cm : local p.a.z BAR II C

Juniperus - Empetrum

Total pollen concentration almost doubles from the preceding zone to this within the same lithostratigraphic unit D, but appears to reach a "plateau" within the zone that is not exceeded in overlying zones. The major contributor is Juniperus (fig. 6.11; 6.12), while Empetrum maintains its concentration and percentage values before declining (fig. 6.11) towards the end of the zone. While grasses, sedges and Dryopteris sustain their representation of the latter half of local p.a.z B (fig. 6.12), Rumex more than doubles its concentration, a rise clearly not reflected in its percentage values. Polypodiaceae display an extreme increase in concentration at 800 cm, before returning to more consistent levels of around 52000 grains per c.c. of sediment. There are slight percentage increases in Ericaceae undiff. and in Filipendula.

797 - 793 cm : local p.a.z BAR II D.

Betula - Salix

While total pollen production (fig. 6.12) appears to remain static, assuming a uniform sedimentation rate, birch far exceeds the representation of any other taxon, and at its peak of 69,000 grains per c.c. of sediment exceeds by a factor of 2 the combined production of all major taxa within the pollen sum (33,500 grains per c.c. of sediment). This dominance is reflected in fig. 6.11 also. Nearly all other taxa decline in concentration and percentage terms, the exception being *Salix* which, although increasing only slightly, exceeds the pollen concentration of other shrubs. All dwarf shrubs are poorly represented in this zone. Herb values, now lower than in zone A are sustained largely by Gramineae (12% T.L.P. average; 13,600 grains per c.c. of sediment). *Rumex* is still present in the pollen rain, and *Filipendula* sustains values of 2% T.L.P. throughout.

Myriophyllum alterniflorum and *Littorella* are the only aquatics recorded, and of the spores only *Sphagnum* shows an increase.

793 - 770 cm : local p.a.z BAR II E.

Coryloid - *Betula*

All taxa, including *Betula*, show percentage reductions as *Corylus* expands. *Salix* and *Filipendula* alone maintain values close to those in the underlying zone. Oak and elm are present consistently above 785 cm.

The majority of the herb-taxa are no longer represented, while among the aquatics Typha angustifolia is of note, up to 2% T.L.P. + aquatics.

e) Interpretations.

The polleniferous sequence outlined above undoubtedly bears a resemblance in most of its features to Barachander I. From correlation with other sites it is apparent that above local p.a.z B the succession is close to that described for other localities, and so little time need be spent discussing this conventional bio-stratigraphy. The exclusively local developments suggested by the pollen record for local p.a.z A need to be discussed.

In the basal zone the high percentages of Alnus and Corylus are probably contaminant, though probably not the Betula pollen. Comparison of the percentages of alder, hazel and Ericaceae show marked differences between Barachander I and II, while birch percentages are remarkably uniform between sites (BAR I A : $\bar{x}$ = 25.09%; S.D = 6.4%; n = 12 = BAR II A : $\bar{x}$ = 26.33%; S.D = 4.2%; n = 6), which is the distribution one might expect from wind-blown pollen, given comparable catchment and basin sizes. As at Barachander I the sediment was not obviously contaminated, and this degree of contamination is worrying in view of the care taken in sampling: one is led to speculate on the level of contamination in material of higher pollen concentration where it is not so readily recognized. Re-sampling of the centre of core 4 (levels 823, 809, 806 cm) resulted (fig. 6.11) in reduced contamination from alder and hazel, and values for Pinus, Cyperaceae and Chenopodiaceae higher than in other levels. The majority of spectra from local p.a.z BAR II A, do not, therefore, provide an accurate picture of contemporaneous pollen influx to the basin. The sequence as seen at 823, 809 and 806 cm , and in spectra re-calculated to exclude the contaminant grains (not depicted) is closely comparable with Barachander I local p.a.z A, and the two sites are believed to show essentially similar biostratigraphies.

The basal pollen zone at Barachander II is believed to represent the earliest post-glacial pioneer colonization of the catchment, in the presence of Ranunculaceae pollen and the consistency with which Gramineae percentages exceed those of Cyperaceae (even after re-calculation: above), a distinguishing feature of the early post-glacial (chap. 3). The overlying zone BAR II B includes the Rumex rise, not clearly recognized in the pollen concentration diagram (fig. 6.12). The over-emphasis of Rumex in percentage calculations is a common feature in periods of low pollen concentration (cf. Pennington and Bonny, 1970).

Empetrum and Rumex appear to expand synchronously, but in view of the pollen sequences outlined at other sites (chaps. 3, 4, 6: discussion chap.5) this feature is probably determined by a slow sedimentation rate, coincident with the change in sediment-type at 804 cm. The rise in pollen concentration at this depth may be the result of this reduction in sedimentation, but equally could be indicative of the establishment of local communities and progressive closure of the vegetational cover, itself reducing sediment input to the lake.

The percentage values of Pinus are not comparable between the two Barachander sites. At Barachander II the Rumex - Empetrum - Pinus zone is only 10% the thickness of the corresponding zone BAR I B, and, assuming synchroneity of upper and lower boundaries between the sites, received a very much greater pollen influx, principally from local communities to the detriment of the representation of long-distance travelled grains. The increase in pine is seen in the pollen concentration diagram. By local p.a.z

BAR II B Pinus had trebled its pollen concentration, and reaches 2,500 grains per c.c. of sediment, exceeding the local production of Rumex.

Pine maintains a constant pollen concentration above zone C, so that its decline in percentage terms is seen to be a result of increases in local pollen.

6.3. EXAMINATION OF ASSUMPTIONS

The six sites described above have been interpreted almost exclusively in terms of the hypothesis of deglacial chronology outlined in chap. 5. Before the sites can be employed in the interpretation of the glacial sequence in the Awe valley, consideration of the several assumptions upon which the validity of the hypothesis is based is essential.

Assumption (iv) (chap. 5; p.241), that the pollen-spectral changes are readily discernible and consistent between sites, is considered to have been satisfied. Only at Barachander II do two key taxa, Rumex and Empetrum, appear in the pollen counts synchronously. At all other sites (bar Ford II) the pollen-spectral changes are clarified by rapid sedimentation rates.

The condition that the earliest colonizers will be absent at sites some distance inside readvance limits (chap. 5; p.237), is questioned by the evidence from Inverliever. At these two sites Empetrum from extra-local sources achieved prominent representation at the base of the sequences, with the lowest pollen abundances, (as anticipated in the hypothesis), but the influx of this pollen was not sufficient to "swamp" the local expansion of Rumex. As a result the complete post-glacial vegetational succession from pre-Rumex pioneer phase to the Juniperus phase can be recognized at both Inverliever and Barachander.

A pre-Rumex phase was not anticipated in the design of the hypothesis being tested (chap. 5), though perhaps it should have been given the discussion on its role in colonization in chap. 3 (sect. 3.2). Analyses of other sites (chaps. 4, 5) did not suggest the prominence of such a phase seen in the diagrams presented here, and it is likely that the rapid sedimentation rates of the Awe valley basins have aided in distinguishing this feature.

At Lateglacial sites delays in the appearance of Rumex are not apparent at the stadial/postglacial transition (though are recognized at the base of the interstadial; cf. Pennington, 1977a). One reason for this must be that this period is included in what are conventionally zoned stadial pollen assemblages. It has been emphasized (sect. 2c,iii,e) that there is little difference in vegetational structure, soil development or sedimentary processes between the stadial *sensu stricto* and the colonization of freshly deglaciated ground. At Barachander II the effects of over-representation of *Rumex* have been considered, and given the harsh conditions the docks experienced in the stadial (chap. 4), sites showing high *Rumex* percentages within the Loch Lomond Stadial (e.g., Coolteen and Belle Lake (Craig, 1978); Pulpit Hill (this study); Kildale Hall (Jones, 1977) and Magheralagan and Woodgrange (Singh, 1970)) probably indicate over-representation in periods of low total pollen influx, or very sheltered conditions.

On Rannoch Moor Walker and Lowe do not distinguish pre-*Rumex* or *Rumex* phases, though their sites are very much shallower than the rock-basins used in this study. Low but distinctive peaks of *Rumex* occur at the base of most of their sites, and it is felt the pollen stratigraphies at these sites are not sufficently clear to establish that the basal pollen spectra are high in *Empetrum* alone.

Assumption (v), that vegetational changes are synchronous must be doubted on the biostratigraphic evidence from Inverliever. Radiocarbon assays are not possible in view of the minerogenic nature of the sediments. The evidence from Inverliever can best be explained by non-synchronous expansion, locally and regionally, of dwarf shrub taxa. The initial regional or extra-local expansion of dwarf shrubs (*Empetrum*) in the basal pollen assemblage zones must be earlier than the post-Rumex development of Empetrum and Ericaceae from local sources. The diachroneity may not be great, and if controlled by edaphic conditions (cf. chap. 4) may be as little as 60 - 100 years (extrapolating from present-day data; Persson (1964); Matthews (1978)), smaller than the standard deviations of C14 dates for this period. On a broad scale, therefore, this diachroneity is essentially insignificant, but within the bounds of the hypothesis under consideration is important, and temporal correlation of the dwarf shrub stages between sites is not feasible.

The assumption of synchroneity in Empetrum growth at post-glacial sites would create anomalies between the Awe valley south-west of Inverliever, and the Teith valley - Rannoch Moor system discussed by Lowe and Walker (1981), in demanding on the grounds of synchroneity of the basal Empetrum-dominated pollen assemblage zones that Rannoch Moor was almost totally deglaciated in the time the Awe glacier retreated some 13 km from Ford to Inverliever, an improbable glaciological situation.

Regarding Rannoch Moor, the C14 dates reported by Lowe and Walker (1980; Walker and Lowe, 1980) from Kingshouse 2 (Lowe and Walker, 1976) and Rannoch Station 2 (Walker and Lowe, 1979) and considered valid in the analyses in chap. 5 (sect. 5e) are the oldest known from Scotland for the Empetrum phase, yet lie close to the centre of ice-accumulation (Sissons, 1976). Hard-water errors in the dates are discussed by Lowe and Walker (1980) who conclude that "it cannot be proved that none of the age determinations have been affected in this way" (p. 135). However, date BIRM - 722 (Kingshouse 2; table 5.3) was obtained on a terrestrial moss, Rhacomitrium lanuginosum which the authors argue (p. 134; 1980) cannot be "affected by hard-water to the same extent as contemporaneous lake-sediments." Lake-sediments, however, reflect the terrestrial chemical environment (Mackereth, 1966), and uptake of soil moisture by mosses must reflect the carbon levels in the ground-water, and the radiocarbon dates may still be "old", and the synchroneity suggested in chap. 5.3 may be based on invalid dates.

SUMMARY OF SECTION 6.3.

In conclusion, therefore, although the majority of assumptions outlined in chap. 5 have been proved valid, either in the discussion of assumptions (sect. 5.3) or in this section, the major tenets of synchroneity and sequential removal of the earlier colonization stages up-valley have been shown to be invalid. The pollen assemblage zones at the three localites reflect local vegetational successions from the pre-Rumex phase onwards.

6.4 EXAMINATION OF THE DEGLACIAL CHRONOLOGY HYPOTHESIS.

As defined in chap. 5 the hypothesis, having been tested within the Awe valley, cannot now be adopted in an analysis of the glacial events. The writer believes, however, that the pollen diagrams can be used to illuminate the role of stadial ice in the valley.

Of greatest significance in this reconstruction are the prominent curves for Pinus at Inverliever and Barachander, which are believed to be synchronous. It might be thought the use of long-distance pollen to be suspect in correlation as any phase of low pollen influx will record an increase in their pollen, without implying synchroneity, but at these sites the pine expansion occurs not in the basal spectra but at horizons dominated by local vegetational developments. Percentage representations vary between sites according to differing sedimentation rates, the importance of contamination and basin size, as seen at the two Barachander sites.

Expansion of Pinus in the early post-glacial was noted at Pulpit Hill (chap. 3), Na Lona Min and Lon Glas (chap. 4), but not from many other Scottish sites, although Tyndrum (Lowe and Walker, 1981) exhibits high amounts of pine in the basal Empetrum zone, Loch Sionascaig (Pennington et. al., 1972) shows a slight increase from 5% to 12% T.L.P. in the Rumex phase, and Loch Cill on Aonghais and An Druim, Eriboll (in Birks, 1980 unpub.) also show small increases in the Empetrum stages. At other sites slow sedimentation rates, the overriding effect of local pollen production or too large a sampling interval may disguise the increase.

Statistical artefacts, sedimentary processes, over-representation of Pinus pollen or the deterioration of grains do not seem to explain the consistent pattern recorded from the four sites of Inverliever and Barachander. Climatic interpretations of fluctuating conifer pollen curves have been used by Lamb (1977) in invoking circulation patterns in the mid-Flandrian from data of Fredskild (1972), but the idea is new to the British early post-glacial. In chap. 3 it was suggested that vigorous westerly winds were dominant in western Britain in the interstadial, and probably the stadial also. If the views of modern workers (Sissons, 1976; Walker, 1982; Gray, 1982) are correct on the importance of the Polar Front (Ruddiman and McIntyre, 1981b) on palaeoclimate, the northward retreat of this feature should introduce more southerly air streams in the early post-glacial as it dragged the major depression tracks northward. This would introduce greater amounts of far-travelled pollen from southern England or the continent, where it appears (Behre, 1967) Pinus might have survived the stadial.

Tentative support for this suggestion is found where the pine expansion occurs immediately prior to the rise in Juniperus, most marked at Inverliever I and II. In chap. 5

(sect. 5) the importance of wind-exposure was considered most important in the growth habit and pollen productivity of this shrub, and one explanation of the Juniperus rise could be a decline in the prominence of westerly winds which allowed the growth of bush-form junipers.

The next section develops the important role played by the Pinus curve in the correlation of localities. In terms of the deglacial chronology hypothesis (chap. 5) it appears that the sites analysed do not prove the hypothesis valid, and do not on this basis demonstrate the presence of Loch Lomond Readvance glaciers within the lower reaches of the Awe valley. More importantly in terms of the application of this or similar biostratigraphically determined hypotheses elsewhere in Scotland, the theory has been seen to founder not on factors unique to the Awe valley, as anticipated might be the major weakness (chap. 5; sect. 5f), but in the more general assumption of biostratigraphical synchroneity.

6.5 CORRELATIONS BETWEEN SITES AND LOCALITIES.

The key to the proposals in this section are found in fig. 6.13. Correlations between sites of one locality are drawn on the assumption of synchroneity within such a limited area. Support for this comes from the appearance of the Pinus peaks in equivalent pollen assemblage zones at Barachander, and at Inverliever. The *Pinus* curve behaves as an independent "marker", being long-distance transported and distinct from local plant communities, so that its appearance in large amounts in similar pollen assemblage zones strongly suggests synchroneity, and may indicate also that pairs of basins successfully reflect regional geomorphological and vegetational changes. Correlations between the two Ford sites are, of course, hampered by the delay in sedimentation at Ford II.

Correlations between localities at and above the *Juniperus* rise are regarded as synchronous, being determined by regional climatic change in the case of juniper, or migration of tree species, again likely to be synchronous within an area the size of the Awe valley.

The diachronous nature of the *Empetrum* peaks makes temporal correlation problematic between localities. The *Rumex* - Gramineae - Dwarf Shrubs zone Ford I A cannot with certainty be correlated with the base of Inverliever (as is shown in fig. 6.13) but if the argument for diachronous *Empetrum* establishment within the valley (sect. 6.2B) is accepted the basal dwarf shrub zones at Inverliever cannot be earlier than zone Ford I A.

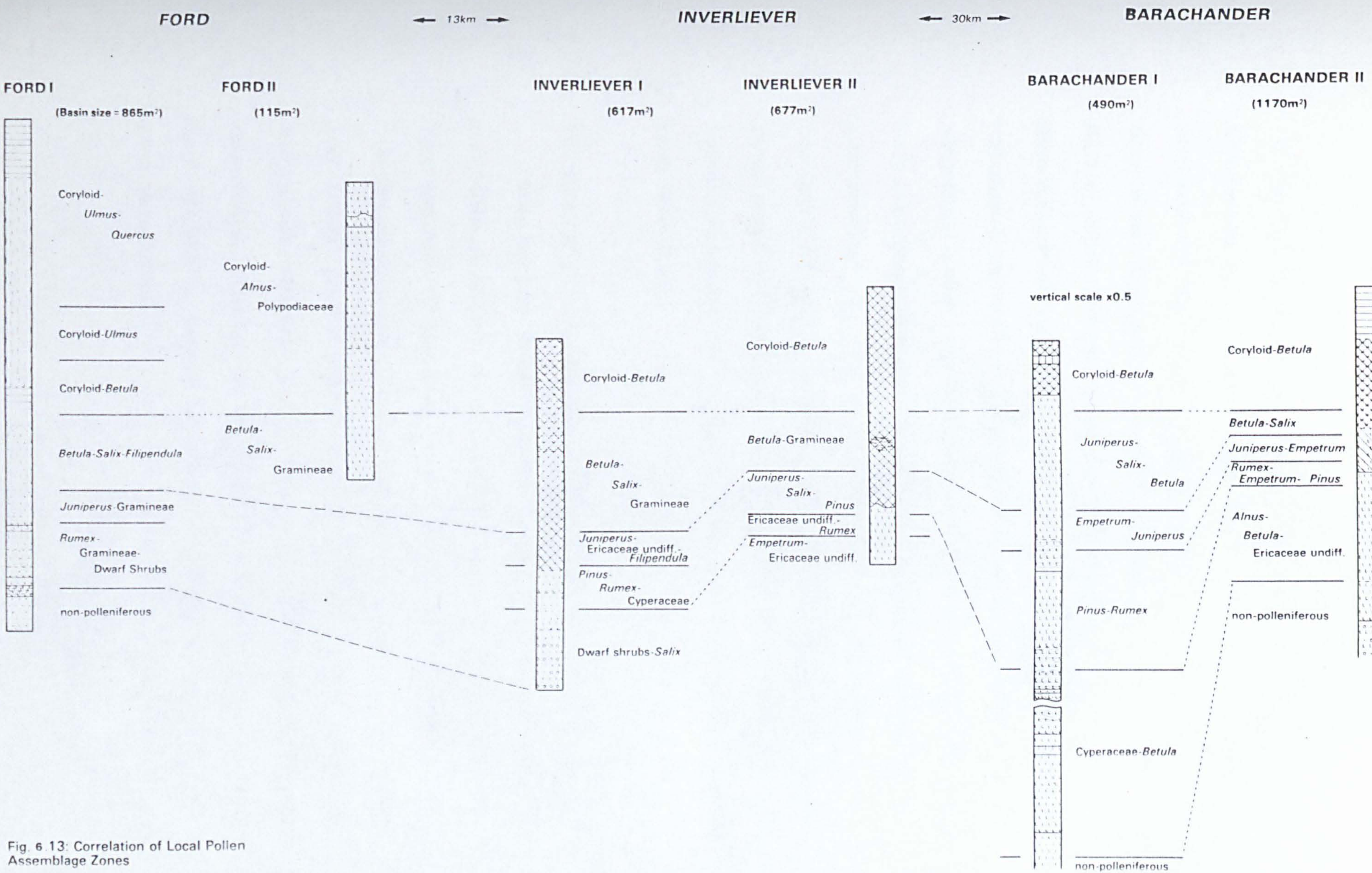


Fig. 6.13: Correlation of Local Pollen Assemblage Zones

On fig. 6.13 the *Pinus* p.a. zones of Inverliever and Barachander are considered synchronous. At Inverliever the pine peak appears in the *Juniperus* assemblage zone, at Barachander the *Rumex* zone, which successionally is the earlier stage. What is implied in this correlation is that Barachander had only reached the *Rumex* phase while Inverliever had passed through the *Empetrum*/dwarf shrub expansion, suggesting a delay in colonization at the site furthest east. Such a proposal does not invalidate juniper's regional synchroneity: *Juniperus* is seen to rise at Barachander together with *Empetrum*, despite the very rapid sedimentation rates noted at Barachander I, so that the time-interval between the *Rumex* and *Juniperus* phases at Barachander need not have been great.

6.6 THE ROLE OF LOCH LOMOND READVANCE ICE IN THE AWE VALLEY.

This section draws together the various palynological and sedimentological arguments developed in this chapter and from the site of Lon Glas (chap. 4). The writer supports the view proposed tentatively by Gray and Sutherland (1977), that Loch Lomond ice extended to Ford at the south-west end of the Awe valley. Individual points to be detailed are by no means conclusive, although it is thought that the body of evidence is difficult to explain on other glaciological reconstructions.

A) No Lateglacial lithostratigraphy has been recorded in this or in Gray and Sutherland's (1977) study. Given that dead-ice is unlikely to have persisted in these basins through the Lateglacial interstadial (chap. 5.5c) and the assurance that bedrock was struck in all the bedrock-floored basins it is felt that the absence of such sediments from basins exceeding 9.0 m. depth, and with demonstrably shallow stream-outlets, is most reasonably explained by ice-occupation of each basin during the Loch Lomond Stadial.

B) Five of the six sites show biostratigraphical records dating from the earliest post-glacial. Even accepting some diachroneity in plant colonization, all the sites (bar Ford II) had commenced sedimentation prior to the Juniperus expansion, and on other glaciological reconstructions, which would have the Awe valley outside stadial ice-limits, one is asked to accept this nearly synchronous (on the Flandrian time-scale) onset of deposition as coincidental.

In particular, it is thought that Inverliever I and II commenced sedimentation synchronously (on the much narrower time-scale of the early post-glacial), as did Barachander I and II, which, it is thought, is difficult to explain on grounds other than the exposure of bare ground by glacial retreat.

C) Despite the failure of the deglacial chronology hypothesis in demonstrating time-transgressive delay in plant colonization up-valley (i.e., from Ford to Barachander), the correlations in fig. 6.13 imply just such diachronous biostratigraphical sequences (cf. sect. 6.5), perhaps controlled by frontal glacial retreat.

D) The site of Ford II is argued tentatively in sect. 6.2A to show delayed sedimentation through dead-ice occupying the kettle-hole. Dead-ice would be of stadial age, giving the age of formation of the kame terraces. However, the evidence is weak, and other mechanisms, e.g., through-drainage of the kame sands in the earliest post-glacial, could explain the sedimentological evidence.

E) The site of Lon Glas (chap. 4) has been interpreted as the result of ponding of a small stream by the growth of kame terraces in the Loch Lomond Stadial.

F) It is considered significant that the site of

Ford I, which is the closest of the three localities to the inferred ice-front, should on the correlation of sites (sect. 6.5; fig. 6.13) have the earliest deposited sediments.

It is conceded that the correlations of localities are based on two unproven features of the diagrams; firstly, that the interpretation of the two dwarf-shrub peaks at Inverliever (sect. 6.2B) is the correct one, and secondly, that the influx of pine pollen into the region is synchronous between sites. Other interpretations of the basal Empetrum pollen assemblage zones at Inverliever would have to conform with what is known of the plant's ecology, pollen production and colonization strategy. It is doubtful whether absolute dating of the Pinus peaks would be possible given the minerogenic nature of the sediments, but until such dates are obtained synchroneity cannot be proved.

Although tentative, the evidence can be considered to indicate the importance of frontal ice-retreat in the Awe valley in that the three localities appear to have been deglaciated at later stages north-eastward. Frontal retreat generally exceeds thinning and down-wasting at glacier termini. Hillefors (1979) described the mode of deglaciation during Main Devensian ice-retreat for the west coast of Sweden, topographically very similar to the Scottish west coast, (chap. 5.5f) where he considered that ice thinned on the plateaux and interfluves between fjords, and flowed laterally into the valleys. This mechanism would maintain a considerable thickness of ice in the Awe valley, promoting frontal retreat over its 20 km length.

In coming to the conclusion that, on the palynological evidence, Loch Lomond Readvance glaciers extended the length of the present Loch Awe, it is seen that this runs counter to the geomorphic evidence of D. G. Sutherland and P. W. Thorp.

Firstly, there is no evidence available to demonstrate that the moraine mapped near Barachander (sect. 6.2Ci) by D. G. Sutherland is a terminal moraine, and it might well be a retreat moraine, formed during a slight pause by an actively retreating Awe glacier.

Second, the extrapolation of glacier limits from evidence such as trimlines (Thorp, 1981) should be considered. Extrapolation from present-day glaciers is weakened by the realization that modern glaciers need not be analogues of stadial glaciers, probably differing in macro- and micro-climate, ablation and accumulation characteristics, basal shear stress, bed roughness and bed slope. Generalizing the longitudinal profiles is, consequently, of uncertain value, and the fitting of parabolic profiles to valley glaciers (e.g., Sissons and Sutherland, 1976) may be incorrect, as Schilling and Hollin (1981) point out that mountain glaciers with bed-slopes exceeding 3° tend to a more slab-like profile, with little difference in ice thickness between a point just above the snout and points some distance up-glacier. Similar slab-like profiles can also develop on an unconsolidated bed such as glacial drift (Boulton and Jones, 1979).

Considering trimline evidence further, it is likely that some indicators (outlined in Thorp, 1981) are of greater reliability than others. For instance, the lowest altitudinal limit of periglacial lobes and terraces is probably a more accurate delimiter of glacial limits than the upper limit of thick till or hummocky moraine, which by their mode of formation can be regarded only as minimal for the ice which formed the drift. Most trimline-indicators become less useful below 4 - 500 m O.D. (Thorp,1981), particularly in the western highlands, and are poorly developed on the resistant, coarse-grained and massive granites such as Ben Cruachan (Thorp, 1981). The evidence around the Pass of Brander is affected by all these problems. Finally, Thorp (1981) concedes the possibility that "periglaciation may have occurred during ice-sheet decay" (p. 52), so that the trimline evidence may not relate to the maximal extent of the ice-sheet or valley-glacier.

In conclusion, the geomorphological reconstructions are not without their weaknesses, and it is possible to re-interpret these features to accord more closely with the palynological interpretations. These conclusions are briefly reconsidered in chapter 8.

Fig. 6.2 FORD I POLLEN PERCENTAGE DIAGRAM

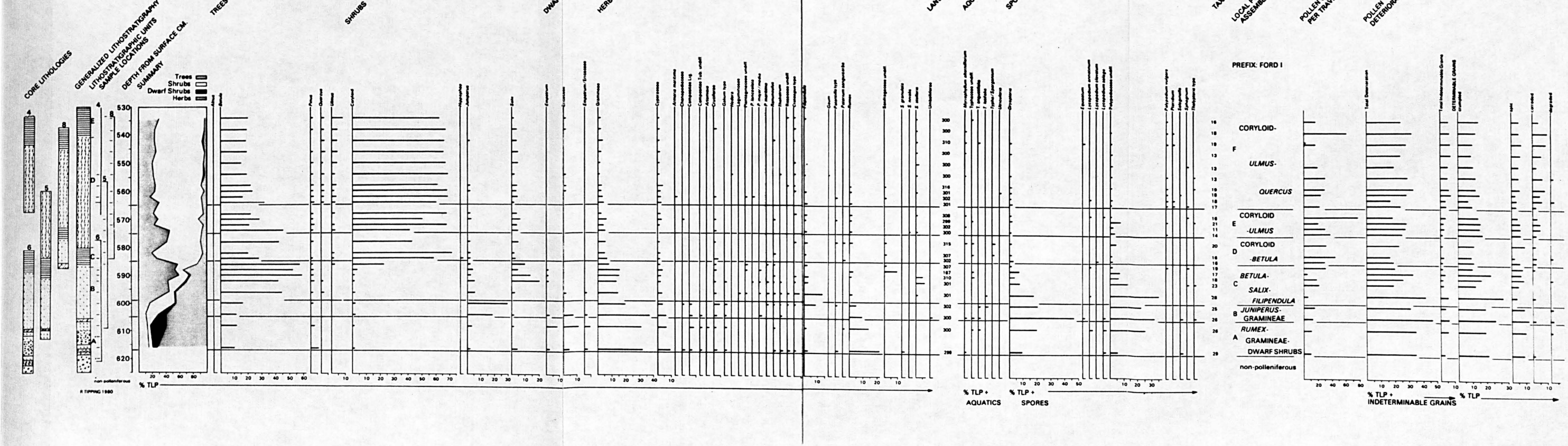


Fig. 6.3 FORD II POLLEN PERCENTAGE DIAGRAM

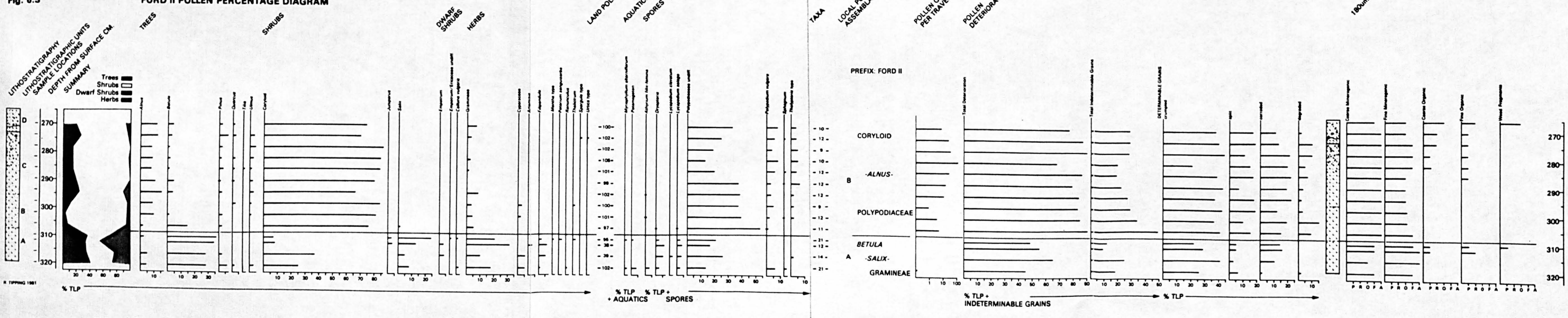


Fig. 6.5

INVERLIEVER I POLLEN PERCENTAGE DIAGRAM

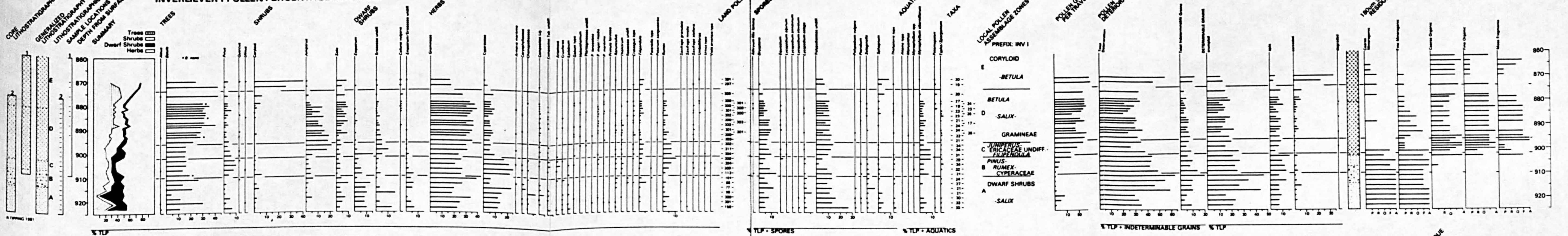


Fig. 6.6

INVERLIEVER II POLLEN PERCENTAGE DIAGRAM

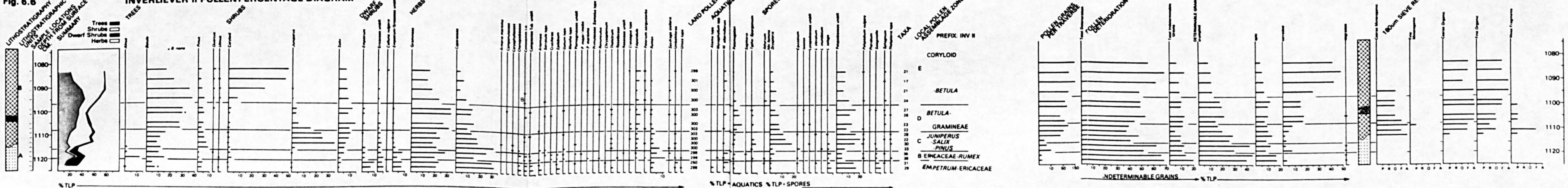


Fig. 6.9 BARACHANDER I POLLEN PERCENTAGE DIAGRAM

Fig. 6.11 **BARACHANDER II POLLEN PERCENTAGE DIAGRAM**

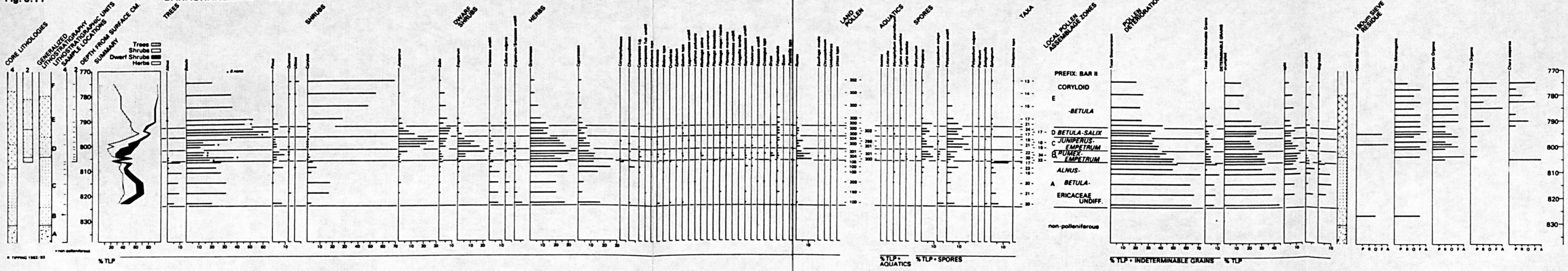
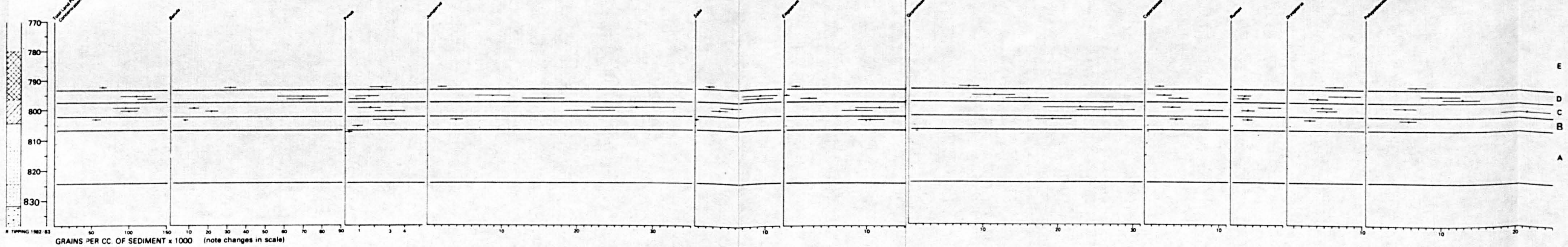


Fig. 6.12 **BARACHANDER II POLLEN CONCENTRATION DIAGRAM**



CHAPTER SEVEN

POLLEN DETERIORATION STUDIES

7.1 INTRODUCTION

Mention of deteriorated pollen studies has been made in earlier chapters in the interpretation of specific problems. This chapter describes the methodological background to the results, and considers the causes and sources of deterioration in the Late-glacial and postglacial sediments of the study area.

7.2 DEFINITIONS

DETERIORATED POLLEN was defined by Cushing (1964) as referring to corroded and degraded pollen (see definitions below). In this study the term also includes crumpling and splitting (cf. Birks, 1973).

DETERMINABLE DETERIORATED POLLEN refers to grains able to be referred to a taxon (cf. Appendix One). Within the dwarf shrubs deterioration frequently rendered identification to genus impossible, and the pollen taxon "*Empetrum*/Ericaeae undiff." represents these decomposed tetrad grains.

INDETERMINABLE DETERIORATED POLLEN are grains rendered unassignable to taxon.

Four categories of deterioration-type were employed in the study, referable to both determinable and indeterminable grains.

Their definitions largely follow Birks (1973), modified from Cushing (1964, 1967).

CRUMPLED grains are heavily folded, twisted, wrinkled or collapsed. No subdivisions were recognized, e.g., "crumpled and exine thinned" (Cushing, 1964, 1967) due to the subjectivity involved and the lack of resolution of such characteristics at the normal counting magnification of x400.

SPLIT or BROKEN grains are ruptured, gashed or broken in several pieces.

CORRODED grains show pitting or etching on the surface of grains, which closely resembles "perforation-type corrosion" (Andersen, in Havinga, 1964; p.632).

DEGRADED grains have their structural elements so altered as to be unrecognizable and amorphous. Major features, pori, colpi, remain distinct but the exine loses all definition: the entire grain is affected this way (cf. Cushing, 1964, 1967; Birks and Birks, 1980; Lowe, 1982). Degraded grains were more commonly considered indeterminable than other types due to the loss of surface sculpture, often crucial in identification.

WELL-PRESERVED grains show no or only slight deterioration.

A further category of indeterminable grains is CONCEALMENT, where grains are usually hidden by sediment. In sandy sediment occasional coarse mineral grains meant that the cover-slip could not be positioned close to the slide, and pollen grains could not be focussed upon. These were also classed as concealed.

UNKNOWN grains are indeterminable, but not deteriorated. Such grains were noted for examination, and only rarely after re-inspection or consultation did this category exceed 1% T.L.P. (3 - 4 grains per level), and are thus not considered further. No pre-Quaternary microfossils were found.

7.3 THE APPROACH TO THE ANALYSES

No hierarchical scheme of recording deteriorated pollen was adopted, in contrast to other workers (Cushing, 1967; Birks, 1973; Lowe, 1982). These authors regarded certain deterioration-types of more significance than others, such that, for instance, a corroded and crumpled grain would be recorded as corroded. The assumptions of relative importance this approach makes are, perhaps, unwarranted in the absence of research on the causes of deterioration and in the distortion of the proportions of characteristic deterioration in differing sediments and sites, which can result in a quite marked loss of information.

Alternative approaches have multiplied the number of categories to include most permutations of deterioration-type combinations. Delcourt and Delcourt (1980), for instance, have 23 deterioration classes in a non-hierarchical scheme. Although information loss is minimized, when applied to all terrestrial pollen grains (the Delcourts included only indeterminable grains) it would be laborious and time-consuming. Multiplying deterioration categories reduces the number of grains per category, and must hinder any statistical examination of trends in preservation.

This study employs only the categories defined above, grains being assigned on the dominant form of decay, as this reflects accurately the relative importance of all deterioration types.

Only grains within the pollen sum (T.L.P.) were assessed, although in important spores and aquatics a note was made of deterioration tendencies (cf. chap.4.4). In addition, *Juniperus* was not described because in pollen identification reference is commonly made to its characteristic splitting (e.g., Moore and Webb, 1978, plate 4d), and this is often the most recognizable feature. Bias towards splitting could therefore be expected. This approach is not unique, as both Birks (1973) and Cushing (1967) are selective in the taxa used in their analyses.

Table 2.4 clarifies the basis for calculation of the deterioration curves presented at the right hand side of the pollen diagrams in chapters 3 - 6. Diagrams in this chapter are explained below. In the analyses the sum of T.L.P. includes Juniperus for direct comparison with the pollen diagrams.

7.4 THE VALUE OF DETERIORATED POLLEN STUDIES

Researchers apply the results of deterioration studies in two principal ways; (a) as a check on the reliability of pollen spectra and diagrams, and (b) as an additional tool in the understanding of the sedimentological history of a pollen site.

(a) The first use is more conventional, and is based on the assumption that the fewer deteriorated grains (principally indeterminable) in a pollen spectrum the more likely will individual pollen percentages reflect the relative proportions of pollen deposited in the sediment. Totals of indeterminable pollen are presented with each pollen diagram (chaps. 3 - 6), where it can be seen that at five of the ten sites investigated levels of indeterminable pollen were less than 5% T.L.P. (+ indeterminable grains). At the remainder values were still relatively small; (averages of all levels at each site):

SITE (CHAPTER)	PERCENTAGE T.L.P. AND INDETERMINABLE GRAINS AVERAGE	MAXIMUM
PULPIT HILL (3)	9	19
LOCH BARNLUASGAN (3)	7	29
LON GLAS (4)	6	22
INVERLIEVER I (6)	7	20
INVERLIEVER II (6)	10	20

and at none of the sites is pollen preservation so poor as to question the palaeoecological interpretations. The deterioration categories at the sites listed above will be dealt with in a later section (sect.7.7b).

A slightly different but related problem in the interpretation of pollen diagrams is the recognition that losses of pollen to the indeterminable category influence the relative proportions of determinable taxa. Specific problems of this kind were encountered in this study at Na Lona Min (chap.4) where the fluctuating representations of *Dryopteris* and Polypodiaceae undiff. were explained by deterioration, possibly microbial attack, of the outer coat of the exines of *Dryopteris* grains during storage. This is thought to have resulted in the total loss of this perine and the subsequent resemblance of these grains to Polypodiaceae. In chap.6 the possibilities were discussed that Pinus percentages at Barachander I (sect.6.2c) were inflated due to the splitting of grains under the cover-slip. These examples are to an extent special cases induced by artificial conditions, but are nonetheless problematic.

(b) The palaeoenvironmental histories of particular basins have been enlightened by deterioration studies, such as inferring pollen re-deposition (Cushing, 1964; Birks, 1970) or Flandrian fluctuations in water tables (Lowe, 1982; Delcourt and Delcourt, 1980). In this study the deterioration counts have been used to suggest several phases of inwashing of material in the Loch Lomond Stadial at Pulpit Hill (chap.3), and were of particular value in showing the continued inwashing when lithological evidence was absent.

These results remain in many ways the most valuable and constructive uses of deterioration analyses, yet the number of such studies has been surprisingly few since Cushing's (1964) initial work. This is in part, no doubt, due to the fact that interpretations are far from straightforward, and considerable problems need to be overcome before interpretations become more than speculative.

7.5 PROBLEMS OF INTERPRETATION

(A) Subjectivity

Not all taxa suffer deterioration to the same degree, not all taxa are susceptible to all types of deterioration, and the same taxon may respond to one form of deterioration with varying intensities in different sedimentary environments. This point is enlarged upon below, but for a valid comparison of deterioration intensity the definitions of deterioration types (sect.7.2) would have to change for each taxon, such that what would pass as, for example, crumpled in a resistant grain would not be thus described in more susceptible taxa.

In fact, this is what with experience the analyst learns to do, and this element of subjectivity is essential. This flexibility has its weaknesses, however. It was suspected during counting, though could not be demonstrated, that the definition of, principally, mechanical deterioration (crumpling and splitting), tended to change as each new grain of a taxon was encountered. The definition becomes determined by a comparison with grains previously counted. This imperceptible change is of most importance in taxa with large numbers of grains, though it is unknown whether this leads to under- or over-estimations of damage.

(B) Differential Susceptibility

Experimental results have shown that taxa are susceptible to corrosion and degradation in varying degrees of intensity. No data are available for mechanical deterioration.

CORROSION

Table 7.1 lists the results of several experiments (Havinga, 1964, 1967) and observations (Havinga, 1964; Andersen, 1967) on corrosion susceptibility (columns 1 - 5, Table 7.2). It can be seen that all such lists show a degree of agreement, particularly at the opposing ends of the order of susceptibility, while the relative order can be modified according to the sediment-type (columns 4 - 5).

DEGRADATION

Uncertainties exist over the type of deterioration some researchers investigated. Elsik (1966), for instance, described "biological degradation" (p.515) but it is clear from microphotograhs illustrating his paper that the

TABLE 7.1

DIFFERENTIAL SUSCEPTIBILITIES TO (A) CORROSION AND (B)DEGRADATION (modified from Konigsson, 1969)

(A)					(B)		
1	2	3	4	5	6	7	
HAVINGA (1964)	HAVINGA (1964)	ANDERSEN (1967)	HAVINGA (1967)	HAVINGA (1967)	SANGSTER AND DALE (1964)	SANGSTER AND DALE (1964)	KEY
Lycopodium	*Lycopodium clavatum*		*Lycopodium clavatum*	*Lycopodium clavatum*			
							1
	Polypodium vulgare		*Polypodium vulgare*	*Polypodium vulgare*	-		Susceptibilities; derived from
							literature.
Conifers	*Pinus sylvestris*		*Juniperus communis*	*Juniperus communis*	*Pinus*		
							2
Tilia	*Tilia* spp.		*Taxus baccata*	*Taxus baccata*	*Ulmus*		Oxidation susceptibility,
							experimental results
Corylus	*Alnus*, *Corylus*	*Quercus*	*Quercus robur*	*Quercus robur*	*Quercus*		
							3
Alnus, *Betula*	*Betula*		*Salix* spp.	*Salix* spp.	*Corylus avellana*	*Pinus*	Corrosion in moss humus pollen
							spectra
	Carpinus betulus		*Fraxinus excelsior*	*Fraxinus excelsior*	*Betula*	*Ulmus*	
							4
Fagus	*Populus*, *Ulmus*, *Quercus*		*Populus* sp.	*Populus* sp.			Perforation-type Corrosion in
							river-clay soil after 20 months
Quercus	*Fagus*, *Fraxinus*		*Acer pseudo-platanus*	*Pinus sylvestris*		*Corylus avellana*	
							5
	Acer pseudo-platanus		*Pinus sylvestris*	*Acer pseudo-platanus*		*Quercus*	as(4); leaf mould
	Salix spp.	*Betula*	*Tilia* sp.	*Betula verrucosa*	*Fraxinus*	*Betula*	6
							Degradation in peat up to
		Tilia	*Betula verrucosa*	*Fagus silvatica*	*Salix*	*Fraxinus*	24 months
		Fagus	*Fagus silvatica*	*Carpinus betulus*	*Alnus*	*Salix*	7
							as (6), in pond sediment
			Carpinus betulus	*Alnus glutinosa*	*Acer*	*Alnus*	
							selected taxa
			Ulmus carpinifolia	*Tilia* sp.			
		Alnus	*Alnus glutinosa*	*Ulmus carpinifolia*		*Acer*	
		Corylus	*Corylus avellana*	*Corylus avellana*	*Populus*	*Populus*	

INCREASING SUSCEPTIBILITY

deterioration resembled perforation-type corrosion. Brooks and Elsik (1974) described the chemical oxidation of spores, and here the definitions are more confusing. From comments in this paper, e.g., "The exine wall material seems to be evenly removed" (p.85), "amorphous clumps of spore material" (p.87) and "general dissolution of the muri" (p.87) it appears very likely that degradation was being described, while the "pitting" they observed, although described as degradation, may be again perforation-type corrosion.

Sangster and Dale (1961) employed the term "decomposition" which is re-defined in 1964 as "faulty" grains which showed "any visible breakdown of either (or both) the cell contents and the exine" (1961; p.37). They seem not to observe corrosion as defined by Cushing (1964) or used in this study. Table 7.1 (columns 6 - 7), therefore, lists Sangster and Dale's (1964, Table IV) order of increasing susceptibility to, it is assumed, degradation *sensu stricto*, and it can be seen that quite marked differences occur between the susceptibilities of some genera to corrode or degrade. Nevertheless, differential susceptibility is still a major problem, and needs to be considered in the interpretation of pollen diagrams and the estimation of deterioration intensity.

(C) Sources of Deterioration

For all forms of deterioration there are three principal periods in which they can develop. These can be defined thus:

i syn-depositional or penecontemporaneous -

this is the period from pollen production to final burial within the sediment of a basin. Processes include all forms of pollen transport (Tauber, 1965; Peck, 1973; Bonny, 1976), residence on or within a soil prior to incorporation into sediment, including secondarily derived pollen, and includes processes of resuspension and re-deposition (Davis and Brubaker, 1973). Such mechanisms re-expose grains to contemporaneous processes, i.e., occurring during the deposition of sediment at the sediment-water interface, whereas final burial isolates grains from such effects. Initial incorporation into peats is included, where fluctuating water tables expose pollen to aerobic influence.

ii post-depositional or diagenetic -

burial, compaction and compression of sediment may advance deterioration in grains already decayed, e.g., Populus (Sangster and Dale, 1961; Cushing, 1964), while heat and pressure may induce new forms (Brooks and Elsik, 1974). Progressive pollen deterioration (Hall, 1981) is included in this phase (but see below).

iii sampling and preparation -

mechanical deterioration may be promoted during the chemical preparation technique; these techniques are known to affect the shape and preservation of grains (Faegri, 1971), as is the mounting medium (Praglowski, 1970) and the emplacement of cover-slips (Cushing, 1961; this study). Storage of cores may expose the sediment to renewed fungal or microbial attack (this study; sect.4.2).

Pollen deterioration can originate in any or all of these phases. Faegri (1971) considered most decay would come from penecontemporaneous processes. Cushing (1967) demonstrated with Pinus and Picea grains that phase iii is important, but was undecided as to whether the changes were gradual and continuous, or occurred in discrete periods. Lowe and Walker (1977) regarded most deterioration to be penecontemporaneous, from inwashing due to high solifluctial rates in the Lateglacial. Lowe (1982) distinguishes contemporaneous processes, broadly those of phase i (above), but would regard enhanced corrosion and physical damage through lowering of water-tables as diagenetic. The difficulties of assigning deterioration to particular phases is shown by Lowe's (1982) discussion of basin-edge collapse and re-deposition of buried pollen, which he would regard as non- contemporaneous. Having once been buried, any further change would be diagenetic by the present author's definition, but the complexity of the interpretation is apparent, and it may be that we will never isolate deterioration phases in grains which undergo polyphase deformation.

Hall (1981) introduced the concept of "progressive pollen deterioration" in arguing for continuous and increasingly intense deterioration to the point where "all or nearly all of the grains have been destroyed" (p.195). He cites as evidence the apparent relation between increasing numbers of indeterminable grains with decreasing pollen concentrations down-profile at archaeological sites in south-west U.S.A. The term might be thought more valid if (a) pollen influx rather than pollen concentration declined with depth (for several sites Hall has good C14 control, yet declines to use pollen influx), thus removing doubts as to sedimentation rates, and (b) the same pattern of increasing deterioration with depth could be shown in determinable taxa also. At present the evidence for progressive diagenetic decay is not convincing.

The best clues as to the origins of deterioration come from an understanding of their causes (below), though here also the evidence is not clear cut, and is totally lacking for some deterioration types.

7.6 CAUSES OF POLLEN DETERIORATION

A) MECHANICAL DETERIORATION

Crumpling and splitting can occur in all phases, and are probably not indicative of any particular process. Peck (in Birks, 1970, 1973, p.338) observed qualitatively a high proportion of crumpled grains in stream-transported sediment. Lowe (1982) suggested that macrofaunal ingestion may increase breakage. Praglowski (1970) showed how facets of the chemical preparation technique, e.g., viscosity and speed of solidification of the embedding medium (when relevant, i.e., glycerol) and the ease with which the medium can fill a grain and resist inward pressure on the grain from the medium, affect crumpling, while Cushing (1964, 1967) was confident in assigning breakage in conifer pollen to the preparation technique, although crumpling was not thought increased.

B) DEGRADATION

Cushing (1964, 1967) and Birks (1970) considered degradation to have a mechanical origin given its association with minerogenic sediment and the lack of correlation between orders of susceptibility to corrosion and degradation (Table 7.1). Faegri (1971) also tentatively inferred from Cushing's and Birks' data that burial time may be an element also. Faegri (1971), however, states that one important component in diagenesis, high temperature, has little effect on sporopollenin.

C) CORROSION

There is general consensus among workers that Havinga (1964, 1967) successfully defined the conditions necessary for corrosion as, principally, aerobic conditions, with high biological activity in the form of microbes or fungi. Faegri (1971) considered that enzymic attack on sporopollenin is not significant, but concedes that Havinga's results strongly suggest this biochemical alteration to be vitally important. Havinga (1967) suggests that the observed differences in intensity of corrosion between different environments is due to different types of micro-organisms.

7.7 RESULTS OF THE ANALYSES

This section is in three parts. First, several lines of evidence will be described which together represent an evaluation of errors induced during sampling and preparation. The second section briefly describes the representation of deterioration types of indeterminable grains at the five sites where the grains were present in some quantity (sect. 7.4). In the final section the main body of data on determinable grains is analysed and discussed.

A) ERRORS INDUCED DURING SAMPLING

A low-viscosity non-solidifying embedding medium (silicone oil; cf. Andersen, 1960) was used, an auto-stirrer was preferred to glass rods (although comparison of a few slides at Pulpit Hill One showed no difference in preservation between these techniques), and following Praglowski's (1970) and Faegri's (1971) suggestions that certain chemical treatments enhance decay, all samples were treated uniformly (chap. 2.4).

(1) Ailanthus Deterioration

During routine pollen concentration counting at

Pulpit Hill Two and Loch Barnluasgan (chap. 3) a tally was kept of deterioration trends in the introduced <u>Ailanthus elegantissima</u> pollen.

Counts of 100 <u>Ailanthus</u> grains before incorporation into sediment resulted in a total deterioration level of 48%, of which 14% was crumpled and 34% was split. (Table 2.1).

Following preparation, percentages of well-preserved <u>Ailanthus</u> grains and deterioration-types were as follows:

SITE	no of spectra	WELL-PRESERVED	CRUMPLED	SPLIT
PULPIT HILL TWO	28	79.6+/-3.4	5.0+/-1.8	15.4+/-2.3
LOCH BARNLUASGAN	20	87.0+/-5.1	3.6+/-1.6	9.4+/-3.7

Only one grain (Loch Barnluasgan; 766 cm) was corroded.

The better preservation at Loch Barnluasgan is borne out by determinable deteriorated pollen analyses (sect. 7.7C). Increased deterioration cannot be demonstrated on this basis, (but see below). Fig. 7.1

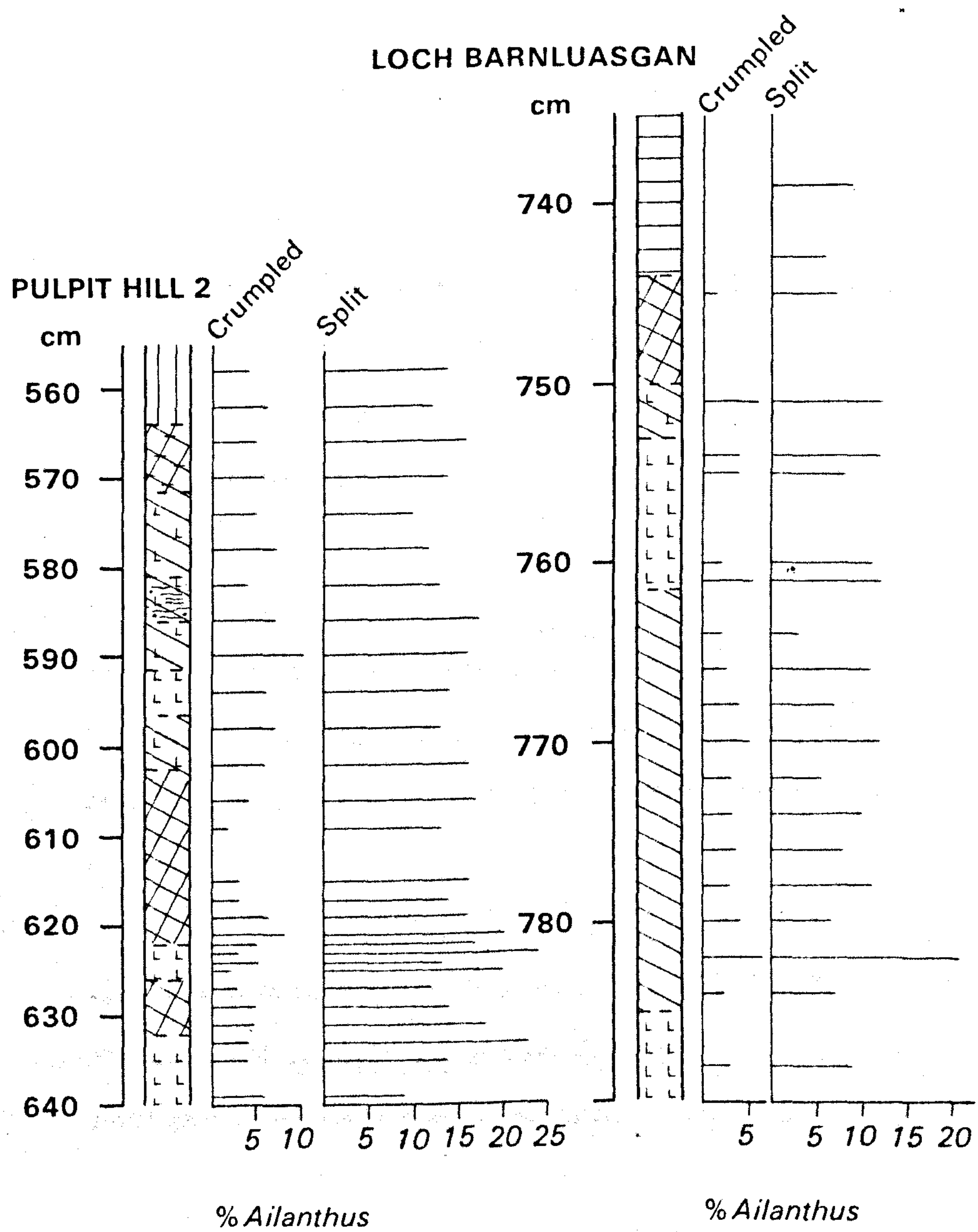
shows that for Loch Barnluasgan deterioration bears little relation to sediment type, and this uniformity is to be expected if derived from either the initial stock or from enhanced deterioration through the preparation technique. The results from Pulpit Hill Two surprisingly show some relation between deterioration intensity and sediment type (fig.7.1), particularly in low values for crumpling in interstadial gyttja (605 - 619 cm) and, less clearly, high values of split grains in clays between 640 - 630 cm and 626 - 622 cm.

It may be that deterioration is increased during preparation, not only by stirring alone but also by abrasion and physical wear in minerogenic sediments. Ailanthus, with its thick exine (avge. thickness = 1.6 μm (n = 30) should be regarded as resistant to mechanical damage, and other subfossil grains may be more susceptible to this process.

(2) Pinus Deterioration

During counting many Pinus grains were seen to be broken in two, and the high frequency with which both parts could be seen in the same field of view at x 400 led to the realization that cover-slip pressure

Fig. 7.1 *AILANTHUS* Deterioration Patterns



had ruptured these grains. In these cases both parts had to be counted as separate grains to maintain consistency with broken grains where this relationship was not apparent.

In section 7.7C evidence is presented which suggests that any syn- or post-depositional deterioration is so accentuated during preparation as to obscure any trends related to, for instance, lithology, and confirms Cushing's (1964, 1967) suggestion that conifer pollen does not reflect environmentally imposed deterioration trends.

(3) Other Observations

i/ A case is made in section 7.7C that at many sites Cyperaceae pollen, and less frequently Gramineae, reflect the overriding influence of the preparation technique.

ii/ The probable deterioration, biological, chemical or physical, of Dryopteris grains during six months cold storage has already been discussed (chap. 3).

iii/ Probable increases in corrosion following the preparation technique have been observed, notably at Pulpit Hill One at 762 cm depth. Here two slides were required to reach the pollen sum (300 T.L.P.), but corrosion in this spectrum (5%T.L.P.) was derived almost exclusively from only one slide, the second, prepared some time after the first. Oxidation may have occurred by either an inadequate application of cover- slip sealant (nail-varnish) allowing seepage of air under the cover-slip (although corrosion was not noticeably higher towards the edge of the slide), or from partial drying out of the sample within stoppered sample tubes between slide preparations.

B) INDETERMINABLE GRAINS

(1) Deterioration Categories

Fig. 7.2 combines the results of counts of indeterminable deteriorated grains for the five sites mentioned in sect. 7.4, breaking the totals down to separate deterioration-types:-

Mechanical Deterioration - the diagrams show that, as with determinable deteriorated grains (sect. 7.7C), the highest amounts are broadly associated with minerogenic sediment.

Corrosion - in most cases indeterminable and determinable grains agree in their increased representation in

Fig. 7.2 Indeterminable deteriorated grains

(A) PULPIT HILL 1

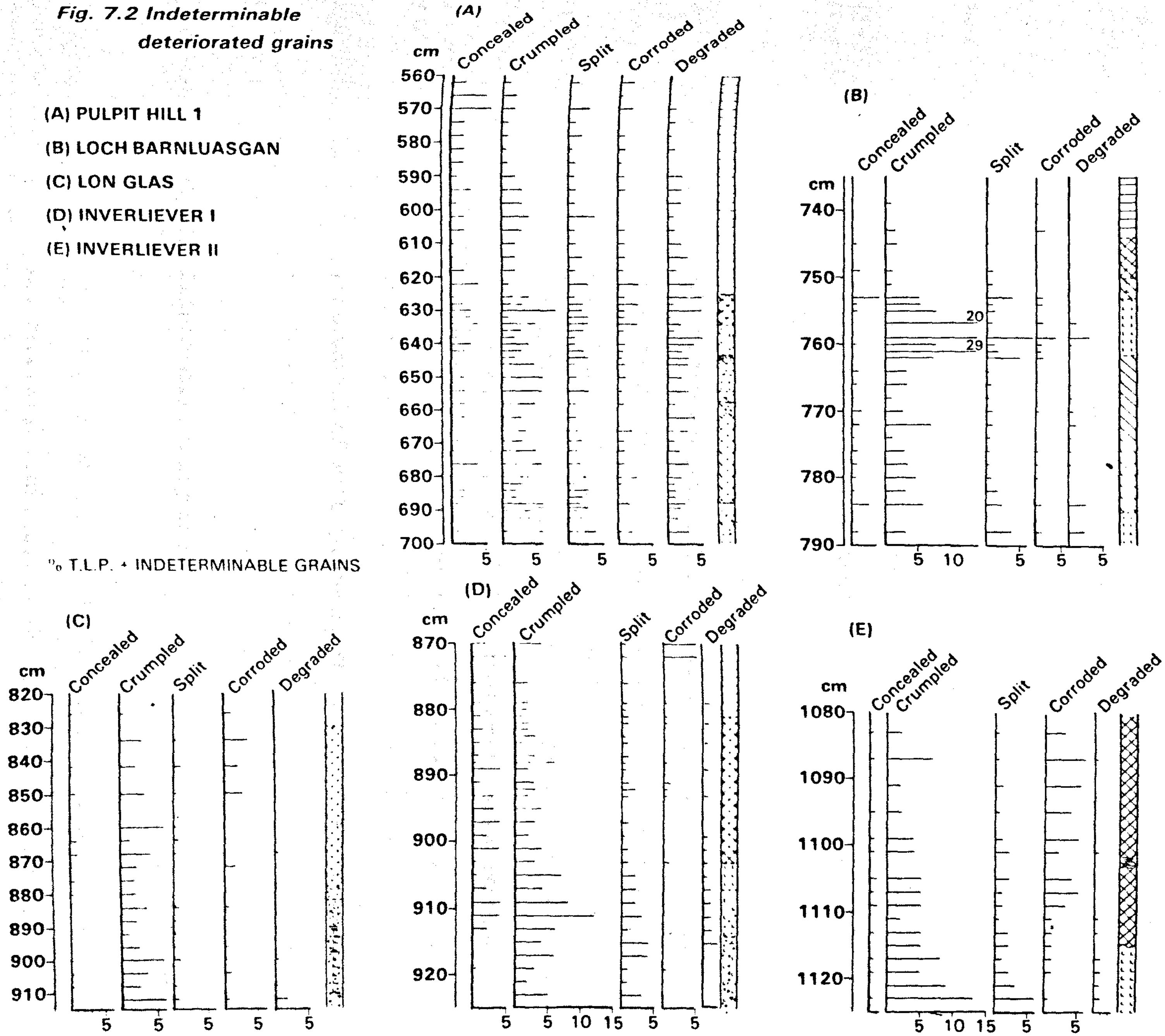
(B) LOCH BARNLUASGAN

(C) LON GLAS

(D) INVERLIEVER I

(E) INVERLIEVER II

% T.L.P. + INDETERMINABLE GRAINS



organic sediment.

Degradation - at all sites these grains are more common in these diagrams than in determinable deteriorated diagrams, the principal reason being the complete loss of identifiable elements on grains thus deteriorated. With the exception of Pulpit Hill One (fig. 7.2A) where no clear pattern is apparent, the diagrams show the clear association of degraded grains and minerogenic sediment.

Concealment - this category is determined by the success of the preparation technique (Cushing, 1967), but only at Inverliever I (fig. 7.2D) is there the expected correlation with lithology, the highest numbers of concealed grains being found in gyttja and coarse minerogenic sediments, both lithologies having separate problems in preparation; abundant coarse organic matter not destroyed during acetolysis in the former, and the persistence of silt grains after HF acid treatment in the latter.

(2) Differential Recognition

It is known that the indeterminable category does not receive pollen from the determinable category in any order of susceptibility to deterioration. Whether a deteriorated grain can be determined to taxon or not depends much more on the clarity of diagnostic features. Thus, highly deteriorated Pinus grains can be recognized as such in nearly every instance, while other grains, notably in this study, small trizonocolpate grains, could not be keyed to species or genus even though commonly only slightly distorted.

C) DETERMINABLE GRAINS

(1) Introduction

For each pollen site a deteriorated pollen diagram has been constructed for determinable grains (figures 7.3 - 7.12). With a number of early postglacial sites (chap. 6; figures 7.8 - 12) deterioration trends and intensities could be compared. For this reason the anomalous pollen diagram from Ford II (chap. 6) was not included for deteriorated analysis, and the discussions will include only the postglacial sequences at Na Lona Min (above 224 cm; fig.7.6) and Lon Glas (above 912 cm, fig. 7.7)

For each site a SUMMARY DIAGRAM showing the relative proportions of well-preserved to deteriorated grains, and the proportions of deterioration-types, is presented.

The principal innovation is the use of DETERIORATION RATIO DIAGRAMS for T.L.P. and major taxa. The taxa chosen are strongly represented at nearly all sites, and in various combinations account for the overwhelming majority of all determinable deteriorated grains. These are *Betula*, *Pinus*, *Corylus*, *Salix*, Gramineae and Cyperaceae, plus *Rumex* and combined counts of *Empetrum* and Ericaceae undiff., excluding the deteriorated dwarf shrub category, *Empetrum*/Ericaceae, dealt with separately (fig. 7.5 and text). Where one or more of these taxa are insignificant components of the pollen diagrams (i.e., < 5% T.L.P.) they are excluded.

A deterioration ratio (D.R.) for T.L.P. and each taxon is calculated for every level where grains are recorded, and is simply:

$$\frac{\text{grains per taxon}}{\text{deteriorated grains per taxon}} = \text{d.r.}$$

As a guide, a ratio of 1.0 means all grains were deteriorated, and a ratio of 2.0 indicates that half the grains were altered. The validity of a ratio increases with the number of grains used in calculation, and a weakness of any measure of this kind is the undue emphasis (either very high or very low d.r.'s) shown in spectra of low representation, hence the depiction of grains per taxon against each d.r. on the diagrams. Given that the taxa illustrated contribute most to total deterioration, some degree of auto-correlation can be expected between T.L.P and major taxa, but in the impersistent nature of individual pollen curves through the Lateglacial and early post-glacial it can be shown (sect. 7.8) that no one taxon influences the deterioration intensity of T.L.P. throughout a profile.

All d.r.'s for each taxon (including T.L.P.) registering some deterioration (i.e., excluding spectra showing d.r.'s of 0) are combined to produce a mean deterioration ratio ($\bar{x}$ d.r.) at a site, against which individual spectra are plotted, emphasizing trends to increasing deterioration ($< \bar{x}$ d.r.) or better preservation ($> \bar{x}$ d.r.). By necessity this calculation will include anomalous d.r.'s, but this cannot be avoided if an estimate of deterioration intensity for the entire profile is to be gained. Selection of spectra with only large numbers of grains would naturally bias the result and mean towards the sediment-type or deterioration-type typical of that taxon's peak representation. For the majority of deterioration ratio diagrams trial recalculation of the mean excluding anomalous spectra had very little effect.

The mean deterioration ratios are measures of total deterioration susceptibility. These are listed in Table 7.2 where each taxon is ranked in order of decreasing susceptibility. An overall mean from all sites for each taxon is also calculated. Fig. 7.13 shows the variation around each $\bar{x}$ d.r. These results are discussed fully below.

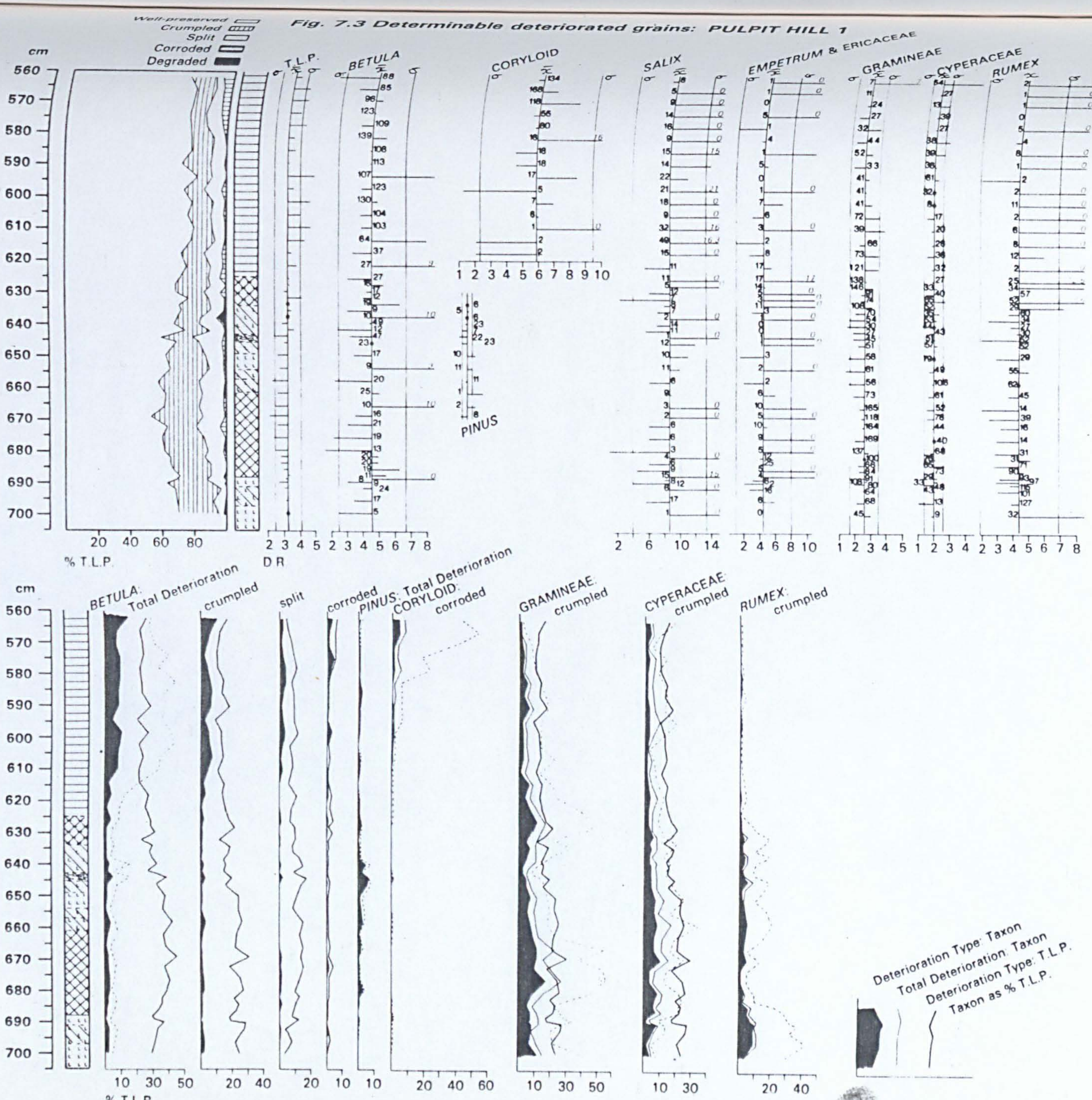
The important deterioration categories for each major taxon are illustrated by "sawtooth" diagrams. Each one follows a conventional pattern (figs. 7.3 - 7.12).

(2) Results from Individual Sites

(A) PULPIT HILL ONE (fig.7.3)

Despite the "complacency" of the deterioration

Fig. 7.3 Determinable deteriorated grains: PULPIT HILL 1



record (chap. 3) the T.L.P deterioration ratio diagram clearly shows a pattern of $> \bar{x}$ deterioration below 640 cm, a transition phase of spectra fluctuating around the mean, and subsequently above 620 cm, close to the appearance of fen-peat at 625 cm, markedly better preservation. No similar improvement in preservation is seen in the interstadial gyttja. The pattern here reflects a general decrease in all deterioration-types.

Mechanical deterioration dominates the summary diagram, with major contributors being Gramineae, Cyperaceae and Rumex below 620 cm, with rising Betula values. Crumpling generally exceeds breakage, except in Cyperaceae. Like Pinus, sedge d.r.'s show no trend resembling that for T.L.P., and the very low $\bar{x}$ d.r. (2.0) and small standard deviations suggest that the preparation technique may have obscured palaeoenvironmental trends.

Salix and dwarf shrubs contribute little to total deterioration due to low representation and resistance to deterioration (high d.r.'s): however, the high d.r.'s reflect the low pollen counts, and little reliability can be placed on these taxa at this site. The same lack of pattern affects _Betula_, despite higher numbers of grains, and the erratic spectra continue when the plant is thought to have been growing around the site. With low numbers of pollen small fluctuations can produce pronounced swings in deterioration intensity, but the same feature above 620 cm is not clearly explicable.

Corrosion is not significant in the summary diagram; _Betula_, and less frequently, Gramineae, contribute all such grains below 620 cm. The limited expansion above 580 cm is not related to any change in lithology, but to the expansion of _Corylus_. Degradation is derived dominantly from indeterminable grains (sect. 7.7B).

The change to better preservation appears not to be determined by a decline in percentages of one or more susceptible taxa, as grasses remain well-represented while total deterioration declines, and this may be of environmental significance. Reduced mechanical deterioration may be seen as the result of lessened abrasion in organic sediment, and may indicate a diagenetic origin for part of the high totals in minerogenic sediment (see discussion; sect. 7.8).

(B) PULPIT HILL TWO (fig.7.4)

Several features show a close comparison with Pulpit Hill One, as would be expected from the same basin. Comparable features include uniformity of deterioration, low representation of corrosion and a similar trend from, firstly, mean T.L.P. deterioration to improving preservation in the early post-glacial. The T.L.P. deterioration ratio diagram from P. H.One has been recalculated using spectra below 620 cm for direct comparison with P. H.Two, and both diagrams are closely similar. The basal 20 cm shows a very close correlation with sediment-type, with reduced preservation in the clays. Also at P. H.Two the trend to greater deterioration (below 2.0) in the interstadial commences above the point at which a climatic deterioration is interpreted from the pollen diagram (local p.a.z. B/C boundary: chap. 3.2 vii). This is not the case at P. H. One however. If, as claimed at P. H.One, organic sediment would not lead to high mechanical damage in diagenesis, the increasing amounts of crumpling are likely to be syn-depositional, and may reflect continued inwashing through the interstadial. This is almost certainly too simplistic an interpretation, but the trend to increasing d.r.'s occurs in local pollen zones

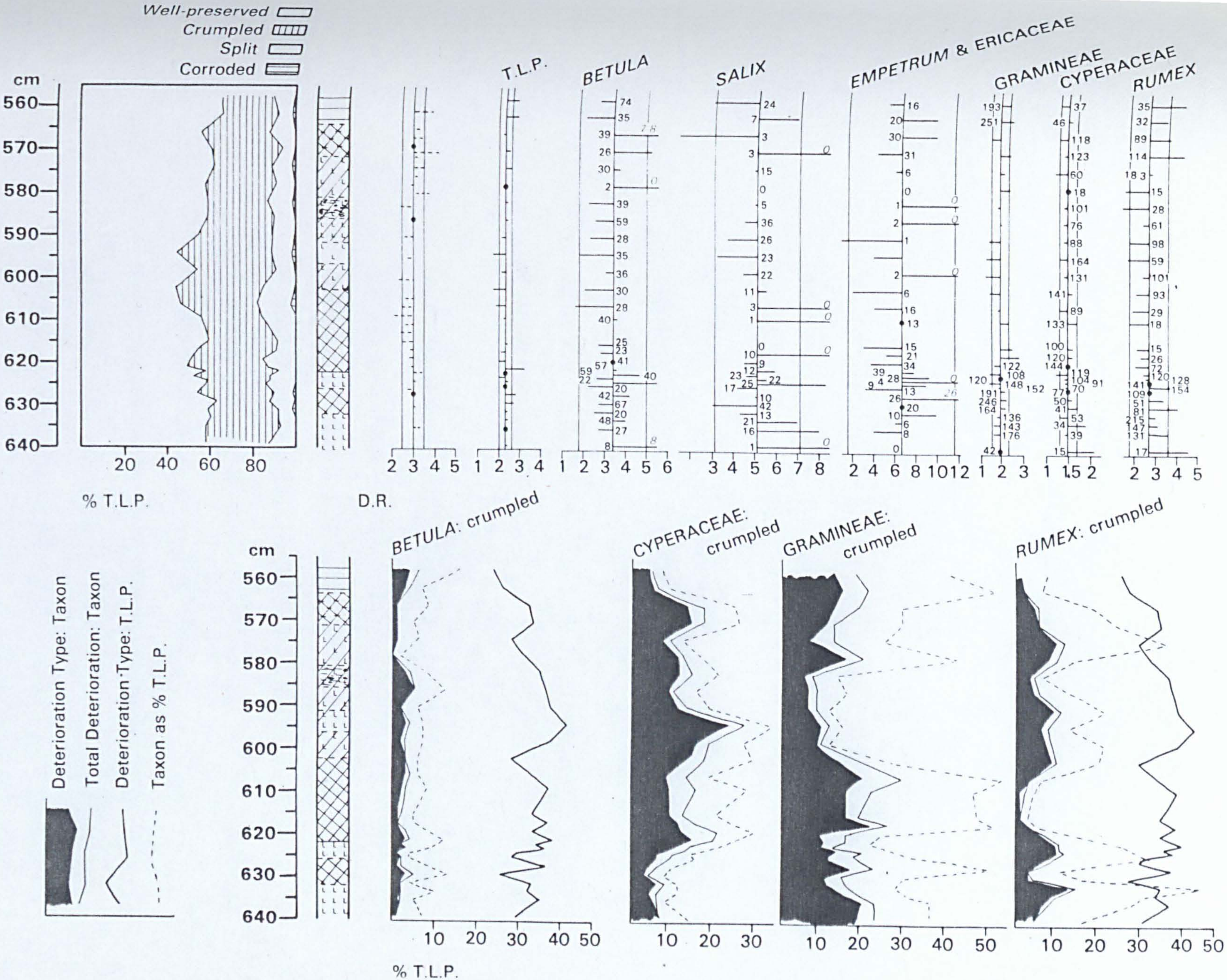


Fig.7.4 Determinable deteriorated grains: PULPIT HILL 2

above the Loch Lomond Stadial at both pollen sites, although deterioration intensity is not greater in these clays.

Degradation is insignificant at P H Two in contrast to P H One. Later (sect. 7.8B) it will be suggested that this largely reflects the analyst's inexperience in over-assessing its role at P H One. The major contrast in T.L.P $\bar{x}$ d.r., 3.3 at P H One, 2.3 at P H Two, may be explained this way, and it is plausible to suggest that the differing estimations of deterioration are a result of an increasing appreciation of mechanical breakdown characteristics.

Individual taxa relate closely to P H One. Betula, generally better-represented at P H Two is correspondingly more consistent above 620 cm, and is strongly deteriorated through crumpling in the late interstadial and stadial. One puzzling feature is the diachronous trend of taxa to $<\bar{x}$ d.r.'s in the interstadial, with Rumex at 622 cm, Betula at 606 cm, and Gramineae at 601 cm. It is this accumulation of deteriorated pollen that "tips the balance" in the T.L.P. deterioration ratio, yet whether the origin of this increased mechanical deterioration is diagenetic or penecontemporaneous, the most highly susceptible taxon shows a delayed response, which is curious.

(C) LOCH BARNLUASGAN (fig.7.5)

Correlation of major deterioration trends in T.L.P. d.r. with lithological changes is very strong, with d.r.'s <2.0 in the stadial clay. While the summary diagram depicts a pronounced rise in crumpled grains, and the deterioration ratios of Betula, Ericaceae and Gramineae mirror the deterioration levels of T.L.P., their pollen contribution is low, and the majority of crumpled grains are from Cyperaceae and Pinus. Their d.r.'s do not show any major increases in deterioration, however. An overall increase in deteriorated pollen does not explain the stadial values, therefore, but simply an increase in numbers of two highly susceptible taxa. A general increase in deterioration does, however, seem reasonable in the response of other taxa (above).

Pinus and Cyperaceae again show no discernible trends, and the very restricted range in spectra and low $\bar{x}$ d.r. are again taken to indicate deterioration at the preparation stage. Salix and Rumex show total

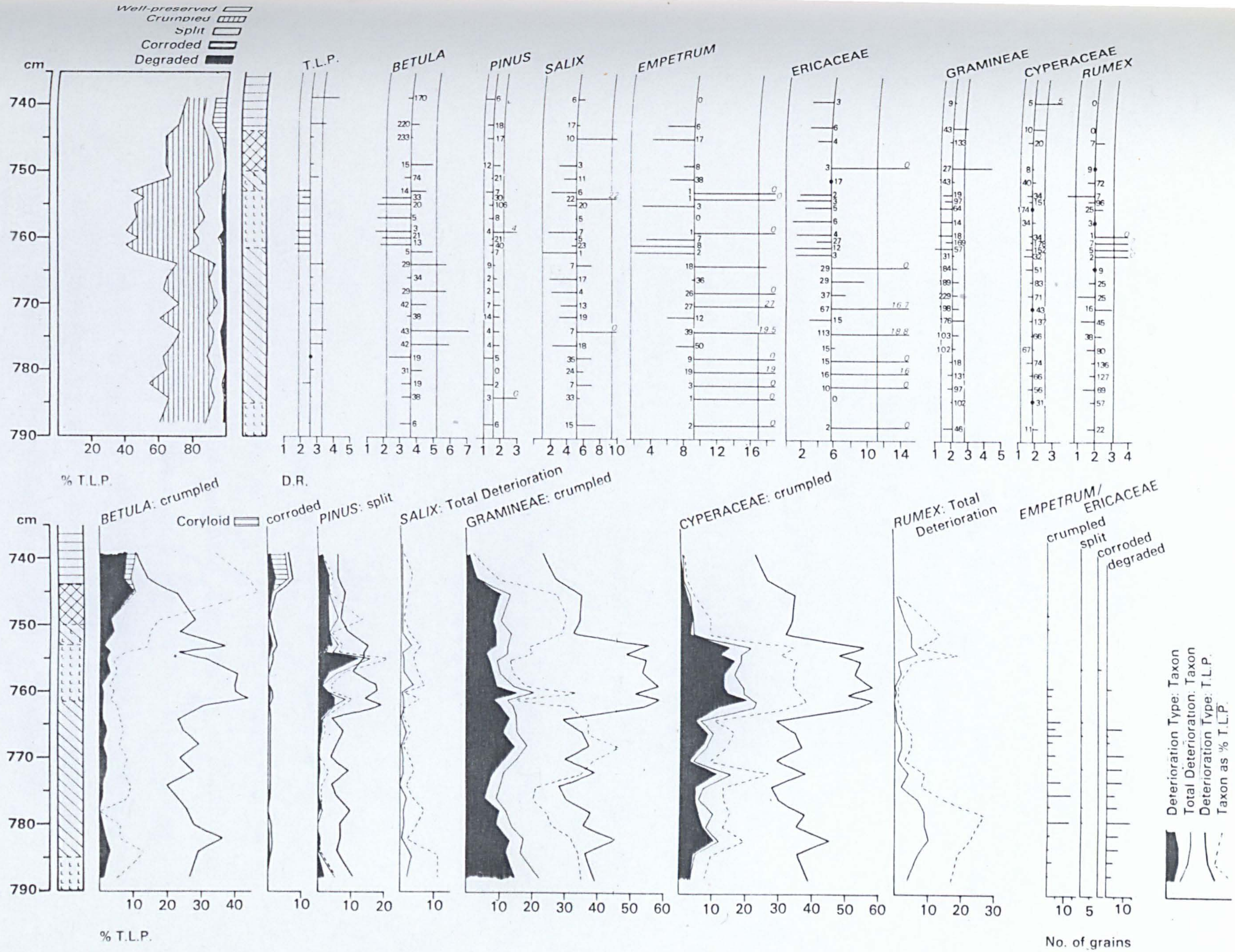


Fig. 7.5 Determinable deteriorated grains: LOCH BARNLUASGAN

deterioration curves which show little response to fluctuations in the pollen curve, so that as the pollen representation declines in the interstadial deterioration ratios become lower with the unchanging representation of deteriorated grains. This pattern suggests that the deteriorated pollen was not a part of penecontemporaneous Salix and Rumex pollen deposition. Syndepositional deterioration should reflect pollen deposition, while post-depositional changes should promote a reduction in deteriorated pollen in common with the T.L.P. trend, and it may be that the deteriorated grains are inwashed, having their origins in the basal local p.a. zone (chap. 3.3) when both taxa are relatively more abundant. Grass grains would also be represented, but in the expansion of Gramineae in the interstadial would be an insignificant proportion, and thus not recognized.

Improved preservation in the interstadial seems general, not specific to a particular taxon, as is the case with the post-glacial improvement in preservation also, although the top two spectra are dominated by only two taxa, Betula and Corylus. Such strong links between preservation and lithology suggest that diagenetic changes are paramount in mechanical deterioration.

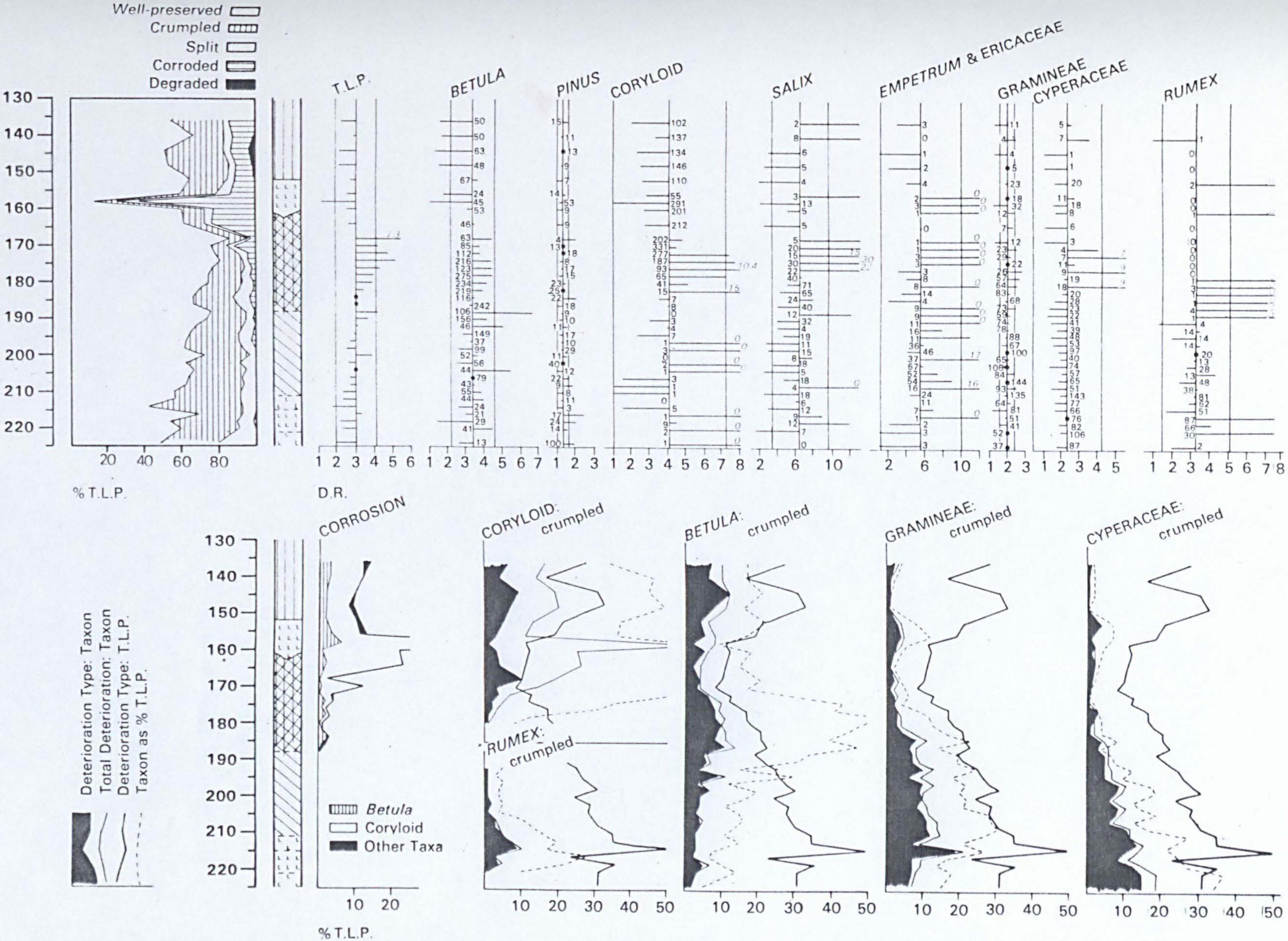
Corrosion, probably penecontemporaneous in its requirement for aerobic conditions, is prominent only in _Betula_ and _Corylus_, and below 750 cm in single grains of grass and, very rarely, of Cyperaceae and _Rumex_. Degraded grains are found in these same taxa, and in the same proportions, being much more common in birch and hazel grains.

(D) NA LONA MIN (fig.7.6)

The trend from poor to good preservation (T.L.P. d.r.) accords well with the sedimentological change from minerogenic to organic sediment, but a sharp reversal of this trend occurs at 165 cm where corrosion becomes very pronounced, and for one spectrum approaches 65% T.L.P.

Between 225 and 165 cm the improving preservation is related to declining mechanical deterioration, but it is clear that this trend is determined by declining percentages of Gramineae and Cyperaceae, and as at Loch Barnluasgan, the summary diagram is misleading in its suggestion of increasingly well preserved spectra. Cyperaceae are predominantly $< \bar{x}$ values (even following recalculation excluding levels 180, 176, 172 cm), while

Fig. 7.6 Determinable deteriorated grains: NA LONA MIN



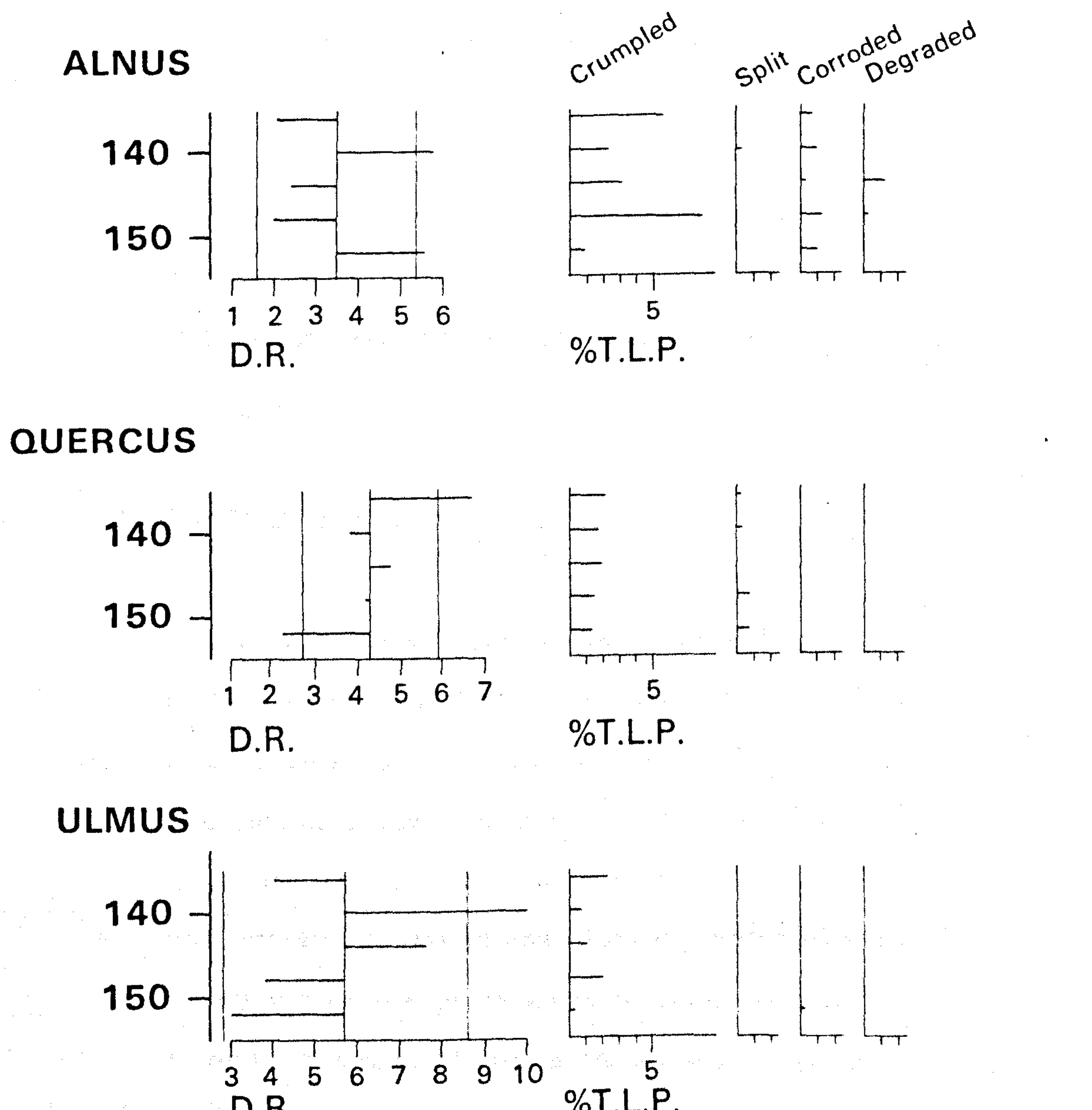
Gramineae show no trend, have a very restricted spectral range around a mean which is lower than the sedges (only one of two sites where this occurs; table 7.3). Whether at this site grass pollen has been affected by the preparation technique is unknown.

Betula and *Corylus* interestingly show no clear trends until it is inferred the genera were growing within the catchment. This is unlikely to be the result of low pollen totals as even when of regional origin *Betula* pollen is well-represented (*Corylus* markedly less so). It is suggested that this erratic pattern indicates the complex pathways of deposition of these long-range types (cf. Konigsson, 1969).

The T.L.P. d.r.'s show no auto-correlation with any major taxon, but show that the sum response below 165 cm is to improving preservation. Above 165 cm the T.L.P. values become more dependent on *Betula* and *Corylus*, and the summary diagram increasingly reflects the influence of a few taxa. The change of T.L.P. d.r.'s to increasing deterioration stems from the rise in corrosion. *Betula* contributes nearly all such grains below 165 cm, and the expansion above 165 cm cannot be explained by the sudden appearance of one highly susceptible taxon, Corylus being prominent from 180 cm onwards. No change in sediment-type is seen, and it is uncertain to what this rise in corrosion can be attributed . The sediment is essentially an organic mud, but frequently peaty, and a lake-margin/prograding marsh is envisaged at this time. Local water tables are seen to fluctuate in the overlying lacustrine clay (chap.4), but whether the increased corrosion is the result of lowered water-tables is unknown. As a marsh extends into a lake it is cut off from inwashing from soil, and so re- deposition from soils or basin-edge collapse is not suspected. The further enormous increases come almost solely from Corylus, and here increased run-off and temporary flooding could, perhaps, account for the increases. Alternatively, corrosion within river clays is noted to be much more pronounced than in peats (Havinga, 1967), and the differing degrees of preservation may be expressed here.

Within the fen-peat above 152 cm corrosion becomes subordinate to crumpling once more. The reason lies, at least in part, in the rise of tree genera. Fig. 7.6a shows their contribution, particularly to crumpling, and the comparatively high susceptibility of Alnus, notably

Fig. 7.6a Tree Genera: Na Lona Min



to corrosion, can be related to Table 7.2. The erratic appearance of d.r.'s in fig.7.6a is partly determined by occasional low counts, but perhaps also reflects again the processes of deposition operating on long distance-transported grains.

The small peak of degraded grains, which does not correspond in this instance to high corrosion values, is related to particularly susceptible taxa, <u>Betula</u> and <u>Corylus</u>.

(E) LON GLAS (fig.7.7)

A tripartite T.L.P d.r sequence of high - low - high deterioration (as at Na Lona Min and for very similar reasons) is here correlated with lithological boundaries. Changes in dominant deterioration types (summary diagram) also do not relate to sediment-types, due to the close correspondence of deterioration - type to specific taxa, so that they alter as the taxa fluctuate in the local and regional vegetation.

The decrease in mechanical deterioration is thus due to the decline of heavily deteriorated Gramineae and Cyperaceae grains. As has been argued for <u>Pinus</u>, the very high deterioration susceptibility of these taxa limit their

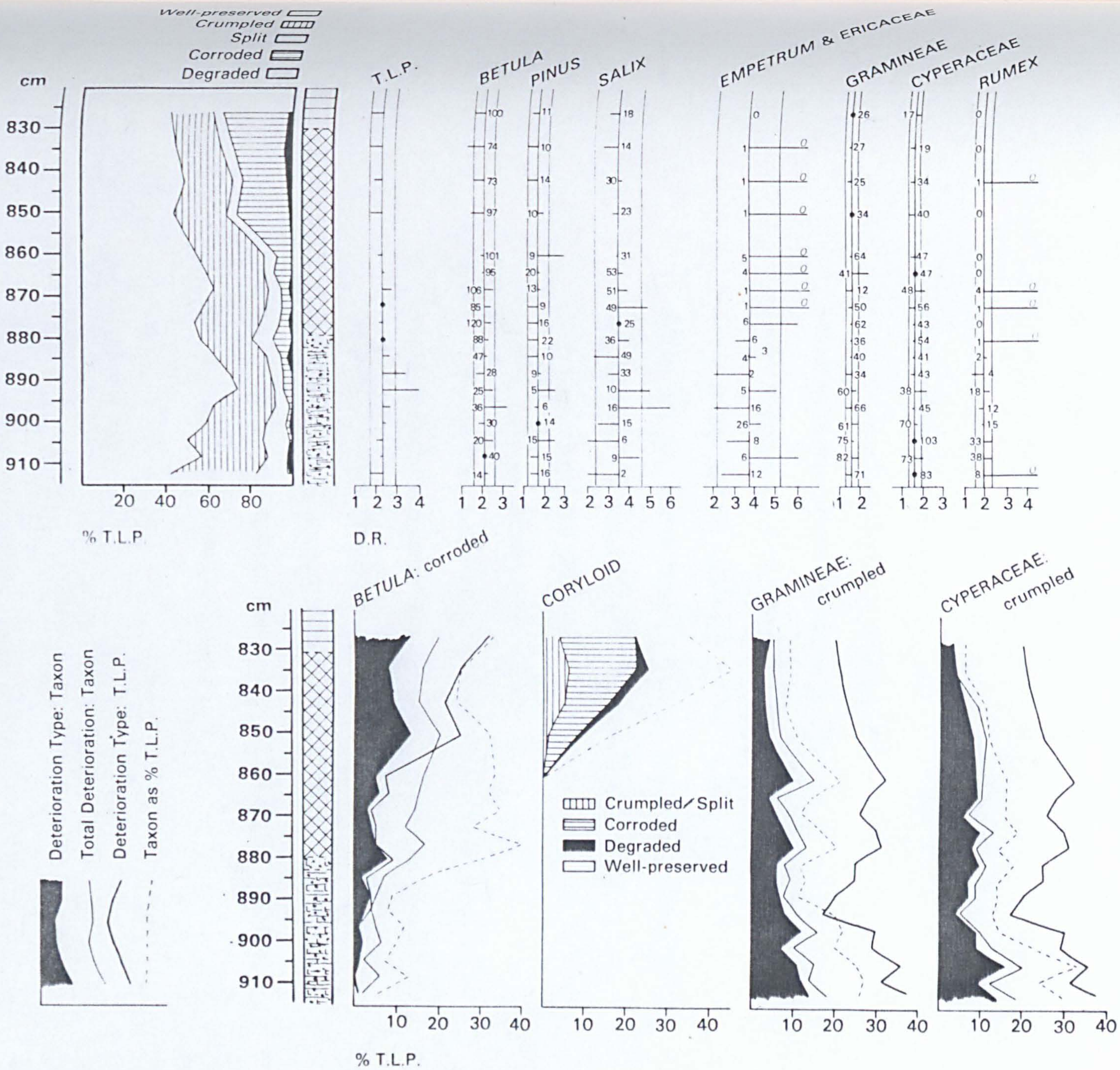


Fig. 7.7 Determinable deteriorated grains: LON GLAS

value in determining palaeo-environmental trends. Above 892 cm grasses and sedges maintain consistent values, as do crumpling (25 +/- 4.6 % T.L.P.) and splitting (6 +/- 1.8 % T.L.P.) , both determinable and indeterminable (Fig. 7.2c), and perhaps these taxa also contribute most to the indeterminable category.

Several patterns in deterioration ratio and type noted at other sites recur here, for instance, the limited range of taxa susceptible to corrosion, principally birch, with low frequencies of Gramineae below 860 cm, above this corrosion in Corylus accounting for between 50 and 60 % of all coryloid grains. Likewise, degraded grains only occur with any consistency in these three taxa.

Again the d.r's of Betula behave without any clear pattern where birch is not thought to have been present locally (below 880 cm), although more consistency is seen in these spectra at this site. These fluctuations in birch do not appear dependent on the pollen sum or particular deterioration types.

(F) FORD I (fig. 7.8)

From consistently poorly preserved T.L.P spectra in minerogenic sediments there is no 'transition' of spectra approaching the mean, but instead a sharp break

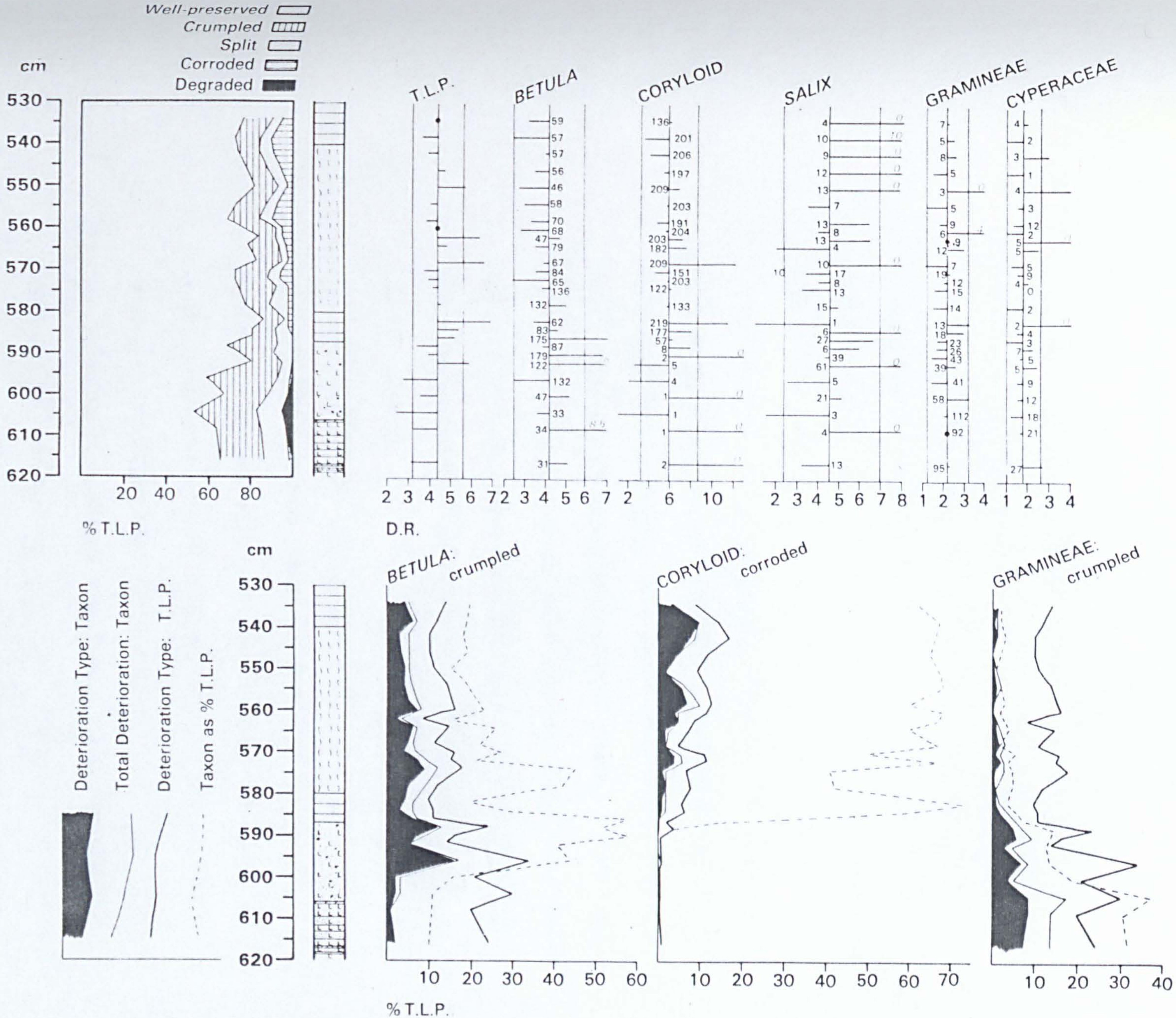


Fig. 7.8 Determinable deteriorated grains: FORD I

to values equally as high above as those preceding were below it.

With the sedges poorly represented, the principal contributor to the spectra with high deterioration values was Gramineae. The $\bar{x}$ d.r. for T.L.P is quite high at 4.4, and deterioration is not intense. Again there is little pattern in the Gramineae d.r's, but its generally higher deterioration ($\bar{x}$ = 2.2) influences T.L.P deterioration until percentages decline. The peakedness of the curve for crumpled grains (summary diagram) can be attributed to Betula, the other major contributor at this time, as the genus established itself in the area.

Degradation is restricted to minerogenic sediments, principally from indeterminable grains, while Betula, Gramineae and deteriorated dwarf shrubs contribute single grains.

Within the peat Corylus and Betula determine deterioration trends. Remarkable uniformity in total deterioration and type are seen in these taxa and in the summary diagram, though whether this is due to the dominance of these taxa or the uniformity of the peat stratigraphy is unknown. The T.L.P d.r's are thought auto-correlated with Corylus. The somewhat inconsistent totals for Corylus pollen produces the fluctuating pattern of the T.L.P d.r's. Corylus contributes all but an average 1 % T.L.P to the corrosion curve, birch being the other major contributor, but as a percentage of each species, Corylus is only slightly more susceptible :

corroded Betula = 3.3 +/- 2.4 % total Betula

corroded Corylus = 5.6 +/- 3.3 % total Corylus.

Corrosion of pollen is not as intense as at Na Lona Min, despite clear lithological evidence for sub-aerially accumulating sedge-peat growth. Corrosion in Betula appears to respond to this change in sediment, but the response of Corylus is difficult to interpret as it expands in total at this boundary, and increases in corrosion may be due to the presence of a highly susceptible taxon rather than to lithological influences.

(G) INVERLIEVER I (fig. 7.9)

The relation between T.L.P deterioration ratio and sediment-type is more marked here than at other sites, and as at Loch Barnluasgan, superficially suggests a strong post - depositional control of deterioration.

The basal three spectra are anomalous in this respect, but are partly influenced by the importance in the pollen record (fig. 6.5) of the resistant Salix, and partly by peaks of long-distance transported Betula,

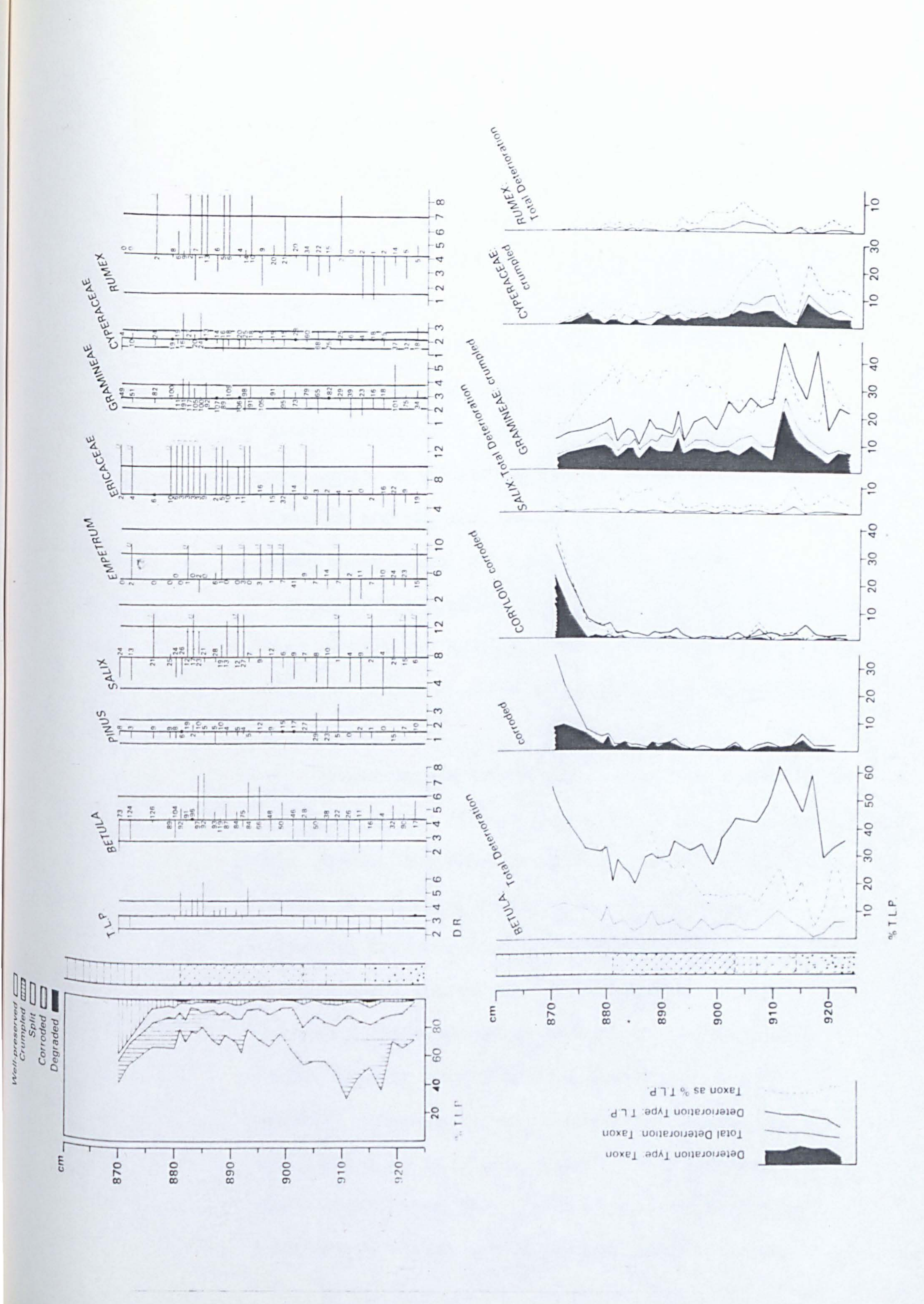


Fig. 7.9 Determinable deteriorated grains: INVERLIEVER I

which in being derived from aerial 'pollen rain' need not be subject to penecontemporaneous deterioration through pedological processes.

Between 918 and 902 cm Betula, although still of regional rather than local origin, is consistently more highly deteriorated in contrast to its inconsistent patterns elsewhere, and with the same trend to higher deterioration being seen in other major taxa (e.g., Salix, Gramineae and Rumex), post-depositional abrasion and physical damage is likely in the coarse sandy silty clays. The same response is seen in indeterminable grains (fig. 7.2d). Further evidence seen clearly in the summary diagram is the sharp drop in crumpled grains at the onset of pure clay deposition at 907 cm.

Greater preservation above 902 cm can also best be explained by the limited tendencies of gyttja to abrade and crumple. The final revertence to high deterioration is due to increases in corrosion. The lithological change at this point may be coincidental as Corylus again expands dramatically at the same depth, and corrosion increases may be determined by this taxon rather than by aerobic or sub-aerobic peat growth, although increases in Betula corrosion suggest the peat development to be of some importance. The observation that at two sites, Ford I and Inverliever I, Corylus percentages expand as the sediment changes to peat is of uncertain significance. The low values for indeterminable corroded grains (fig. 7.2c,d) do not indicate that differential preservation of Corylus is being depicted, and this feature may be coincidental, as mentioned above.

(H) INVERLIEVER II (fig. 7.10)

The tripartite sequence seen in the T.L.P d.r diagram is a now familiar pattern at post-glacial sites. In the summary diagram the sequence is (i) high but declining mechanical deterioration at the base of the diagram, (ii) improved preservation in the overlying gyttjas, and (iii) increasing corrosion, determined at Inverliever II by the susceptible taxa, Betula and Corylus and not by lithological changes.

Of interest is the uniformity of deterioration intensity between 1106 and 1092 cm, seen in T.L.P.,Betula, Gramineae and Cyperaceae, particularly in the herbs, which show a pronounced consistency in the relative proportions of deteriorated grains. The consistency of deterioration ratios in Betula is difficult to interpret, but appears to represent a balance betwen declining mechanical deterioration and increasing corrosion. The absence of clear trends in deterioration in the major herbaceous taxa and in Pinus

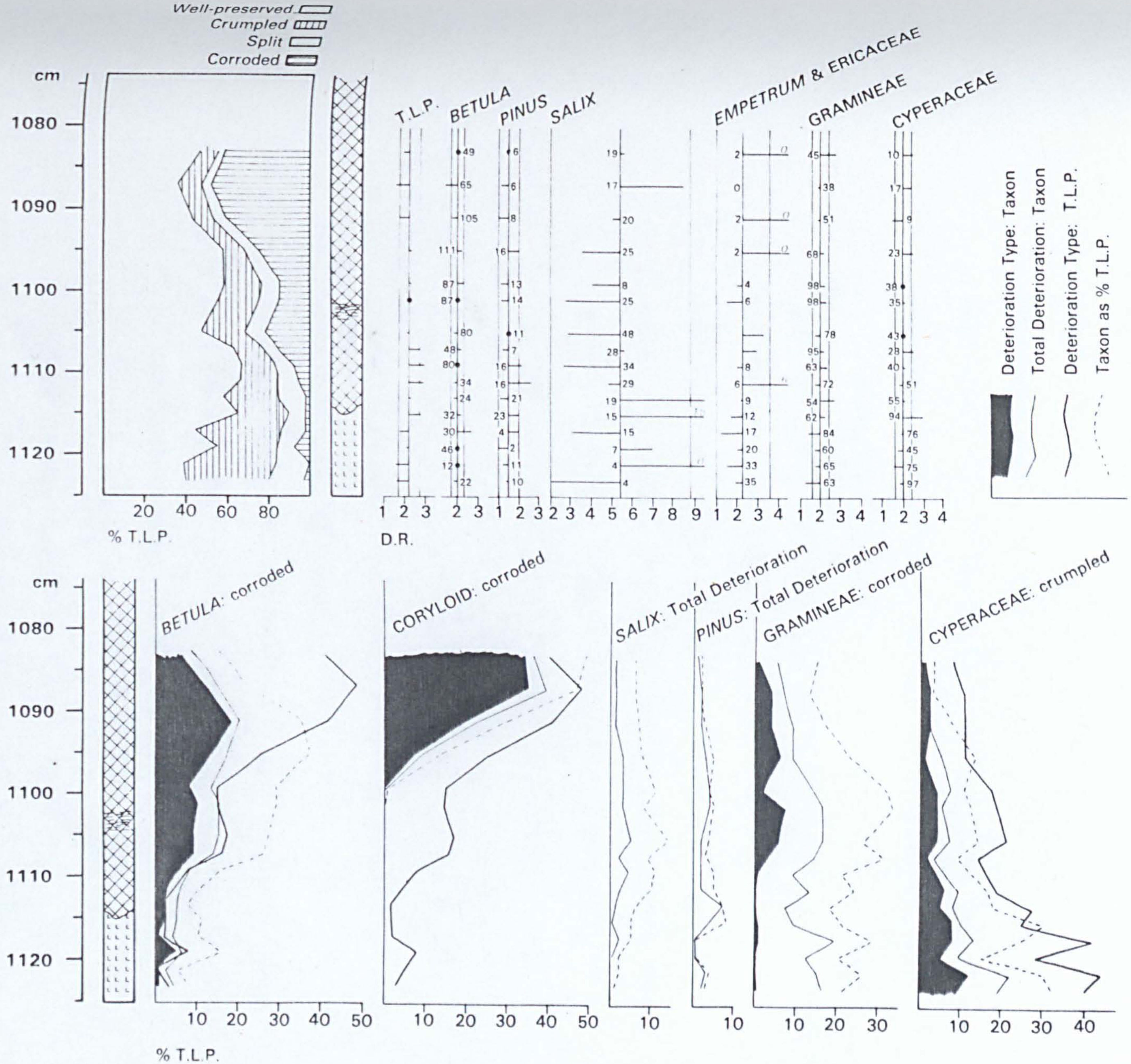


Fig. 7.10 Determinable deteriorated grains: INVERLIEVER II

have been explained as reflecting the influence of preparation techniques, and this seems likely where sedimentological changes are marked but d.r's consistent. At this site the same feature may be expressing the uniformity of syn-depositional or diagenetic processes in an unchanging sediment-type.

Corrosion is evident continuously from the basal spectrum. In limnic sediment at a depth of 11 metres it is most unlikely that this reflects non - contemporaneous alteration. The curve for Gramineae shows much higher corrosion levels than at other sites, as does that for Corylus, the latter approaching the high proportions seen at Na Lona Min. This pattern contrasts strongly with that from Inverliever I (although Betula's behaviour appears similar), even though processes of sedimentation are thought to have been virtually identical. In chap. 6.2B it was suggested that the sedimentation rate was slower at Inverliever II, which perhaps implies a longer residence time on or in developing soil-profiles around the basin, but this difference cannot be solely responsible for the differences in corrosion. (see later ; sect. 7.8).

One final puzzling feature which suggests that processes of deterioration were not the same between the Inverliever sites is the high level of deterioration in the normally non-susceptible Salix, while other taxa show no increases. Given this it is doubtful if this feature is the result of diagenetic mechanisms as proposed for Inverliever I. Presumably this increased mechanical deterioration is penecontemporaneous, but what it signifies is unknown.

(I) BARACHANDER I (fig. 7.11)

The prolonged minerogenic sequence containing nearly all the peaks of the important early postglacial vegetational components makes this site particularly interesting.

Corrosion is insignificant, with the curves for birch and Gramineae contrasting with those from Inverliever II, although Corylus is strongly represented in only two spectra (excluding contaminant grains). Degradation, distinctive in the minerogenic sediments below 950 cm is related to Betula and Corylus, with indeterminable grains contributing single grains.

Corylus at this depth was thought derived through contamination from overlying sediments (chap. 6.2), and if so then the degradation must either have been syn- or post-depositional (in which case its association with minerogenic sediments need not be diagnostic), or the degradation occurred during the chemical preparation, which is thought unlikely.

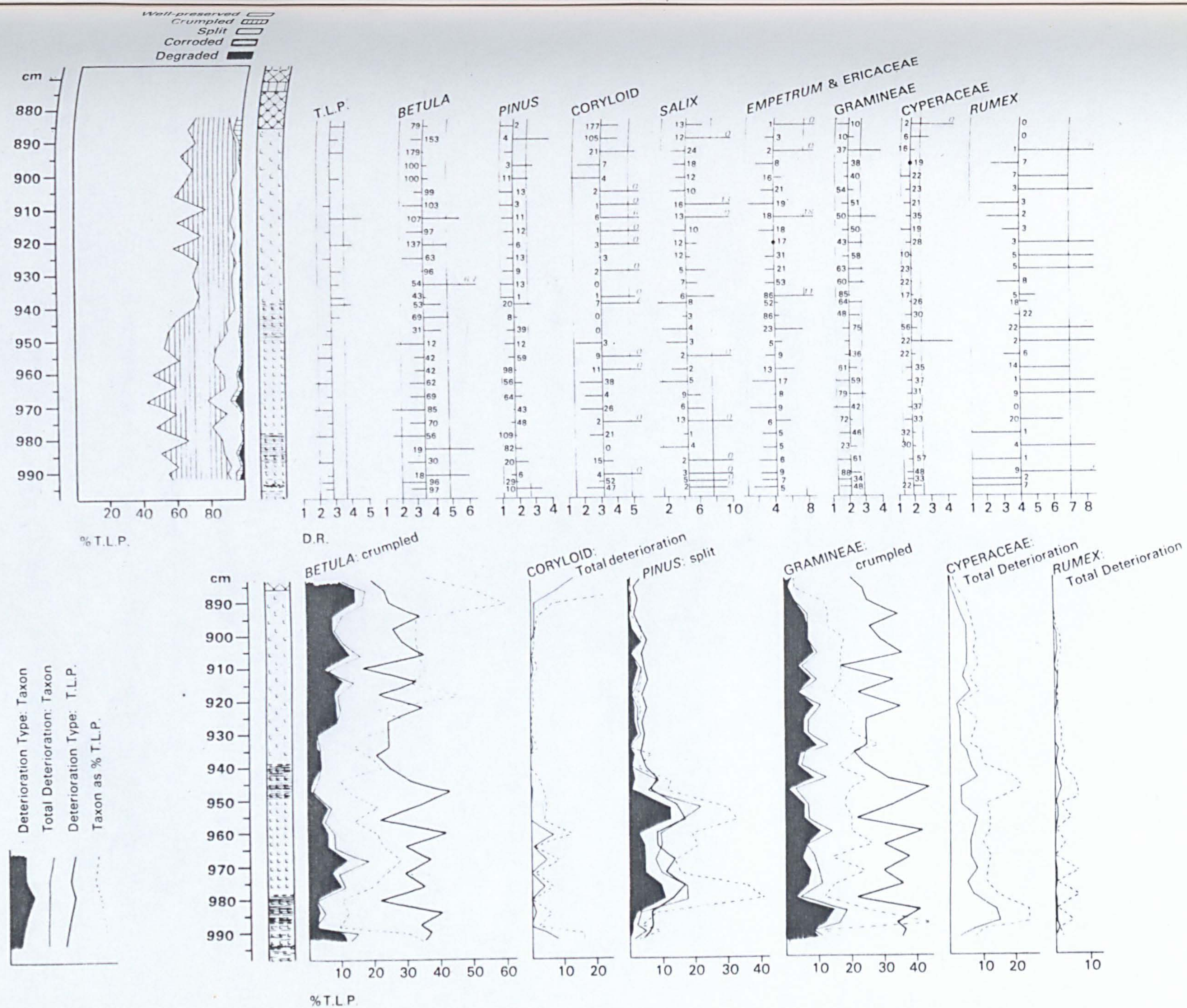


Fig. 7.11 Determinable deteriorated grains: BARACHANDER I

In chap. 6.2c the alternating peaks of Corylus and Rumex were thought to be the result of statistical suppression of Rumex by contaminant hazel. The deterioration diagram supports this interpretation. Rumex' total deterioration is very consistent, though low, and shows no response to the percentage peaks, while Corylus peaks show a major response in all deterioration types, and so the coryloid peaks can be seen to be from actual increases in pollen, while the Rumex 'troughs' of low representation are statistically induced.

The change to better preserved spectra at 940 cm is determined not by sedimentological changes but by the decline in percentages of Pinus, which appears highly susceptible to mechanical deterioration. Again, however, Betula and Gramineae also show a general move tobetter preserved grains at this time, suggesting that this improvement in preservation is of a general nature.

(J) BARACHANDER II (fig. 7.12)

The decline in mechanical deterioration (summary diagram) that produces the gradual change to better preservation at 800 cm is generated by a general trend in all major taxa, and is not clearly seen in any single deterioration ratio diagram. Gramineae and Cyperaceae

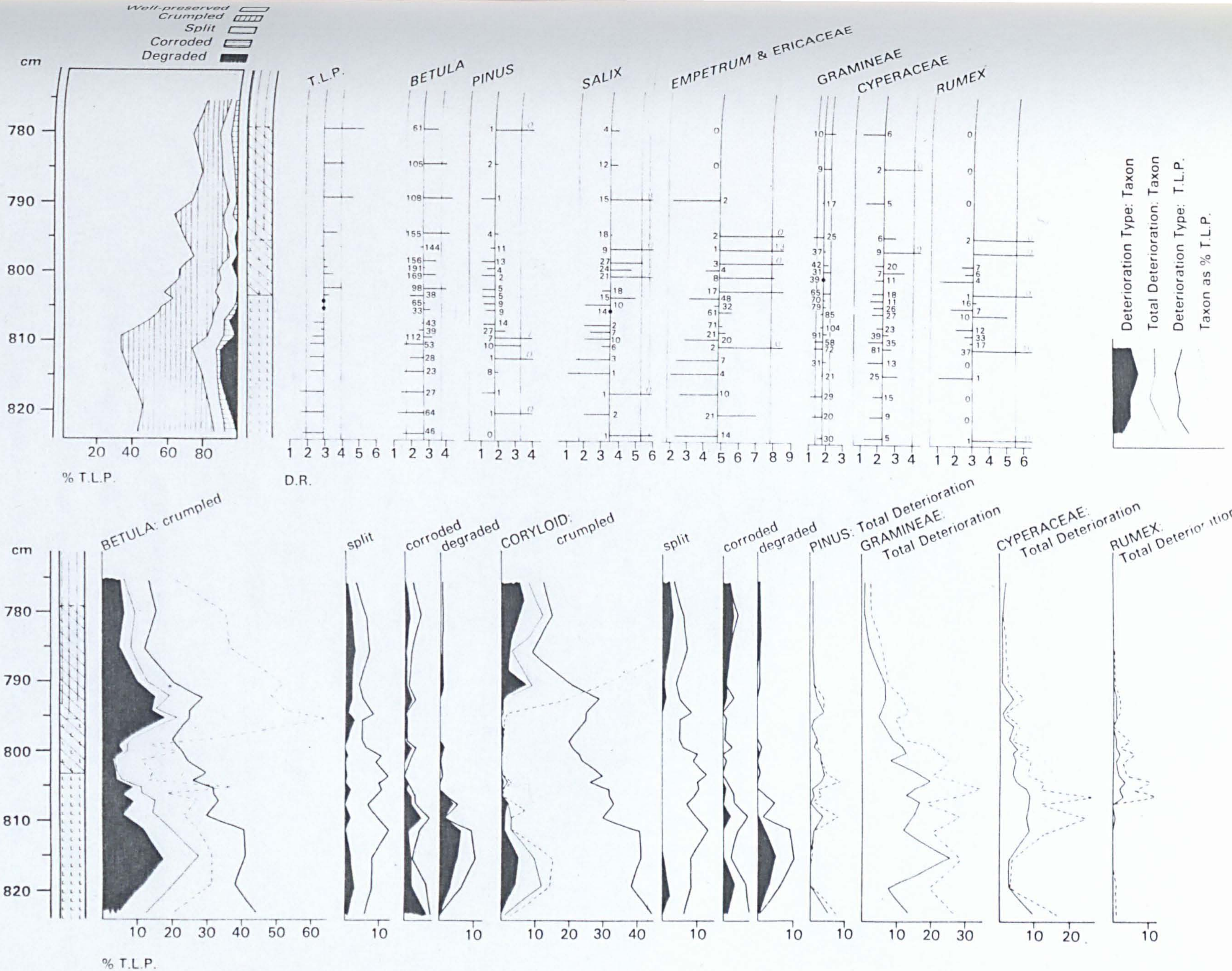


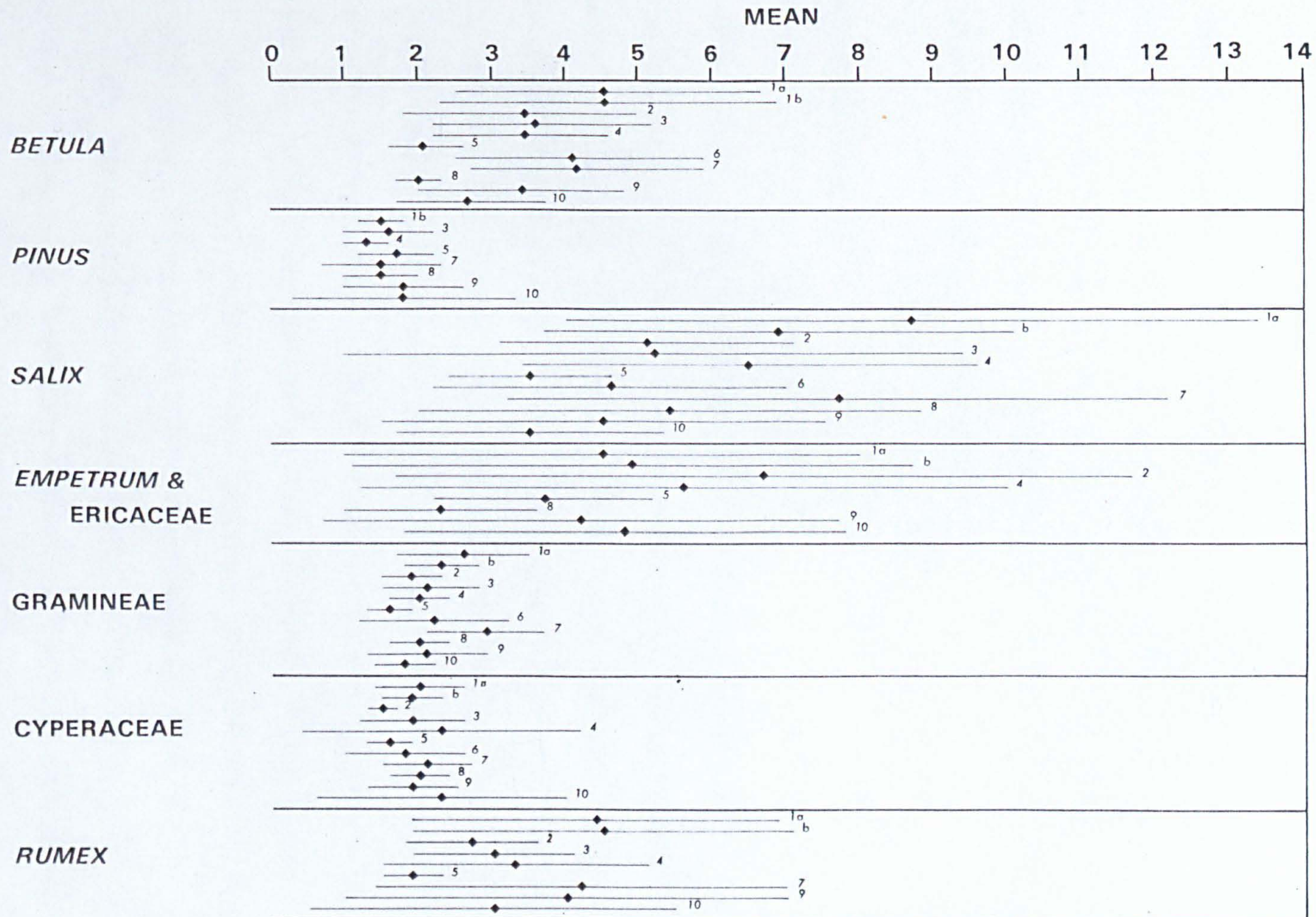
Fig. 7.12 Determinable deteriorated grains: BARACHANDER II

decline in percentages, though not in deterioration intensity so that their d.r's do not change. The two taxa perhaps show the effects of preparation technique deterioration.

High amounts of deteriorated contaminant hazel and birch are present below 805 cm. These genera contribute nearly all corroded and degraded grains. When these taxa attain percentages high enough to signify local presence in the catchment degradation is no longer significant, emphasizing the importance here of minerogenic sediment. If the majority of these grains below 805 cm are contaminant the degradation almost certainly originates in the preparation technique. If the interpretation of contamination (chap. 6.2c) is wrong, and long-distance transport is responsible the degraded grains may conform to the influences of diagenetic derivation suggested for other sites. However, there is evidence (chap. 6.2c) that at least part of the high proportion of trees and shrubs in these basal spectra is contaminant, which has implications for the origins of degradation in pollen.

Corrosion in these minerogenic limnic sediments is largely related to birch and hazel, and is assumed to be penecontemporaneous. Above 790 cm _Corylus_ is a major taxon, yet corrosion only reaches 5% T.L.P in sediment and inferred environment of deposition akin to Na Lona Min, with that site's large representation of corroded grains.

Fig. 7.13 Variation in mean deterioration ratios



Key to site numbers, see Table 7.3

7.8 DISCUSSION

The discussion of these results will concentrate on the validity of using the deterioration ratio measure, the order of total deterioration susceptibility deduced from this measure, and evidence derived from the investigations for causative factors in the types of deterioration described.

A/ DETERIORATION RATIOS

The use of a ratio illustrating relative intensities of deterioration is new to such analyses. The T.L.P deterioration ratio is regarded as successful in detecting significant changes in deterioration intensity, particularly where these are difficult to discern from the purely graphic summary diagram. In this way the strong association of deterioration intensity and lithological change has been effectively demonstrated at several sites,while equally importantly at other sites these changes have been shown to be independent of sediment-type. Although in a few instances (Loch Barnluasgan, Barachander I) auto-correlation with one particularly dominant taxon was suspected, at the majority of sites these phases were seen to be reflected in other taxa also, so that a general trend was essentially only emphasized by the dominant taxon.

The principal reasons for the successful employment of the d.r measure are undoubtedly the consistently high pollen sums at each site. Individual taxonomic d.r.'s are weakened by varying pollen totals. Although the ratio measure should give equal weight to all spectra, so that low pollen sums should not influence the interpretations, a ratio of 10 calculated on a sum of 100 is of considerably more significance than the same ratio where one grain of ten is deteriorated. This weakness unfortunately affects the interpretation of most taxonomic deterioration ratio diagrams.

Nevertheless, the trends seen in the deterioration ratio diagrams have been employed in an interpretative sense, and seem to draw some interesting conclusions. Firstly, comparison of all d.r. diagrams for major taxa quickly establishes whether T.L.P trends to increased deterioration are general or confined to one particular taxon. A general trend suggests that the phase of deterioration affected the pollen assemblage as a whole, and indicates a diagenetic origin for the pollen alteration. When specific to one taxon it might suggest that the deterioration occurred independent of the pollen assemblage in which the pollen-type is incorporated.

Secondly, with regard to the three most highly susceptible taxa, *Pinus*, Gramineae and Cyperaceae, it was proposed that the mechanical deterioration suffered by these taxa derives from the chemical preparation procedure. The deterioration characteristics of these three taxa, e.g., very low mean d.r's, small standard deviations very close to and fluctuating around the mean, show no relationship to T.L.P trends or lithology. It appears that any trends imposed on these grains from syn-depositional or diagenetic deterioration are obliterated or 'overprinted' by increased crumpling and splitting affecting all spectra during pretreatment.

Thirdly, grains of such taxa as Betula and Corylus which, because of their consistent pollen totals were regarded as of long -distance origin, exhibited rather erratic deterioration ratios (not generally induced by low pollen sums), which became a discernible pattern only when the taxa were considered to be locally growing. This is thought to be related to the different pathways of incorporation into the sediment of such long-range transported grains. These pollen grains can fall on the catchment soils before incorporation, or directly from aerial pollen 'rain', and the fluctuations may simply reflect the differing proportions from each source.

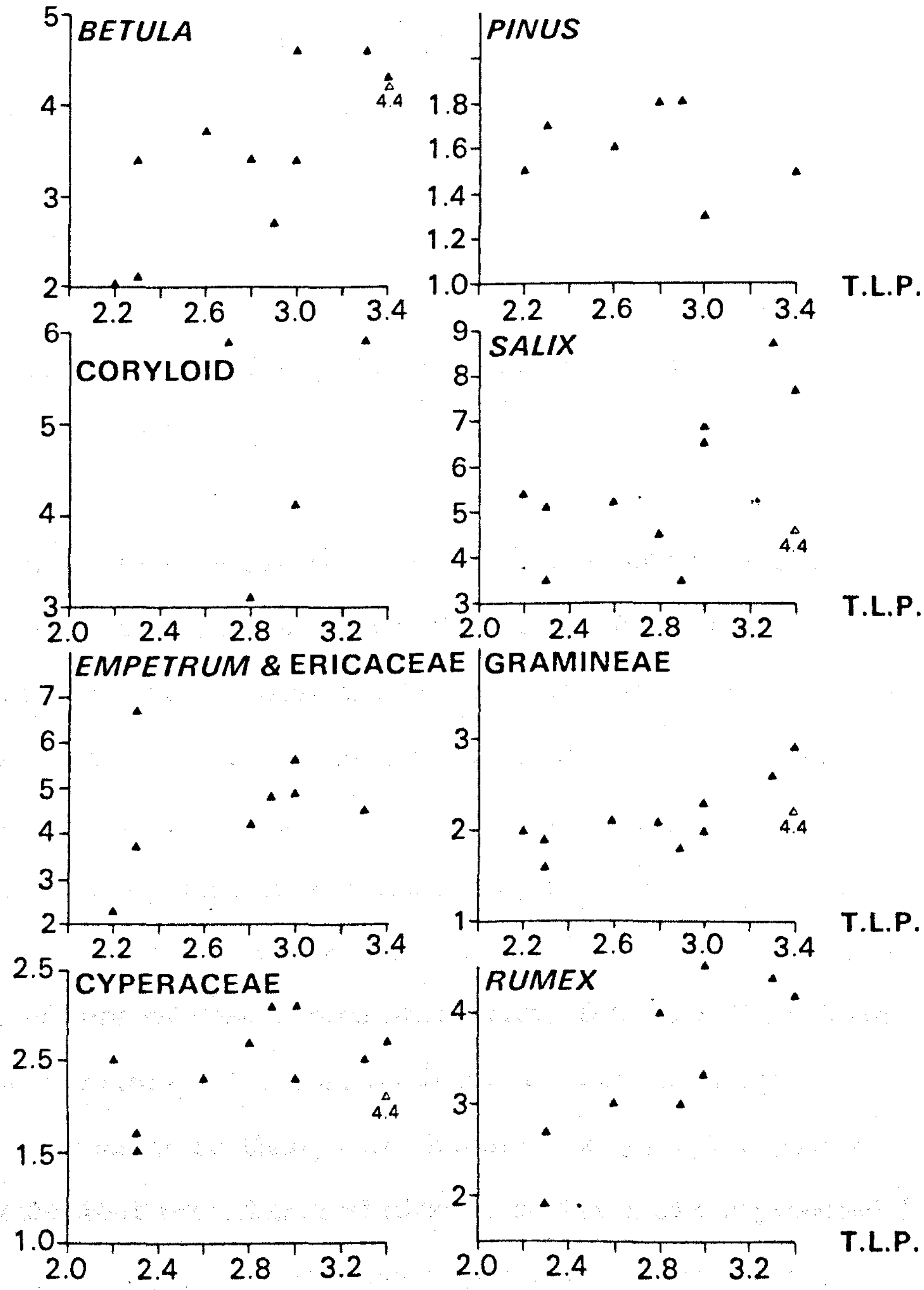
Considering more closely the results of this analysis, it is evident that the demonstration of any trend in deterioration depends on the validity of the mean deterioration ratio. It has been shown (sect. 7.7c) that anomalous d.r's do not distort the mean sufficiently to affect the reliability of the $\bar{x}$ d.r. The mean d.r. is at best a generalized measure, and individual deterioration types need to be examined, but the statistic appears to have some validity (above), and in the consistency with which each taxon lies in a relative order of susceptibility to total deterioration (table 7.2). The relative size of each taxon's $\bar{x}$ d.r. is in

TABLE 7.2

MEAN DETERIORATION RATIOS

	PULPIT HILL ONE all counts (1a)	PULPIT HILL ONE below 620cm (1b)	PULPIT HILL TWO (2)	LOCH BARNLUASGAN (3)	NA LONA MIN (4)	LON GLAS (5)	FORD I (6)	INVERLIEVER I (7)	INVERLIEVER II (8)	BARACHANDER I (9)	BARACHANDER II (10)	$\overline{X}$	ORDER OF TOTAL DETERIORATION SUSCEPTIBILITY
BETULA	4.6 ± 2.1 [5]	4.6 ± 2.3 [5]	3.4 ± 1.6 [4]	3.7 ± 1.5 [5]	3.4 ± 1.2 [5]	2.1 ± 0.5 [4]	4.2 ± 1.7 [3]	4.3 ± 1.6 [5]	2.0 ± 0.3 [2]	3.4 ± 1.4 [5]	2.7 ± 1.0 [3]	3.5 ± 0.9	5
PINUS		1.5 ± 0.3 [1]		1.6 ± 0.6 [1]	1.3 ± 0.3 [1]	1.7 ± 0.5 [2]		1.5 ± 0.8 [1]	1.5 ± 0.5 [1]	1.8 ± 0.8 [1]	1.8 ± 1.5 [1]	1.6 ± 0.2	1
CORYLOID	5.9 ± 3.6 [6]				4.1 ± 3.1 [6]		5.9 ± 2.7 [5]			3.1 ± 1.7 [4]		4.75 ± 1.4	7
SALIX	8.7 ± 4.7 [7]	6.9 ± 3.2 [7]	5.1 ± 2.0 [5]	5.2 ± 4.2 [6]	6.5 ± 3.1 [8]	3.5 ± 1.1 [5]	4.6 ± 2.4 [4]	7.7 ± 4.5 [8]	5.4 ± 3.4 [4]	4.5 ± 3.0 [8]	3.5 ± 1.8 [5]	5.6 ± 1.7	8
EMPETRUM & ERICACEAE	4.5 ± 3.5 [4]	4.9 ± 3.8 [6]	6.7 ± 5.0 [6]		5.6 ± 4.4 [7]	3.7 ± 1.5 [6]			2.3 ± 1.3 [3]	4.2 ± 3.5 [7]	4.8 ± 3.0 [6]	4.6 ± 1.3	6
EMPETRUM				9.3 ± 7.7 [8]				4.9 ± 3.6 [6]					
ERICACEAE				5.7 ± 5.6 [7]				5.9 ± 4.0 [7]					
GRAMINEAE	2.6 ± 0.9 [2]	2.3 ± 0.5	1.9 ± 0.4 [2]	2.1 ± 0.7 [3]	2.0 ± 0.4 [2]	1.6 ± 0.3 [1]	2.2 ± 1.0 [2]	2.9 ± 0.8 [3]	2.0 ± 0.4 [2]	2.1 ± 0.8 [3]	1.8 ± 0.4 [1]	2.1 ± 0.4	3
CYPERACEAE	2.0 ± 0.6 [1]	1.9 ± 0.4	1.5 ± 0.2 [1]	1.9 ± 0.7 [2]	2.3 ± 1.9 [3]	1.6 ± 0.3 [1]	1.8 ± 0.8 [1]	2.1 ± 0.6 [2]	2.0 ± 0.4 [2]	1.9 ± 0.6 [2]	2.3 ± 1.7 [2]	1.9 ± 0.2	2
RUMEX	4.4 ± 2.5 [3]	4.5 ± 2.6	2.7 ± 0.9 [3]	3.0 ± 1.1 [4]	3.3 ± 1.8 [4]	1.9 ± 0.4 [3]		4.2 ± 2.8 [4]		4.0 ± 3.0 [6]	3.0 ± 2.5 [4]	3.4 ± 0.9	4
T.L.P.	3.3 ± 0.8	3.0 ± 0.5	2.3 ± 0.3	2.6 ± 0.7	3.0 ± 1.1	2.3 ± 0.6	4.4 ± 1.2	3.4 ± 1.0	2.2 ± 0.5	2.8 ± 0.8	2.9 ± 1.0	2.9 ± 0.6	

Fig. 7.14 Correlations between Taxonomic $\bar{x}$ D.R.'s and T.L.P. $\bar{x}$ D.R.'s



accord at nearly all sites, although the actual mean ratio varies between sites.

Fig. 7.13 shows that the majority of $\bar{x}$ d.r's listed for individual taxa (and T.L.P) in table 7.2 overlap at one standard deviation. The range of means within a taxon can, however, be quite large, which must relate to site differences. Figs. 7.15 and 7.16 represent a preliminary attempt at explaining these differences in terms of site-dependent features, basin-size (fig. 7.16a), catchment area (fig. 7.16b) and the proportion of minerogenic sediment in each pollen diagram (fig. 7.15).

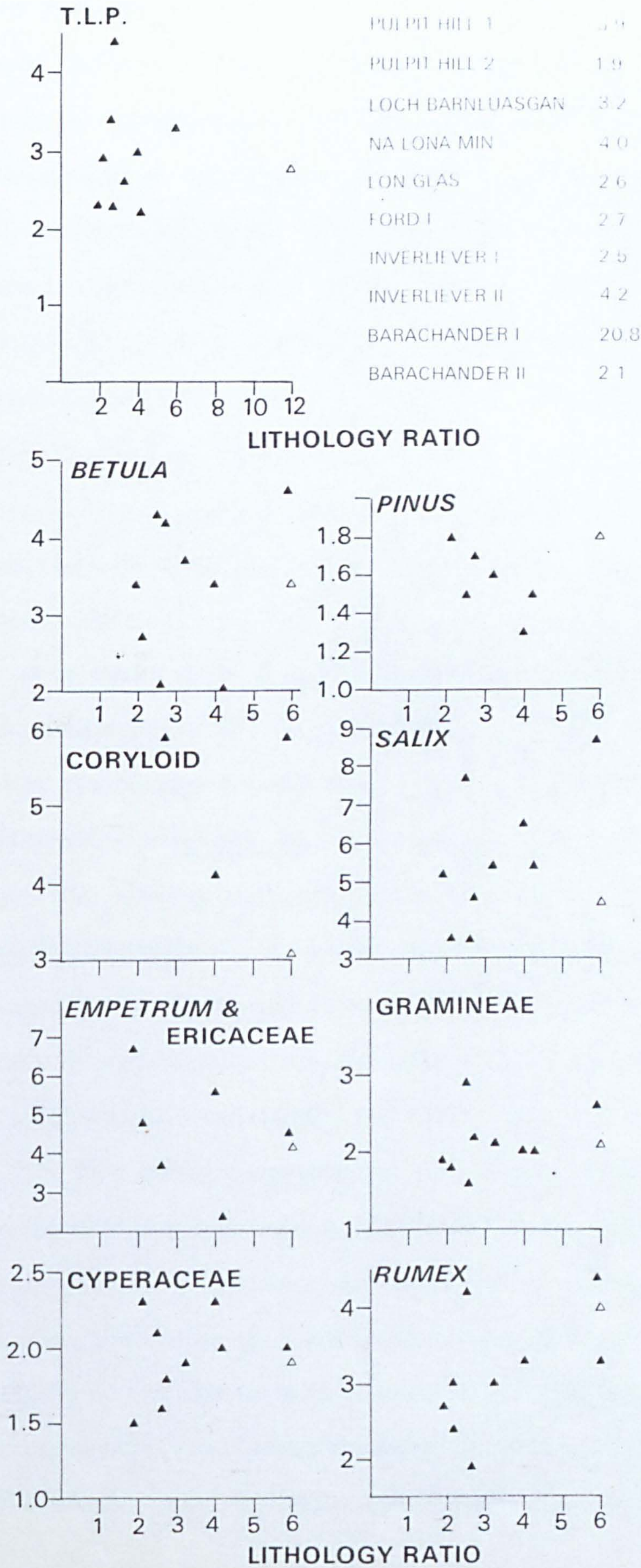
Total deterioration tends to increase in minerogenic sediment, probably as a result of physical wear and abrasion following deposition of the grains. The ratio of the thickness of minerogenic sediment to total thickness of sediment (fig. 7.15) thus becomes an indirect measure of this diagenetic deterioration. Yet in the series of graphs (fig. 7.15), plotting $\bar{x}$ d.r's for each major taxon against this sedimentological ratio (figs. 7.3 - 7.12) few trends can be determined. The limited number of points restricts the use of descriptive statistics, but only Pinus shows an inverse correlation (visual estimation) with minerogenic sediment. This might be thought to demonstrate the relationship between mechanical breakdown and mineral matter already proposed (sect. 7.7c) but other highly susceptible taxa, Gramineae and Cyperaceae, do not show this correlation, and this series of graphs disappointingly fails to explain the variation in $\bar{x}$ d.r's.

Catchment area can be regarded, given our understanding of

Fig. 7.15 Correlations between $\bar{x}$ D.R.'s and Lithology

LITHOLOGY RATIO

PULPIT HILL 1	5.9
PULPIT HILL 2	1.9
LOCH BARNLUASGAN	3.2
NA LONA MIN	4.0
LON GLAS	2.6
FORD I	2.7
INVERLIEVER I	2.5
INVERLIEVER II	4.2
BARACHANDER I	20.8 △
BARACHANDER II	2.1

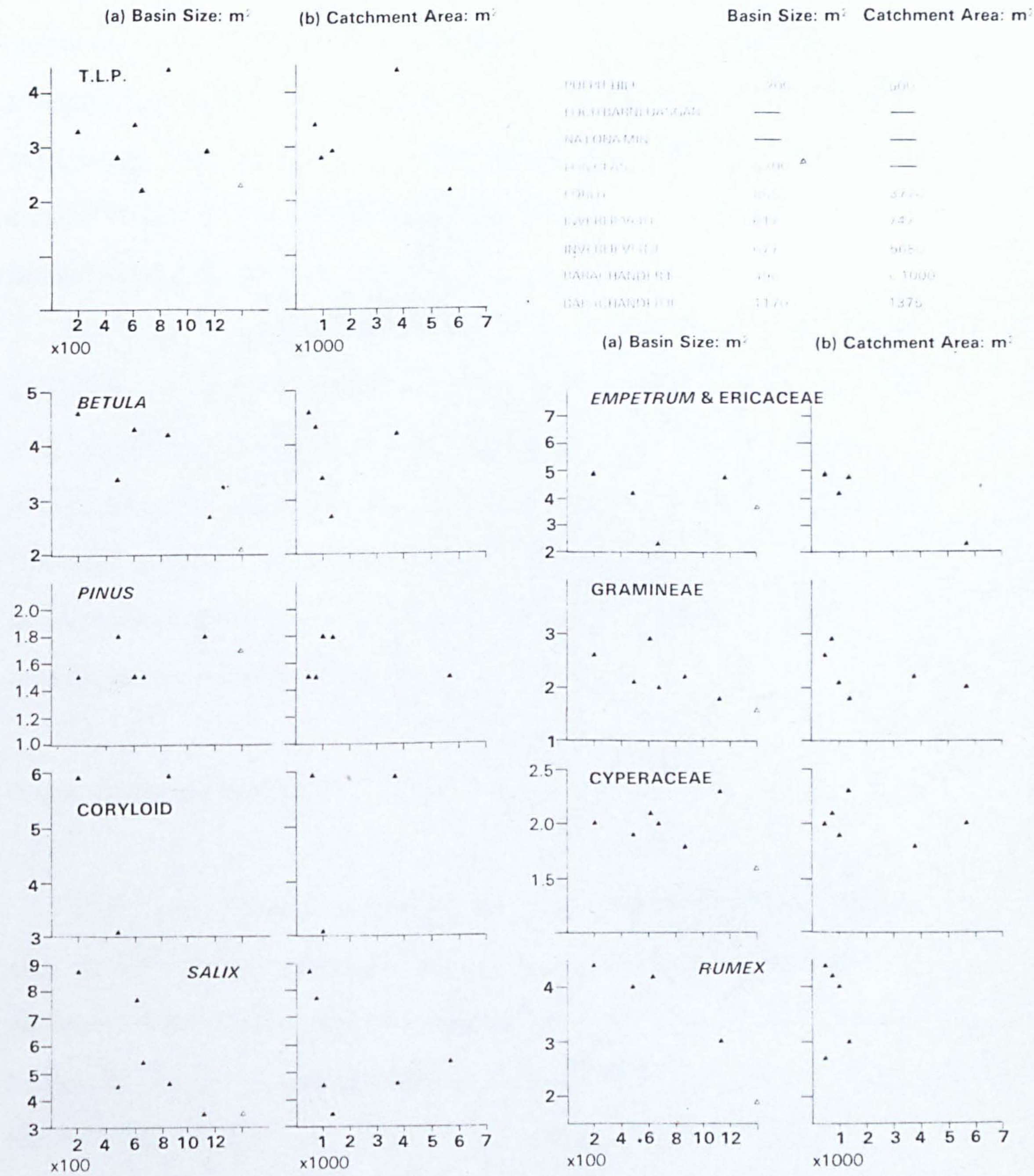


present-day pollen incorporation (Peck,1973; Bonny,1976) as another indirect measure of the importance in the total population of locally derived pollen. It is assumed that penecontemporaneous deterioration of these grains through oxidation (Havinga,1964, 1967; Sangster and Dale, 1961, 1964) and mechanical decay in stream- and overland-flow (Peck, in Birks, 1970) will produce a positive correlation between high deterioration and large catchment area, more locally derived grains being transported to basins situated in larger catchments. As a corollary, basin size can be analyzed, bearing in mind the importance of this in the proportions of local to regional pollen received (Jacobsen and Bradshaw, 1981).

Once again it is apparent that neither catchment area or basin size explain the varying mean d.r's. It is not proposed to discuss the results in any detail. Basin size appears to be significant for <u>Betula</u>, <u>Salix</u> and <u>Rumex</u>, the correlations suggesting, surprisingly, that deterioration increases with increasing basin-size. It is not known whether this suggested correlation is valid, and it seems difficult to explain this pattern in genera which, it has been argued (chaps. 3,4,6) had different pollen recruitment characteristics.

The absence of correlations, and uncertainties concerning the validity of those few considered above, can be explained by several reasons ; (i) the $\bar{x}$ d.r is, as noted above, a generalization of several deterioration types which are of varying significance throughout each diagram and in differing sediments, (ii) for several taxa their immigration into the area changes the proportions of local to regionally distributed pollen with time,

Fig. 7.16 Correlations between x̄ D.R.'s and (a) Basin Size and (b) Catchment Area



	Basin Size: m²	Catchment Area: m²
[illegible]	[illegible]	[illegible]
[illegible]	—	—
[illegible]	—	—
[illegible]	[illegible]	—
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	747
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	c 1000
[illegible]	1170	1375

• (iii) certain taxa (Pinus, Gramineae, Cyperaceae) have deterioration ratios independent of any palaeoenvironmental parameter, and (iv) perhaps most importantly, deterioration, principally mechanical which dominates the majority of taxa in this study, cannot be easily assigned to a particular phase, and a single origin for any deterioration-type may be the exception rather than the rule.

In conclusion, therefore, the deterioration ratios appear to be quite useful in determining trends in deterioration, and might well prove more productive when employed in situations where pollen sums are consistently high, such as in the mid- Flandrian. The mean derived from these ratios is less useful in interpretation, but serves as a very useful indicator of deterioration susceptibility.

B/ ORDER OF SUSCEPTIBILITY

Total deterioration susceptibility is measured by the mean, and in most pollen-types in this study this relates directly to mechanical deterioration. Each taxon will be considered briefly below, in order of susceptibility (table 7.2), the most susceptible first.

1, 2, 3

Pinus, Cyperaceae and Gramineae have by far the lowest means and standard deviations (fig. 7.13), and these features, together with their indifference to changing lithologies have led to the suggestion that these taxa more than others are prone to mechanical deterioration (crumpling predominantly in the herbs, splitting in Pinus) during chemical preparations. Because of their high susceptibilities the appearance in summary diagrams of declining mechanical deterioration has been linked to percentage fluctuations in these taxa, and serious errors of interpretation are likely when the deterioration intensity of such taxa is not determined.

Grass pollens are occasionally corroded, and very infrequently so too are sedge grains, but no pine grain was so deteriorated. This conforms with experimental results (table 7.1) while the high values for mechanical deterioration in pine confirms Cushing's (1964, 1967) results.

4

Rumex grains are almost exclusively mechanically deteriorated, principally through crumpling, and are only very infrequently corroded or degraded (table 7.3). On average 33% of all grains were crumpled. This relatively high susceptibility in a taxon which is only occasionally abundant tends to induce more anomalous spectra as a result of low pollen numbers than other taxa, and this means that Rumex is of only limited significance as an indicator of deterioration at the pollen site in general.

5

Betula has a mean (3.5) very close to that of Rumex, but is much more informative, due to its susceptibility to all types of deterioration and its abundance in the counts. Birch grains seem to be as easily corroded as crumpled, while breakage is noticeably less important, and degradation is more common than in other taxa. Sediment-type does not consistently determine the amount or style of deterioration.

6

Empetrum and Ericaceae have an overall mean of 4.6. Means determined for each pollen taxon at Loch Barnluasgan and Inverliever I are too erratic to consider either as more susceptible. A fifth of all grains are deteriorated, predominantly through crumpling, but at some sites, Loch Barnluasgan, Inverliever I and II and Barachander II this proportion is an under-estimate of deterioration due to the high numbers of indeterminable tetrad grains. At these sites also a distinctive type of crumpling rendered generic determination impossible : this resembled a collapsed balloon with wrinkled exine, as if air had been withdrawn from each sac. At Loch Barnluasgan indeterminable grains were of sufficient importance to depict on fig 7.5.

7

Corylus is not a major contributor at many sites, and because of the limited representation mean d.r.'s are quite variable. It is clearly less susceptible to total deterioration than Betula, and this is due to its resistance to mechanical deterioration, or its occurrence in non-minerogenic sediment. Corylus is noticeably more susceptible to corrosion than is Betula.

The variation in deterioration intensity is due to the remarkably erratic representation of corrosion. Although it is consistently recorded in most spectra major expansions of corroded grains appear independent of sediment-type. For instance, high values in fen-peat are recorded at Inverliever I (fig. 7.9) but not in similar sediment at Ford I (fig. 7.8). In limnic sediment this might simply reflect the proportion of locally inwashed pollen, but in peats where this source is perhaps reduced other factors must be responsible, presumably site-dependent, such as pH, soil fertility and biological productivity (cf. Havinga, 1967).

8

Salix is the most resistant taxon analysed, and no corroded or degraded grains were recorded. From table 7.1 (column 2) Salix appears more susceptible to oxidation than either birch or hazel, and is generally thought more susceptible to corrosion than hazel (table II in Havinga, 1964), while Sangster and Dale (1961, 1964) also regard willow as more susceptible to degradation than Corylus or Betula (table 7.1 ; columns 6, 7). However, Havinga's experimental results (1967) on perforation - type corrosion show that *Salix* is markedly less responsive to this deterioration - type, and this seems confirmed by these results.

Other Taxa

Broadleaved tree genera were only analysed at Na Lona Min (fig. 7.6a), where the order of total deterioration susceptibility accords with that recognized by Sangster and Dale (1964).*Alnus* is seen to be more susceptible to corrosion than *Ulmus*, contrary to Havinga's (1964) findings, but little can be made of this limited sample.

Table 7.3 shows that the principal control of biochemical deterioration (corrosion, degradation) in the lesser herbaceous taxa is the abundance of the taxon in the pollen counts ; genera are more likely to display such traits if they are well represented. There seem few other connections between taxa. It was noted, however, on re-examination of marked grains, particularly at Pulpit Hill One, that many showed heavy staining, notably genera with thick exines, Compositae, Chenopodiaceae, Ranunculaceae, *Epilobium*, Cruciferae and *Armeria*, and this amorphous and blotchy appearance may acount for the exaggerated total of degraded grains at this site, where the analyst was least experienced. This may be a problem at other sites, although the consistency with which degraded grains relate to minerogenic sediments suggests that a characteristic and significant pattern is being replicated.

C/ CAUSES AND SOURCES : A RESUMÉ

It is not possible for the palaeoecologist to provide answers to questions concerning the origins of pollen deterioration. Further attention to present-day processes is necessary, and all that can be done here is to tentatively suggest some conclusions deduced from this study.

Regarding mechanical deterioration, an order of susceptibility, which for most taxa represents their response to physical processes, has been constructed, and emphasis has been placed on the exaggerated appearance of summary curves when the most susceptible taxa are present in the pollen counts. The importance of damage during chemical pretreatment has probably been under-estimated in the past, only Cushing (1964, 1967) giving it due attention with regard to *Pinus*, but the problem may be greater than he considered, and it is probable that a number of only moderately susceptible grains are also abraded and broken during stirring, particularly if the correlation between *Pinus* $\bar{x}$ d.r. and lithology (fig. 7.15) is valid. Experiments are required to deduce the amount of deterioration induced in this way in different taxa and differing sediment-types, and such results would be of no little significance. Cover-slip pressure, described in *Pinus* (sect. 7.7A (2)), is thought to be of importance for large grains only.

Consistent trends towards increasing deterioration in several

TABLE 7.3

Lesser Herbaceous Taxa: Corrosion and Degradation

CORROSION (number of grains per site)	1	2	3	4	5	6	7	8	9	10	DEGRADATION (number of grains per site)	1	2	3	4	5	6	7	8	9	10		
▲ *CARYOPHYLLACEAE*		1									CARYOPHYLLACEAE	1		1						1		1	PULPIT HILL 1
▲ *CHENOPODIACEAE*					1						▲ CHENOPODIACEAE	2	1	1								2	PULPIT HILL 2
▲ *Comp. LIGULIFLORAE*								1			▲ Comp. LIGULIFLORAE	2		1								3	LOCH BARNLUASGAN
▲ *Comp TUBULIFLORAE*								1			▲ Comp. TUBULIFLORAE	2								2		4	NA LONA MIN
▲ *ARTEMISIA*	1									1	▲ *ARTEMISIA*	8	1	2					1	1		5	LON GLAS
▲ CRUCIFERAE	1					1					▲ CRUCIFERAE	2										6	FORD I
▲ *FILIPENDULA*	9				3			3			▲ *FILUPENDULA*	5							1			7	INVERLIEVER I
PLANTAGO undiff	4										*PLANTAGO* undiff			1				1	1			8	INVERLIEVER II
▲ *PLANTAGO Maritima*	1			1					1		▲ *PLANTAGO Maritima*	1										9	BARACHANDER I
ROSACEAE undiff							1				ROSACEAE undiff	1		1								10	BARACHANDER II
▲ *RUMEX*											▲ *RUMEX*	6	1										
▲ *CRATAEGUS*-type						1					*ARMERIA*						1						
SEDUM	1										▲ *EPILOBIUM*					1							
											GALIUM	1											
											LEGUMINOSAE		1										
											▲ *RANCULACEAE*	3											
											▲ *THALICTRUM*	1											
											UMBELLIFERAE	1											

▲ Taxon common (see pollen diagrams)

taxa are thought to be indicative of diagenetic change. Among individual taxa the origins of crumpled and split grains are indecipherable and probably multi - phase. It may be this complexity that has led authors to place mechanical decay below corrosion and degradation in hierarchical clasifications (Cushing, 1964, 1967; Birks, 1970, 1973; Lowe, 1982; Lowe and Walker, 1977) but it is clearly of very great importance.

Corrosion of grains has in this study consistently been interpreted as penecontemporaneous in origin, from aerobic biological attack whilst residing on or in catchment soils, in accord with experimental results (sect. 7.6). It is difficult to ascertain, however, what exactly determines the representation of corrosion at sites. The opportunity of examining several pollen sites which must have undergone very similar sedimentological, pedological, hydroseral and palaeoecological changes has clearly shown that patterns of biochemical decay are not at all consistent between sites. Although site - dependent chemical and biological factors were proposed in the last section, it is difficult to explain where such differences might lie on uniform bedrock. The depths of the sites rules out post-depositional corrosion induced by lowered water-tables. This characteristic is problematic, where one is dealing often with order of magnitude differences in corrosion between what appear to be virtually identical sites.

Degradation proved to be difficult both to recognize and to interpret. The relationship between this and minerogenic sediment is repeated at many sites and implies a mechanical, possibly diagenetic origin (cf. Cushing, 1967; Birks, 1973). On the other hand degradation in determinable grains is associated strongly with *Betula* and *Corylus*, the two taxa most susceptible to corrosion, and a biochemical or chemical origin would find support from Sangster and Dale's (1961, 1964) and Brooks and Elsik's (1974) experimental work. The findings remain inconclusive, and are further complicated by the possibility that degraded grains can be produced during the chemical preparation.

CHAPTER EIGHT

CONCLUDING COMMENTS

8.1 INTRODUCTION

The results of the research have been presented in the preceding chapters. Chap. 3 examined the two Lateglacial pollen sites of Pulpit Hill and Loch Barnluasgan, and analysed the importance of these sites to the vegetational changes in the country as a whole. Palaeoclimatic inferences were discussed with reference to these pollen analyses. The next section of this chapter examines these conclusions in conjunction with other palaeoclimatic reconstructions, from Coleopteran studies to marine faunal investigations and the glacio-geomorphic reconstructions of Sissons (e.g., Sissons and Sutherland, 1976).

Chaps. 4 and 6 examined more specifically the determination of Loch Lomond Readvance ice-limits from pollen-analytical investigations. It remains to examine how these conclusions accord with what is known of the glacial geomorphology of the region (chap. 1), in section 8.3.

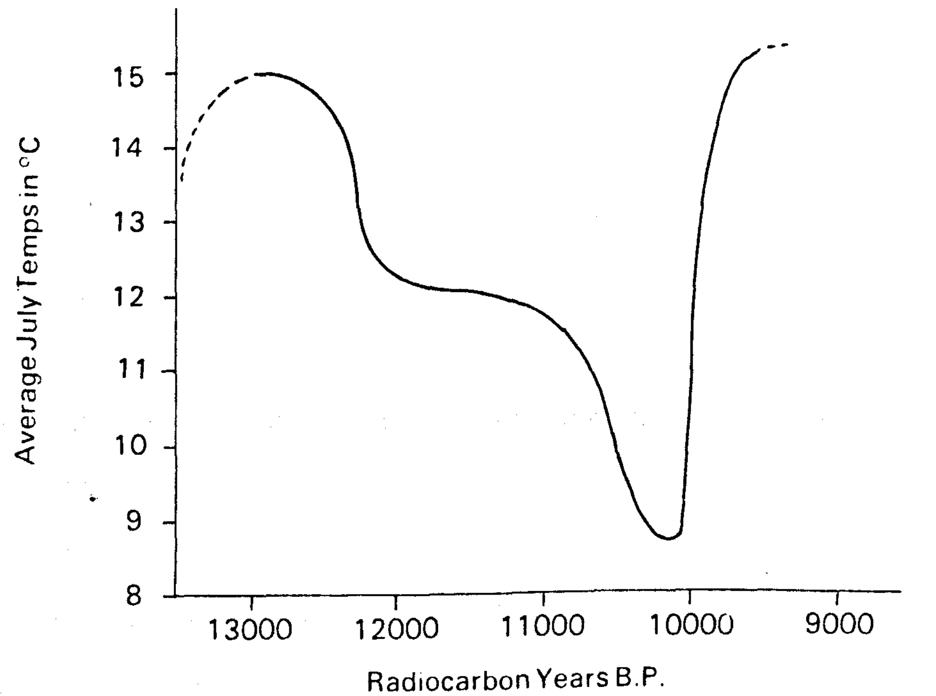
8.2 PALAEOCLIMATIC RECONSTRUCTIONS

It now seems clear that palynology is quite a poor indicator of palaeotemperature. Coope (1977) has proposed that the concept of gradually ameliorating temperature to a mid-interstadial peak before declining to low stadial values, rather like a sine curve,

Fig. 8.1: Lateglacial Palaeotemperature Estimates

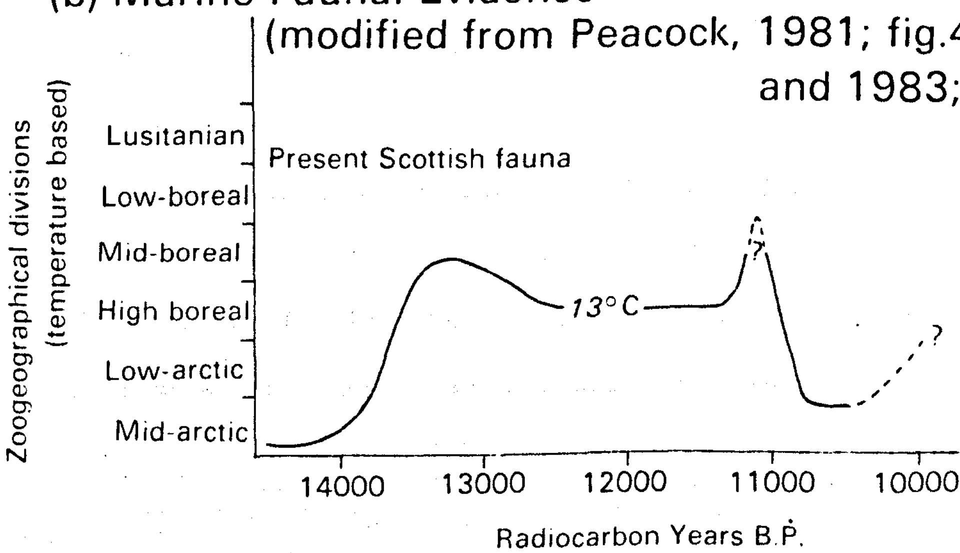
(a) Coleopteran Evidence

(modified from Bishop & Coope, 1977: fig.11)



(b) Marine Faunal Evidence

(modified from Peacock, 1981; fig.4 and 1983; table 3)



is a misconception, and that changes, particularly the initial climatic improvement, was much more dramatic, perhaps occurring in a few centuries (Coope and Joachim, 1980). Fig. 8.1a reproduces the palaeotemperature curve constructed by Coope for the nearest location to the study area so far examined, from S.W. Scotland (Bishop and Coope, 1977). Several criticisms can be levelled at the interpretation of Coleopteran remains (Lowe and Gray, 1980), and this curve depicts the palaeotemperature with an accuracy unwarranted from the data: it would probably be more realistic to depict such curves with "error bars" such as are portrayed on sea-level curves (e.g., fig. 8.3; sect. 8.3), as many suggested palaeotemperatures are not precisely defined. Nevertheless, the curve illustrated closely corresponds to curves from other areas, although some regional differentiation is detected (Coope, 1977).

Fig. 8.1b is a generalized curve showing Scottish sea-temperatures for a similar time-period as fig. 8.1a, taken from Peacock (1981), more quantitative temperature estimates for surface-water (considered more closely comparable to terrestrial temperatures) between 12500 - 12000 B.P. taken from Peacock (1983). The diagram is based on dates adjusted for the marine "reservoir" effect (Peacock, 1981).

Although the patterns elucidated by these independent measures are strikingly similar, there are certain anomalies which need to be examined. Firstly, the increase in temperature close to 11,000 B.P. (fig. 8.1b; Peacock, 1981), inferred from three sites in western Scotland, is not recorded in Coleopteran studies (although here the problem of bulk-sampling may obscure small stratigraphical oscillations; cf. Caseldine, 1980; Lowe and Gray, 1980). The sequence at Garvel Park (Peacock, 1981), however, has no modern description of faunal assemblages; at Lochgilphead (Peacock et. al., 1977) the apparent "warming" is not noted in the original paper; and at Ardyne (Peacock et. al., 1978) the fluctuation is seen principally in benthic forams and not in mollusca, which led Peacock (1983) to suggest that the amelioration did not affect water at depth. Peacock (1981) places marked emphasis on the boreal foraminiferid Ammonia batavus (Hofker), but later (1983) suggests its distribution and ecology are poorly known. The significance of this fluctuation remains unknown. With regard to short-lived increases in Juniperus late in the interstadial at Loch Barnluasgan and other sites (chap. 3.3v; 3.5D) a climatic amelioration was not thought necessary to explain the pollen records.

The second feature of the marine temperature curve is the increase in temperature at close to 10500 B.P. This is recorded in only one sequence, in the Cromarty Firth (Peacock et. al., 1980). Examination of the data shows that this amelioration, which contrasts with the interpretation of pollen analyses (chap. 3), depends solely on the interpretation of contradictory lithological and faunal evidence, the horizon itself being undated (Peacock _et. al._, 1980). The authors prefer the assignment of the problematic Ardullie Beds to the latter part of the Loch Lomond Stadial, but equally they could be of the earliest post-glacial.

The major difficulty in relating these studies to the pollen stratigraphies (chap. 3) is the absence of valid C14 dates for these sequences. If, however, the correlation with the C14-dated sites on Mull (Walker and Lowe, 1982; unpub.) are correct (chap. 3.4) then the palaeoclimatic changes inferred can be seen (fig. 8.2) to closely correspond in direction and timing (intensity of change cannot realistically be assessed from the pollen analyses) with the independently derived curves of fig. 8.1.

The consistency of the pollen sequences in the south-west highlands (inset; fig. 8.2) makes it reasonable to tentatively propose a sequence of regional pollen assemblage zones for the study area and immediate vicinity (fig. 8.2). This is based in terms of time-scale largely on the important site of Loch an t'Suidhe (Walker and Lowe, 1982; unpub.) which for the present must serve as the standard for the region.

The peak in interstadial warmth at c. 13000 B.P. is poorly seen in pollen diagrams, but appears to relate to the _Juniperus_ - _Empetrum_ regional pollen assemblage zone. The initial

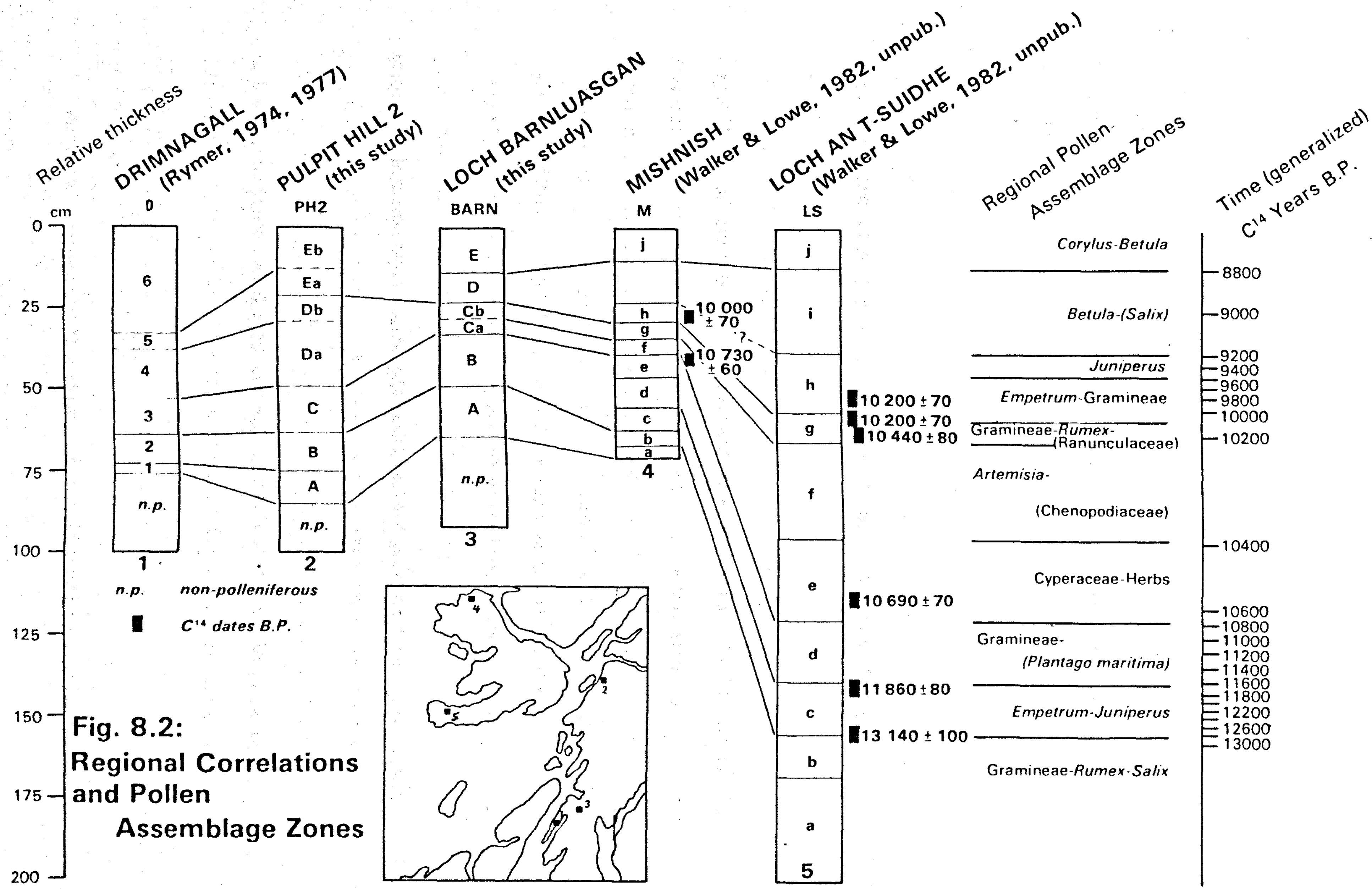


Fig. 8.2: Regional Correlations and Pollen Assemblage Zones

colonization phase of the Gramineae - Rumex - Salix regional p.a.zone clearly represents an expansion for which it is difficult to discern a climatic control, and this may have been independent of climate.

The climatic deterioration of the Gramineae - (Plantago maritima) regional p.a. zone occurs slightly less than 12000 years ago. Peacock (1983) points out that faunal evidence for a climatic decline at this time is slight and, at present, speculative, but at this date (c. 12000 B.P.) the rate of deposition of marine sediments increases (Peacock, 1981), which is suggested to represent renewed climatic harshness increasing erosion at this time. The evidence seems clear from terrestrial evidence (Coope, 1977; Craig, 1978), which has led at least one worker (Robinson, 1977) to speculate on the possible early establishment in Torridon corries of Loch Lomond Readvance glaciers. Sissons (1979a) has also embraced the idea of an early onset to Readvance/Advance glaciation, suggesting that glaciation may have been established in Scotland by 11500 B.P. Sutherland (1981) has also proposed that the Main Lateglacial Shoreline, believed to have developed through frost action in intense cold (Sissons, 1974; Dawson, 1980), commenced formation as early as 11500 B.P.

What is unclear is the cause of the climatic deterioration at this time. The Polar Front, generally regarded as the principal determining factor in Late Devensian climatic oscillations in western Europe (Ruddiman and McIntyre, 1973; Ruddiman et. al., 1977; Sissons, 1976, 1979a; Lowe and Gray, 1980) is thought to have remained north of Iceland until c. 11000 B.P., although as many suggested dates are extrapolated from presumed linear sedimentation rates and lithostratigraphic markers, which are now known to undergo sometimes severe distortions through bioturbation (Ruddiman and McIntyre, 1981a), it is unclear to what this and other dates are related. In one major respect the interest shown by workers in the Atlantic Polar Front in recent years is somewhat misleading, in that the movement of the Front is itself a response to changes in either atmospheric circulation patterns or in ocean temperatures (Ruddiman and McIntyre, 1981a). It is therefore more appropriate to see Polar Front movements as not the fundamental causative factor in climatic change they are sometimes thought.

The scale of temperature fluctuations in this short 3000 year period of the Lateglacial is close to those expected between glacials and interglacials (Duplessy et. al., 1981), and this has generated many suggestions as to causes (Manley, 1959, 1971; Lamb, 1964b; Lamb and Woodroffe, 1970; Mercer, 1969; Denton and Karlen, 1973; Ruddiman and McIntyre, 1981b). The three principal approaches are summarized in Table 8.1.

TABLE 8.1

The Principal Theories of Lateglacial Climatic Development

(after original papers and Ruddiman & Mc Intyre (1981))

1) MELTPRODUCTS	2) RE-ORIENTATION OF ATMOSPHERIC FLOW	3) EXTERNAL CONTROL
MERCER (1969)	MANLEY (1971)	DENTON AND KÁRLEN (1973)
Mechanism "sudden great increase in North Atlantic ice" p.229 (A) break-up of Arctic ice-shelves due to warming by both volumetric and temperature increase of warm Atlantic water and air temperatures (B) cooling of North Atlantic waters (C) southward displacement of depression tracks	Mechanism. "eastward displacement of ..... the Iceland low " p.169 (A) eastward dislocation of Iceland low to position over North Sea (B) eastward spread of colder Atlantic surface waters (C) ocean temperatures approach those of maximum glaciation	Mechanism: varying corpuscular emissions from the sun affect climate, so that high solar activity is equated with warm climate and *vice versa*

Mercer (1969) suggested that climatic perturbations (Manley, 1959, 1971) could not explain the "apparent abruptness of the cooling" (p. 229); however, the evidence assembled above suggests that the initial deterioration need not have been so abrupt or sudden. Mercers' theory (Table 8.1), favoured by Ruddiman and McIntyre (1981a) on deep-sea core evidence, has also gained much support in recent years from the postulation of extensive ice-shelves in the north Atlantic (Hughes et. al., 1977; Denton and Hughes, 1981). Mercer's (1969) ideas that the cooling is itself brought on by warm Atlantic currents induced northward in the mild interstadial makes it, perhaps, likely that an earlier date for ice-shelf break-up could be expected than anticipated by Mercer (1969), given the early time (c. 13000 B.P.) for the interstadial climatic optimum.

Manley (1971) noted Lamb's (Lamb, H.H. and Johnson, A.I.; 1959, 1961) discussion of the cold intervals 1790 - 1829 and 1900 - 1939, and described the Lateglacial example as analogous, believing the determining factor to be atmospheric in origin. However, in a significant but largely overlooked paper Lamb (1964b; reprinted 1966), in a discussion of the role of atmosphere and ocean in small-scale historical fluctuations and the larger problem of ice-sheet development, attributed climatic deterioration to the spread of Arctic sea-ice and the resultant cooling of northern oceans, in much the same way as Mercer was later to do. Noting the similarity of effect of these documented historical oscillations (in the Little Ice Age North Atlantic sea temperatures (July) were comparable with those of the Lateglacial) with the major ice ages, Lamb considered that the recurring pattern, perhaps reminiscent of Denton and Karlen's (1973) cyclicity theory (Table 8.1), "can be attributed to the fact that the Atlantic opening between Greenland and Europe was the only effective outlet for sea-ice from the Arctic Ocean" (Lamb, 1964b; p. 137), explaining the greater effect of fluctuating climate on areas adjacent to the north Atlantic (Lamb, 1964b; Mercer, 1969; Watts, 1980).

Lamb (1964b) predicted the displacement of the Gulf Stream to southern Portugal (Ruddiman and McIntyre, 1973), with accompanying southward movement of major Atlantic depression tracks. As accumulation of snow is greater when precipitation is greatest, high-latitude ice-sheets need show no expansion (Lamb, 1964b; Boulton et. al., 1982). The problem of precipitation intensity and character is a major one when reconstructing Loch Lomond Stadial ice build-up. There is some evidence from palynology (chap. 3.5E; fig. 8.2) and Coleopteran studies (Coope, 1977) for the stadial to be more continental in character, more extreme in temperature range (Sissons, 1979b) and more arid than the more oceanic interstadial (Ruddiman and McIntyre, 1981b). Such a climate is not conducive to glacier growth; indeed, Sissons (1980b) has explained the low volume of ice in the northern

Scottish mainland by aridity induced by the southward movement of the Polar Front. Earlier reconstructions of Polar Front movement (Ruddiman _et. al._, 1977) placed its eastward end near S.W. Ireland, but recently evidence (Duplessy _et. al._, 1981) has indicated intense cold in the Loch Lomond Stadial as far south as the Bay of Biscay, which has necessitated a revision of the Front southward to northern Portugal (Ruddiman and McIntyre, 1981b). This isolates the British Isles several hundred km. behind the moisture-bearing depression tracks lying south of the Polar Front, and during this period (nominally 11000 - 10000 B.P.; Ruddiman and McIntyre, 1981b) Britain may have behaved much as high-latitude regions in terms of precipitation-starvation and restricted glacier-growth.

Undoubtedly the climatostratigraphic horizon at c. 11,000 B.P., marking the onset of the Loch Lomond Stadial _sensu stricto_, is of considerable significance, being marked in both terrestrial and marine environments (fig. 8.1) on sedimentological, faunal and floral evidence (chap. 3). The change from a probable tundra environment in the Cyperaceae - herbs regional p.a. zone to the aridity of the _Artemisia_ - (Chenopodiaceae) zone occurs within the stadial, and due to the minerogenic content of the sediment remains undated. It has been argued above that much of this period was not one of major glacial advance on new information as to the location and effects of the more southerly extent of the

Polar Front, proposed independently on investigations of the mode and rate of formation of stadial glacial deposits (Hodgson, 1982). The principal period of glacial development is thought to have been in the early stadial (Cyperaceae - herbs zone) and late-interstadial (Gramineae - (Plantago maritima) zone), when cold and oceanic conditions were introduced by southward-moving depression tracks across the British Isles, in turn induced by the ice-shelf break-up. The synoptic condition at this time would be little different from that envisaged as responsible for glacier growth in the south-east Grampians by Sissons (1979 b; 1980 b).

The most reasonable interpretation of the climatic decline at 11000 B.P. is the southward movement of the Polar Front, following the earlier frontal systems. Inherent in this suggestion is a certain inertia in the delayed response of the Polar Front to the initial ice-shelf collapse, for which evidence is lacking. Ruddiman and McIntyre (1981b) concede that their evidence is not sufficiently precise to map transitions between stable phases, or the persistence of these phases.

Irrespective of the period of formation of Readvance glaciers climatic conditions pertaining to their development from the work of Sissons (1979b, 1980b) and Sissons and Sutherland (1976) are valid, being derived from glaciological constraints. The basic pattern of southerly winds being those principally involved in snow-accumulation is now well-known. Two points with reference to the western highlands need to be commented on.

Firstly, Sisson s' (1979b) consideration that westerly winds were more common in the west is supported by the pollen-analytical evidence, in the palaeoclimatic interpretations (chap. 3, 5c) for the absence of trees and tall shrubs in the late-interstadial. Secondly, it was tentatively stated in chap. 3.5e that the apparent intensification of aridity on the western seaboard in the stadial, seen in the high *Artemisia* percentages, could be reconciled with synchronous glacier development on Mull without altering the precipitation intensity of the present-day, but merely lowering temperature. From the above discussion of the possible revised timing of environmental changes,however, there need be no relation between glacier growth and *Artemisia* growth. It is interesting to note that Sissons (1979b) considers no increased precipitation necessary to explain the large western Scottish ice-sheet. Clearer understanding of Polar Front fluctuations, glacier build-up and climatic changes must await more detailed work and, most importantly, accurate dating.

The close comparison of early interstadial and early post-glacial vegetational assemblages has long been noted (Watts, 1977). Whether the climatic responses were similar is unknown, as the same successions would be expected to recur regardless of impetus, but the dramatic retreat of the Polar Front to the coast of Labrador (Ruddiman and McIntyre, 1981b) might suggest a similar train of events to that which followed the 13000 B.P. retreat to a similar position.

A change of prevailing wind-direction is suggested at approximately 9600 B.P. (Juniperus regional p.a. zone) to account for the expansion of juniper and, in particular, the marked increase at several sites in Pinus pollen (chap. 4.4; 6.5). This feature needs further demonstration before its reality is confirmed.

8.3 THE EXTENT OF THE LOCH LOMOND READVANCE IN WESTERN ARGYLL.

Pollen sites are limited in the amount of information they can convey in this type of study, as each site is but a point sample. The Awe valley investigation (chaps. 5, 6) was an attempt to partially circumvent this problem, but did not prove entirely successful (see below; section b). Where geomorphological evidence is confusing or absent, pollen sites can be employed with success in weighting the arguments towards one probable alternative.

The discussion that follows is rather intricate and complex. The approach adopted is to examine the sites under investigation, from Pulpit Hill and Loch Barnluasgan to the Awe valley and

Na Lona Min, analysing problems specific to those areas. General points will be stressed when encountered initially or exemplified best. Because the evidence is geographically wide-ranging the arguments are synthesized in the final section.

(a) Pulpit Hill and Loch Barnluasgan.

The complete Lateglacial litho- and bio-stratigraphies at these sites makes it apparent that Loch Lomond Readvance glaciers failed to encroach into their basins (Donner, 1957; Sissons et. al., 1973). This is not unexpected for Loch Barnluasgan, which like Drimnagall (Rymer, 1974, 1977) is not directly related to the uncertainties expressed in chap. 1 (fig. 1.2) regarding Readvance extent.

The confirmation of Donner's (1957) unproven Lateglacial stratigraphy at Pulpit Hill, although unsuccessfully C14 dated, places a restriction on the possible extent of the Loch Etive glacier. In chap. 1.5 it was concluded that most workers (e.g., Peacock, 1971) do not consider the outwash spreads in several valleys in western Scotland (fig. 1.3) as representing a terminal feature: Pulpit Hill shows that in the case of Loch Etive the glacier could not have extended far off-shore, perhaps not more than 2 km if it were to maintain a lobate form commonly depicted for such glaciers.

Several re-examinations of Charlesworth's (1955) stage M limit (Donner, 1957; Synge and Stephens, 1966; Gray, 1972, 1975) south of Oban to Loch Nell (fig. 1.2) have resulted in little modification of this line. To Donner's (1957) postglacial sites of Oban 3 and 4 (fig. 1.5), within his limit can be added a site at Muircroft in Glen Cruitten (NM 884293) examined by the author but not included in the discussion.

At Donner's other (1957) "Lateglacial" site in the Oban area, Oban 1 a/b (fig. 1.5) no interstadial sediments were recorded in over 85 cm of clay, and uncertainties over the age of the basal clay must be raised (Gray, 1975). Being an extant loch Donner sampled from (a) the lake-edge, as did Gray (1975), and (b) a separate infilled basin. H. J. B. Birks (pers. comm., 1980) cored the centre of the lake with a Livingstone corer and retrieved nearly 3 m of clay, containing no pollen in countable numbers, and "no obvious sediments that lithologically might have been interstadial". The similarity between this sequence and those at Na Lona Min and Lon Glas is interesting in the glaciological implications drawn from those sites (chap. 4), but without rigorous investigation little can be made of this pattern at this particular site.

(b) The Awe Valley.

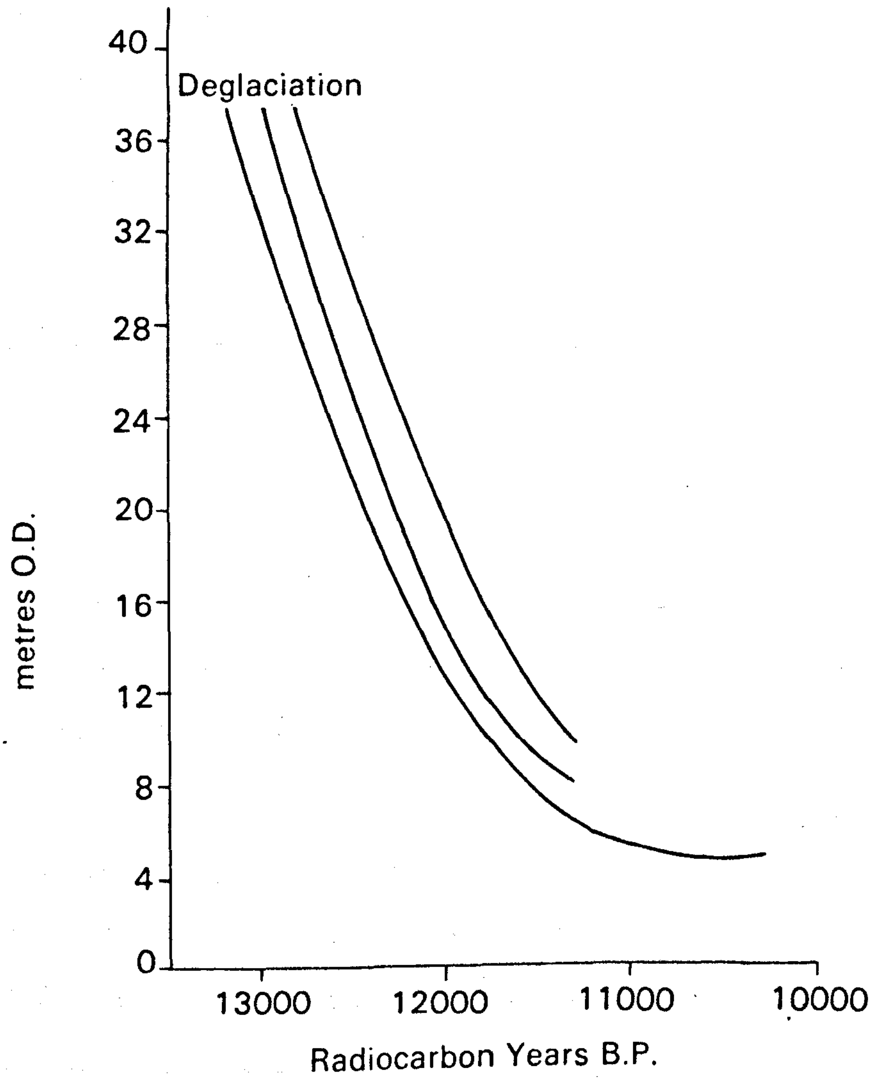
Chaps. 1 and 6 detailed the geomorphological information on which earlier hypotheses (chap. 1) were based. This will not be reported here, but the significance of Lateglacial sea-level changes in the area needs to be examined in relation to the outwash spreads in this valley.

The site of Lon Glas was interpreted as dating from the Loch Lomond Stadial (or the time of the Loch Lomond Readvance; cf. sect. 8.2): see chap. 4.2. Prior to that stage the valley is thought to have been through-draining. If the lake was the result of ice-damming, the kame material and associated low-level (graded to 9 - 10 m O.D.) outwash must also be of stadial age (Gray and Sutherland, 1977).

This clarifies chronologically the relation between the two ice-fronts near Ford, (1) at Eurach accordant with high (35 - 36 m) sea-levels, and probably to be associated with the Otter Ferry stage (Sutherland, 1981) of the Cowal Peninsula (chap. 1), and (2) 1 km up-valley at Glennan, of the same age as the kame-terraces blocking Lon Glas. Fig. 8.3 is a Lateglacial sea-level curve for the southern part of the study area, although in broad terms it can be applied here as the inferred isobases for Lateglacial sea-levels are closely similar (Gray, 1978): the spread of dates on the

Fig. 8.3: Lateglacial Sea-Level Curve

(after Sutherland, 1981; fig. 63)



diagram, associated with a particular altitude, and _vice versa_, are a consequence of combining standard deviations of C14 dates and uncertainties over specific sea-levels (see Sutherland, 1981, from which fig. 8.3 is modified). The evidence in the Ford valley suggests that despite the pronounced 25 m drop in the marine limit between Eurach and Glennan, the two ice-fronts were separated by, perhaps, 1500 - 2000 years, and as Gray and Sutherland (1977; p. 38) indicated, the second ice-position "was not necessarily a _slightly_ later stage in the retreat of the Eurach ice-front" (my italics).

Although it is commonly recognized that stadial sea-levels lay below the Flandrian series (McCann, 1966; Synge, 1966; Synge and Stephens, 1966; Gray, 1972), relating a low sea-level to the stadial cannot be done without independent supporting evidence such as provided at Lon Glas. Fig. 8.3 shows the large range in possible age, between c. 11900 B.P. to beyond the end of the stadial, with which such sea-levels can be correlated: this point is considered further in the next section (c).

The postglacial sites examined in chap. 6 from the Awe valley present an interesting but inconclusive sequence. It is very difficult to prove an hypothesis on absence of evidence. All such sites proposed as evidence for stadial ice-occupation (Sissons et. al., 1973) suffer from this weakness; the key lies in the consistency of such a pattern in all investigations. To this extent the Awe valley sites successfully conform to the pattern.

The further evidence of stadial ice-occupation in the Awe valley expected to be gained from a successful demonstration of the hypothesis proposed in chap.5 proved inconclusive, due not to site-specific problems but to unsuspected anomalies in the predicted reflection of vegetational changes by pollen analysis. Nevertheless, the possibly synchronous increased Pinus percentages at certain sites have allowed a tentative correlation of localities which suggested that sedimentation was delayed in the presumed direction of ice-retreat, affirming the conclusions from Lon Glas as to the probable occupation of the present Loch Awe basin by stadial ice.

(c) Na Lona Min and related valleys.

The results from the lake-basin of Na Lona Min (chap. 4.2) suggest that Loch Lomond Readvance glaciers dammed the lake-basin, depositing the very thick sequence of laminated clays and silts. The location of an alluvial fan at the valley-head (chap. 4.2.i) graded to a high (Otter Ferry stage) sea-level led Sutherland (pers. comm.) to suppose the moraine and sediments of the valley-floor to be of the same age, but they do not appear to be so on the evidence presented, and there is no necessity for the landforms to be related.

Stadial ice-occupation of Leth Allt (fig. 4.1) is of undoubted regional significance. That figure shows that local snow accumulation must have been very limited given the smooth slopes and absence of corrie-forms on the surrounding hills. The geomorphic mapping (fig. 4.1) traced the drift-limit close to the col with Glenbranter at c. 350 m O.D. as recognized by Gunn et. al (1897). If correct the source of ice must lie within the Loch Eck catchment (see section d), in Glenbranter, where large masses of 'drift with well-defined moraines' (Gunn et. al., 1897) are recognized.

Of particular interest with regard to Na Lona Min are the glacial deposits mapped by Sutherland (1981) in the parallel and adjacent valley of Glendaruel (fig. 1.2), described in chap. 4.2.i, graded to low sea-levels.

Suggestions that these deposits are of stadial age on the absence of other glacial stages related to such low sea-levels is questioned by Sutherland (1981) on sea-level evidence. He proposed that the major readvance or halt of the Otter Ferry stage at c. 13000 B.P. resulted in a still-stand phase of ice-front stability until c. 12700 or 12250 B.P. (the range of dates is, again, a result of the construction of fig. 8.3) based on an apparent drop in the marine-limit signified by successive Lateglacial shorelines (CLG 2 to CLG 5) not extending up-valley of the earliest shoreline, as would be expected during uniform ice-retreat. The period of ice-retreat would in Sutherland's (1981) reconstruction have occurred when sea-level was close to those of the Glendaruel deposits. This reconstruction of glacial movements needs to be examined in some detail.

The evidence for glacial activity associated with the well-developed shoreline CLG 2 is difficult to dispute. Examples related to lower shorelines are harder to locate. Dead-ice hollows exist at a few localities (Sutherland, 1981), but need not represent active ice, and constructional glacial landforms are absent below shoreline CLG 2. At Loch Eck fluvioglacial outwash with kettled kames is possibly graded to a 21 m sea-level, but this is uncertain, and may equate to one below 14 m O.D. (section d). In Glen Finart Terrace 457 at 24 m O.D. is thought from the evidence of quiet water sediments in an apparently anomalous location to indicate glacier damming (Sutherland, 1981), but this also is inconclusive evidence.

Ice-front stability is founded on an absence of evidence: shorelines are not found inland of the oldest, and are presumed not to have existed due to ice occupation of the valley. The problems in proving such an argument are, ironically, similar to those discussed with regard to postglacial pollen sites (sect. b).

Several valleys in the Cowal Peninsula have little or no record of Lateglacial sea-level changes below the distinctive shoreline CLG 2. One such is Glendaruel, which has no younger shorelines, and there is little clear evidence for a marine limit in this valley (see section d for discussion of the distinctive drop in the marine limit in mid-Loch Fyne).

In regression analysis of the shoreline fragments certain weaknesses in the data were revealed (Sutherland, 1981), with no shoreline having a minimum gradient (this character and the maximum correlation coefficient define the optimum projection plane, itself a reflection of the centre of isostatic tilting of the shorelines) along the quadrant analysed (210° - 220°) or optimum plane eventually selected (215°; S 35°W). Correlation coefficients are strong (> -0.95) for shorelines 1 - 4, but below -0.95 for the later ones, so that their recognition is not supported by approved statistical controls. One reason for this may be the small number of shoreline fragments recognized, between 8 (CLG 4) and 11 (CLG 3,5) for shorelines CLG 3 - 7. One anomalous result is that shoreline CLG 5 has a less steep gradient than the lower and, presumably, younger shoreline CLG 6; whether this is due to miscorrelation is unknown.

It is thus suggested that the marine record in the Cowal Peninsula lacks sufficient detail to define with confidence the pattern of ice-front fluctuations below shoreline CLG 2, the Otter Ferry stage. There is little evidence for active ice after this stage, and suggested ice-front stability is thought unproven. The inferred drop in the marine-limit is analysed in section d.

It may, therefore, be reasonable to accept that glacial deposits linked to low sea-levels are indeed of stadial age, a view Sutherland (1981) considered, but questioned on the problem this raised over sources of ice (section e). At the time the results of the analyses from Na Lona Min (chap. 4.2) were unknown. However, it must be pointed out that no direct connection between the superficial deposits of these valleys has been proved. The south-east slopes of Glendaruel may have been washed during deglaciation. As argued in chap. 4.2, it seems likely, assuming the existence of Garvie Burn (fig. 4.1) during ice advance, that glaciers would have spilled into Glendaruel from Leth Allt, though whether this was the only source is unknown.

(d) Other Localities in the Cowal Peninsula.

Glacial landforms of Loch Lomond Stadial age (demonstrated by included interstadial marine shells) enabled Sutherland (1981) to produce a map of stadial ice-limits (fig. 1.2). The five small terrestrial glaciers depicted are not the total mapped, but others remained unchecked at the time of writing (Sutherland, 1981; p. 239). In the absence of those data it is difficult to know the full extent of this glacial episode envisaged by Sutherland, although all glaciers are described as small, and Sissons (1980b) has suggested that such missing data points would affect but little the conclusions drawn in that analysis (Sissons, 1980b).

In the sea-lochs end-moraines are not present. In Loch Long the maximum extent of the Readvance glacier is determined by high (Otter Ferry) shorelines near Ardentinny. The sequence by Loch Eck and Strath Eachaig (fig. 1.2) cannot be related to a specific sea-level (section c), and both the possibilities of sustained ice-front stability and stadial readvance remain open in this key area.

In mid-Loch Fyne the limit is drawn at the westernmost extent of hummocky moraine near Furnace and at Strathlachlan, across the loch, where an ice-limit grades into outwash which could not be linked to a specific sea-level, and which could be a retreat feature. Neither of these localities is conclusive in fixing the Readvance's maximal extent. The nearest limiting Lateglacial shorelines lie at Minard, 7 - 8 km downvalley, where a drop in the marine limit has been noted (Sutherland, 1981). Interestingly, Gunn et. al. (1897) record at Lephinmore (g.r. NM 987925) a section of contorted blue clay beyond Sutherland's (1981) inferred limit, which may imply ice readvance well beyond Strathlachlan. Such differences in ice-limit reconstruction would not be insignificant given that the loch at this point is an average 2 km wide, which must represent sizeable differences in ice-volume.

More importantly, perhaps, is the questioning of the origin of the drop in the marine-limit at Minard. At certain localities the absence of interstadial shorelines is attributed to erosion by Readvance glaciers (Sutherland, 1981; p. 200). At the localities where a drop in the marine limit is suspected Sutherland stated they "have not been influenced by glaciers of the Loch Lomond Stadial" (1981; p. 189). One of these localities is Glendaruel, where it has been suggested that this is, perhaps, an unsafe conclusion. In mid-Loch Fyne there is reason to propose a more westerly extent of the ice-mass. These localities are considered the best examples of a drop in the marine limit, and to this can be added Eurach in the Awe valley (Gray and Sutherland, 1977), considered in section b. All such localities cannot be proven to be distinct from later glaciation. Indeed, such shoreline features can perhaps be suggested as good terminal indicators for Readvance glaciers, as in Loch Long.

These conclusions cannot be said to cast doubts on other areas where abrupt drops in sea-levels are found (Sissons et. al. 1966; Peacock, 1970; Dawson, 1982), which need to be assessed independently.

(e) Synthesis.

Evidence for a drop in the marine limit has been re-interpreted (above) and suggestions of interstadial ice-front stability (Sutherland, 1981) questioned, such that glacial deposits related to low sea-levels have been suggested as likely to be of Loch Lomond Stadial age.

It is also implicit in the above discussion that Loch

Lomond Readvance glaciers were more extensive than considered in recent reviews (Sissons, 1976, 1979a, 1980b; fig, 1.1). It is not the role of this thesis to delineate in detail the extent of Loch Lomond Readvance ice; the limitations of pollen sites in this respect have been mentioned already. Instead, key areas of considerable uncertainty have been examined, and appear to show that reconstructions favouring more extensive glacial development (fig. 1.2) are worthy of consideration. It is quite clear from Sisson s' (1979b, 1980b) palaeoclimatic reconstructions (section 8.2) that precipitation intensity was adequate to supply this mass of ice, and the calculated firn-line altitudes (Sissons, 1980b; Sutherland, 1981) and known existence of large valley glaciers at sea-level in the region suggest that fig. 1.1 (Sissons, 1979a) is, on theoretical grounds alone, an underestimate.

8.4 SUMMARY.

Chapter 1 (sect. 6) outlined the aims of the study as perceived at the outset of the investigation. It remains to consider very briefly the extent to which the six points (a - f; sect. 1.6) have been examined.

(a) Two Lateglacial biostratigraphies (chap. 3) have been located, at Pulpit Hill and Loch Barnluasgan, which record biostratigraphical changes through this period.

(b) A detailed set of eight radiocarbon dates were obtained for the site of Pulpit Hill (chap. 3), but, although showing no date-inversions, do not accord with the accepted chronostratigraphy for the Devensian Late-glacial, and are not considered valid in this context. Future investigations would hope to clarify the mechanisms operating at Pulpit Hill that produce such an intriguing set of dates.

(c) The extensive data-base of Scottish Late-glacial sites is utilized in a detailed quantitative analysis of particular vegetational features (chap. 3), and in discussing the extent to which many controversial or newly-proposed palaeoclimatic changes, e.g., the Older Dryas phase, mid-interstadial climatic decline, late-interstadial warming, can be recognized in Scotland (chap. 3).

(d) Sites at Na Lona Min and Lon Glas (chap. 4) were shown to be distinctive curtailed Lateglacial bio- and litho-stratigraphies. Their thick Loch Lomond Stadial sequences were related to glaciers of that stage, and were later used (chap. 8.2) to propose that the Loch Lomond Readvance glaciation was more extensive than had been considered.

(e) An absolute chronology for the glacial stages defined was impossible, given the lack of success in C14 dating (above), but evidence was presented (chap. 8.1) that in palaeoclimatic terms the commencement of the Loch Lomond Readvance was more likely to have been close to the proposed climatic deterioration at c. 12,000 B.P., and not at the onset of the Loch Lomond Stadial *sensu stricto*.

(f) A biostratigraphically determined deglacial chronology was outlined, and the assumptions examined in some detail (chap. 5). Investigations in the Awe valley (chap. 6) demonstrated that the initial hypothesis was too simple, and that such a deglacial chronology is possibly unworkable.

APPENDIX ONE.

POLLEN IDENTIFICATION.

A1) INTRODUCTION.

A complete list of the taxa identified in this study is presented in Appendix Table 1. The level of determination for h eacpollen type is indicated by the conventions established by ks Bir(1973; pp 225 - 6). The taxa are arranged initially under theecological headings used in the pollen diagrams (i.e. trees, shrubs), and are listed within this scheme under their family es namin the order set out in Clapham <u>et.</u> <u>al.</u> (1962).

Many taxa are common to all published diagrams, and will not discussed; for details on these the reader is referred to Moore be Webb (1978); pp 50 - 70. The less common types and pollen anda not considered by Moore and Webb will be commented upon with tax source of identification in each case, and the taxonomic theges, where applicable, which the pollen types represent.
ran

A2) TAXA IDENTIFIED.

<u>TREES</u>

. <u>Tilia cf. cordata</u>: regarded as <u>T.cordata</u> in accordance with the
1 views of Andrew (1971) and Codwin (1975).

APPENDIX TABLE 1 POLLEN CLASSIFICATION

FAMILY	POLLEN TYPE	PULPIT HILL ONE	PULPIT HILL TWO	LOCH BARNLUASGAN	LON GLAS	NA LONA MIN	FORD I	FORD II	INVERLIEVER I	INVERLIEVER II	BARACHANDER I	BARACHANDER II
TREES												
PINACEAE	*Pinus*	X	X	X	X	X	X	X	X	X	X	X
TILIACEAE	*Tila* cf. *cordata*		X					X				
ULMACEAE	*Ulmus*	X	X	X	X	X	X	X	X	X	X	X
BETULACEAE	*Alnus*	X	X	X	X	X	X	X	X	X	X	X
	Betula Undiff	X	X	X	X	X	X	X	X	X	X	X
	Betula cf. *nana*	X	X	X	X	X	X			X		X
FAGACEAE	*Castanea sativa*	X			X	X			X			
	Fagus sylvatica		X	X								
	Quercus	X	X	X	X	X	X	X	X	X	X	X
SHRUBS												
CUPRESSACEAE	*Juniperus*	X	X	X	X	X	X	X	X	X	X	X
ELEAGNACEAE												
	Hippophae rhamnoides				X		X			X		
MYRICACEAE	*Myrica gale*						X	X				
CORYLACEAE	Coryloid/*C aveliana*	X	X	X	X	X	X	X	X	X	X	X
SALICACEAE	*Salix*	X	X	X	X	X	X	X	X	X	X	X
DWARF SHRUBS												
ERICACEAE	Ericaceae undiff.	X	X	X	X	X	X		X	X	X	X
	Calluna vulgaris	X	X	X	X	X		X	X	X		X
EMPETRACEAE	*Empetrum*	X	X	X	X	X	X	X	X	X	X	X
	Empetrum/Erica		X	X	X	X	X	X	X	X	X	X
HERBS												
RANUNCULACEAE												
	Ranunculaceae undiff.	X	X	X	X	X		X	X	X	X	X
	Caltha type		X			X						X
	Aconitum	X			X	X						
	Trollius			X								
	Thalictrum	X	X	X	X	X	X	X	X	X	X	X
	R arvensis type					X	X					
	R trichophyllos type		X			X	X			X	X	X
PAPAVERACEAE	*Papaver* undiff.					X						
	Chelidonium	X										

IDENTIFICATION: X CERTAIN

X UNCERTAIN

APPENDIX TABLE 1 POLLEN CLASSIFICATION cont.

FAMILY	POLLEN TYPE	PULPIT HILL ONE		PULPIT HILL TWO		LOCH BARNLUASGAN		LON GLAS		NA LONA MIN		FORD I		FORD II		INVERLIEVER I		INVERLIEVER II		BARACHANDER I		BARACHANDER II
UMBELLIFERAE	Umbelliferae	X		X		X		X		X		X				X		X		X		X
POLYGONACEAE	Rumex	X		X		X		X		X		X				X		X		X		X
URTICACEAE	Urtica type	X		X		X				X				X		X		X				
PLUMBAGINACEAE																						
	Armeria maritima	X		X		X				X		X				X		X		X		
PRIMULACEAE	P.farinosa															X				X		
	Anagallis arvensis type	X																				
	A.tenella type	X		X		X				X								X		X		X
	Glaux																					X
	Samolus/Trientalis	X																X		X		X
GENTIANACEAE	*Gentaurium*			X				X														
	Gentianella							X														
BORAGINACEAE	Boraginaceae									X												
SCROPHULARIACEAE	*Digitalis*			X																X		
	Rhinanthus type	X																				
LABIATEAE	*Mentha* type	X				X							X					X				
PLANTAGINACEAE	P.undiff	X										X				X		X				
	P.coronopus			X						X												
	P.lanceolata	X		X		X				X		X										
	P.major/P.media	X		X		X		X		X		X				X		X		X		X
	P.maritima	X		X		X		X		X		X				X		X		X		X
CAMPANULACEAE	*Campanula* type																	X				
RUBIACEAE	*Galium* type	X		X				X		X		X				X		X		X		X
VALERIANACEAE	*Valeriana*	X						X														
DIPSACACEAE	*Succisa pratensis*	X																				
COMPOSITAE																						
	Compositae(Liguliflorae)	X		X		X		X		X		X				X		X		X		X
	Compositae(Tubuliflorae)undiff.	X		X		X		X		X		X				X		X		X		X
	Centaurea nigra type									X												
	Cirsium/Serratula type	X		X		X				X						X		X		X		
	Anthemis/Bidens type			X		X		X		X						X				X		X
	Artemisia	X		X		X		X		X		X		X		X		X		X		X
ORCHIDACEAE	*Listera* type							X														
GRAMINEAE	*Gramineae*	X		X		X		X		X		X		X		X		X		X		X
CYPERACEAE	*Cyperaceae*	X		X		X		X		X		X		X		X		X		X		X

IDENTIFICATION: X CERTAIN

X UNCERTAIN

APPENDIX TABLE 1 POLLEN CLASSIFICATION cont.

FAMILY	POLLEN TYPE / SITES	PULPIT HILL ONE	PULPIT HILL TWO	LOCH BARNLUASGAN	LON GLAS	NA LONA MIN	FORD I	FORD II	INVERLIEVER I	INVERLIEVER II	BARACHANDER I	BARACHANDER II
AQUATICS												
ISOETACEAE												
	Isoetes cf. *echinospora*	X			X	X				X	X	
NYMPHAEACEAE	*Nuphar*		X		X							
	Nymphaea	X	X			X					X	
HALORAGACEAE												
	Myriophyllum undiff.	X							X	X		
	Myriophyllum alterniflorum	X	X	X	X	X	X	X	X	X	X	X
MENTANTHACEAE	*Menyanthes*	X							X			
LENTIBULARIACEAE	*Utricularia*						X					
ALISMATACEAE	*Alisma* type		X			X			X	X		
	Sagittaria sagittifolia									X		
POTAMOGETONACEAE												
	Potamogeton	X	X	X		X		X	X	X		
TYPHACEAE												
	Typhaceae undiff.	X	X	X	X	X	X		X	X	X	
	T. angustifolia	X	X	X	X		X					X
	T. latifolia	X	X	X	X	X	X					X
LEMNACEAE	*Lemna*	X	X			X						
SPORES												
LYCOPODIACEAE												
	Lycopodium undiff.	X	X	X	X	X			X	X	X	
	L. alpinum	X							X			
	L. annotinum					X	X		X			X
	L. clavatum	X		X		X	X	X	X	X		
	L. inundatum									X		
	L. selago	X	X	X	X	X	X	X	X	X	X	X
SELAGINELLACEAE												
	Selaginella Selaginoides	X	X	X	X	X	X		X	X	X	X
POLYPODIACEAE												
	Polypodium undiff. / *filicales*	X	X	X	X	X	X	X	X	X	X	X
	Polypodium vulgare	X	X	X	X	X	X	X	X	X	X	X
	Pteridium			X		X	X		X	X		
	Athyrium filix femina	X						X	X	X		

IDENTIFICATION: X CERTAIN

X UNCERTAIN

APPENDIX TABLE 1 POLLEN CLASSIFICATION cont.

FAMILY	POLLEN TYPE (SITES)	PULPIT HILL ONE	PULPIT HILL TWO	INCH BARNLUASGAN	LON GLAS	NA LONA MIN	FORD I	FORD II	INVERLIEVER I	INVERLIEVER II	BARACHANDER I	BARACHANDER II
	Asplenium type	X	X									
	Thelypteris	X	X	X	X	X	X	X	X	X	X	X
	Dryopteris type	X	X	X	X	X	X	X	X	X	X	X
EQUISETACEAE	*Equisetum*	X	X				X		X	X		
OPHIOGLOSSACEAE	*Ophioglossum*	X										
	Botrychium			X		X						X

IDENTIFICATION: X CERTAIN

X UNCERTAIN

2 Alnus: no assumption to species, A. glutinosa or A. incana is made, contrary to Faegri (1963), Godwin (1975) and Birks (1977), who assume the species to be A. glutinosa.

At several sites it has been suggested that local alder establishment occurred a considerable time before the regional Flandrian expansion (Nichols, 1967a; Rymer, 1974; on, 1975; GunsBeckett, 1981). It was hoped to examine the extent to which a similar alder peak (12%) at the base of the Inverliever II diagram (chap. 6.2) could be attributed to the more hardy A. incana, using the keys of Erdtman et. al. (1961; 1963) to determine the species.

The criteria used were:

a) the angle between the sexine and nexine inside the aspides: 40°- 45° for A. incana
35° for A. glutinosa.
(Erdtman et. al., 1963)

b) porus circular in A. incana; ovoid in A. glutinosa.

c) sculpture equals ridge-like microprocesses in A. incana; baculae in A. glutinosa. (Erdtman et. al., 1961).

This was eventually abandoned for several reasons; (a) 36% of grains examined were deteriorated, principally affecting pori and arci (cf. Elsik, 1966); (b) there appear to be inadequacies in available keys; (c) criteria 1 and 2 were difficult to assess due to grains lying at awkward angles in the medium, and (d) the sculpturing elements were very difficult to separate at x 1000 mag. It is also possible, though uncertain, that the blurring of the definitive criteria was due to a real effect of hybridization between the two species (McVean, 1953; Praglowski and Wenner, 1968).

The fossil pollen types cannot, in the authors view, be as successfully distinguished as macrofossil remains (cf. Godwin, 1975). Further work is needed at sites in Britain before the presence of the more robust A. incana can be disproved at these sites.

3 Betula cf. nana: a subjective assessment of birch grains showing shallow, less prominent pores than Betula undiff. (Webb, 1977; Andrew, 1980) was made, and those grains were included in this taxon. Many grains could not be confidently allocated, and consequently the pollen diagrams show only the presence rather than the proportion of B. cf. nana.

Classification by size of grain (Birks, 1968) was not attempted, although small size helped "tip the balance" with certain grains. Variations in size between embedding media (Anderson, 1960), slides of differing thickness (Cushing, 1961), lengths of acetolysis treatment (Webb, 1977) and between sediment types (Prentice, 1981) suggest this method to be suspect. Standardization procedures (Anderson, 1980) require that the standard recent pollen is treated identically with fossil pollen, and assures that any size changes are equal between the two sets, which is very unlikely. Publication of mean grain-size curves (Caseldine, 1980) only begs the question of the proportions of mixtures of two or more pollen types, the curve itself being pointless as an indicator of representativity. This problem appears to have been solved by Prentice (1981), but its publication came too late to aid this study.

SHRUBS

4 Myrica gale: distinguished from Corylus by the absence of nexine near pori (Moore and Webb, 1978; Faegri and Iversen, 1975), supported by a more angular shape when well-preserved than Corylus (Andrew, 1980). It is acknowledged that doubts persist as to this approach (Edwards, 1981).

5 Coryloid: includes deteriorated Myrica gale grains whose pori

could not be examined. It is felt that C. avellana dominated the counts, as has been argued elsewhere (Walker and Lowe, 1979).

6 Salix: although two types were distinguished in routine counting, based on the size of lumina and coarseness of mesh (reticulum), the types could not be satisfactorily placed in an existing key (Faegri and Iversen, 1975). The taxon thus includes all native spp.

DWARF SHRUBS

7 Ericaceae undiff.: the common deterioration of these grains meant that species identification (Oldfield, 1959; Moore, 1979 unpub.) was not feasible except with Calluna vulgaris:- very irregular tetrad; coarsely verrucate sculpture; 4 colpi, half the length of individual lobes. This category thus includes Vaccinium (5 native spp.), Pyrola (4 spp.), Andromeda, Arbutus, Daboecia and Erica (6 spp.).

8 Empetrum: separated from the Ericaceae on: colpi half the length of individual lobes; relatively psilate to faintly scabrate sculpture. This class includes E. nigrum and E.hermaphroditum, as size differences (Moore, 1979 unpub.; Birks, 1973) could only rarely be determined due to crumpling.

9 _Empetrum/Erica_: a classification enforced by the extreme deterioration of many grains.

HERBS

10 _Ranunculus arvensis_ type: Trizonocolpate scabrate-verrucate grains with dimorphic columellae, the finer columellae arranged, occasionally fused, around the larger columellae and verrucae, with clear "light" rings due to the absence of fine columellae adjacent to the verrucae (Andrew, 1980; Moore and Webb, 1978). This approximates to the _R. acris_ type of Birks (1973), and includes _R. acris_, _R. repens_, _R. bulbosus_, _R. scleratus_, _R. ophioglossifolius_, _R. reptans_, _R. lingua_, _R. paludosus_ and _R. flammula_ (Birks (1973) classes this with the _R. trichophyllos_ type, yet Andrew (1980) describes it as having dense ringed spots), as well as _Clematis_ (2 spp.) (Andrew, 1980).

11 _Ranunculus trichophyllos_ type: as above, but the fine columellae are scattered evenly over the grain, and the light ring is absent. The class includes _R. trichophyllos_, _R. fluitans_, _R. aquatilis_, _R. peltatus_, _Pulsatilla vulgaris_ and _Anemone_ (3 spp.) (Andrew, 1980).

12 _Chelidonium_: distinguished from _Helleborus_ (Moore and Webb, 1978; p. 60) on the presence of a margo in type slides of the latter.

APPENDIX TABLE 2

	HEXAZONOCOLPORATE	TRIZONOCOLPORATE	TRIZONOCOLPATE	GEMMATE	SCABRATE/ECHINATE	STRIAE VISIBLE AT X 400	STRIAE VISIBLE AT X 1000	CURVED STRIAE	TRANSVERSE ENDOCOLPUS	OPERCULUM	BRIDGE TO COLPUS	COLUMELLAE UNEQUAL *longest in mesocolpium*	COSTAE COLPI
SANGUISORBA	X						X						
RUBUS chamaemorus		X		X	X		X						
AGRIMONIA		X				X	X	X					
FILIPENDULA		X			X		X						
APHANES		X	X				X					X	
ALCHEMILLA		X	X				X					X	
POTERIUM		X				X	X			X			
DRYAS		X	X			X	X						
GEUM		X					X				X		
RUBUS		X					X				X		
PRUNUS		X						±					
ROSA		X				X	X			X			X
POTENTILLA TYPE													
POTENTILLA		X				X	X			X			
FRAGARIA		X				X	X						
CRATAEGUS TYPE													
CRATAEGUS		X					X						
SORBUS		X					X						
MALUS		X					X						
PYRUS		X					X						

POLLEN MORPHOLOGY IN THE FAMILY :ROSACEAE

13 *Viola arvensis* type: tetracolpate/colporate (occ. penta -); colpi long; psilate - scabrate; 30 m : includes *V. arvensis*, *V. tricolor* plus *V. riviniana* and *V. palustris* (Moore and Webb, 1978; pp 62, 72 - 3).

14 Leguminosae undiff.: includes grains tentatively assigned to *Lathyrus palustris*.

15 *Lotus* type: the grains resemble *L. uliginosus* rather than *L. corniculatus* on size criteria (Godwin, 1975), although *L. pedunculatus*, *L. tenuis*, *L. angustissimus* and *L. lispidus* are also of a similarly small size as grains recorded in this study (Birks, 1973).

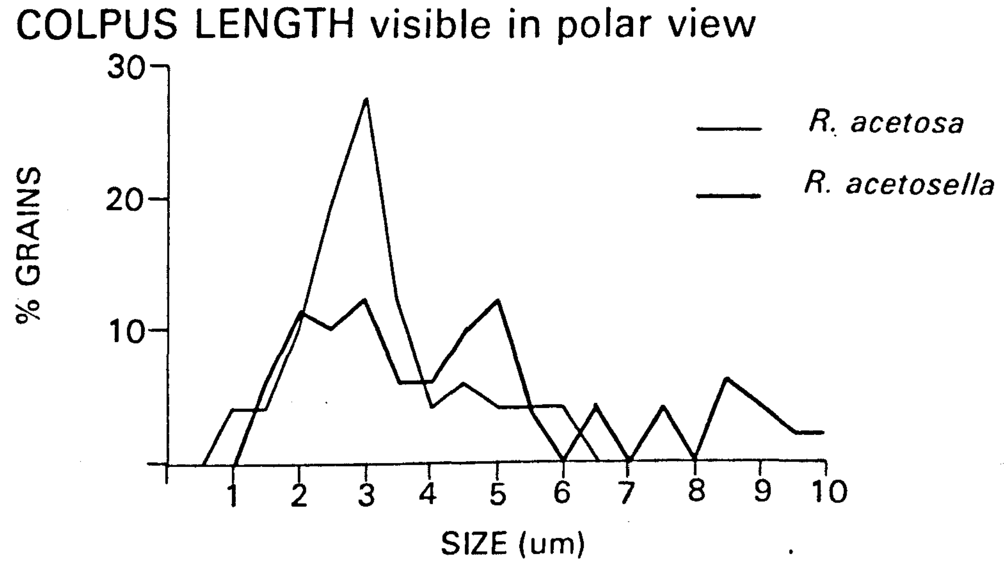
16 Rosaceae undiff: Table 2 indicates the criteria used to determine the individual spp. (see also Reitsma, 1966).

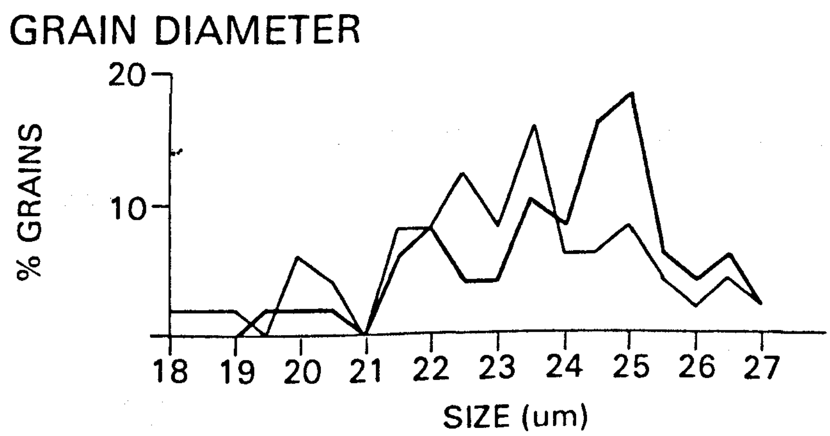
17 *Saxifraga nivalis* type: includes *Chrysoplenium*, as Moore and Webb's separation (1978; p. 58) based on size was considered unreliable.

18 Umbelliferae: no sub-divisions of this family were made.

19 *Rumex*: Fig. 1 shows the measurements of colpus length and grain diameter (longest diameter) for populations of *R. acetosa* (1 collection; n = 50 grains) and *R. acetosella* (1 collection; n = 50) made at x 1000 mag. (accuracy = 0.5 m) to establish

Appendix Fig. 1: *Rumex* Grain Size Determinations





R. acetosa	mean diameter	24.24 um
	S.D.	2.45 um
	mean colpus length	3.15 um
	S.D.	1.15 um
R. acetosella	mean diameter	24.95 um
	S.D.	2.04 um
	mean colpus length	4.48 um
	S.D.	2.36 um

whether colpus length, or rather, the ratio of colpus length to longest grain diameter (to avoid absolute size increases), was a diagnostic criterion in separating the two Rumex spp. at magnifications lower than the x 1000 mag. usually exployed (Moore and Webb, 1978). R. acetosa has a tendency to have shorter colpi, but this is clearly unreliable. This species does lack columellae lying in the lumina, which R. acetosella shows consistently, but magnifications of x 1000 are essential for this, and with the large number of grains involved this criterion was considered too time-consuming.

Rumex thus includes grains of all R. spp. and Oxyria digyna.

20 Urtica type: no distinction between U. dioica and U. urens was possible.

21 Armeria maritima: A and B - type grains were identified. Both morphological types are regarded as being A. maritima (Baker, 1948).

22 Samolus/Trientalis: difficulties in separating the spp. on size and aperture were found, and this taxon represents a compromised solution to identification problems.

23 Boraginaceae: the majority of grains could be classified as _Cynoglossum_ (2 spp.), but this category includes _Myosotis_ (10 spp.); _Mertensia_ and _Lithospermum_ (2 spp.).

24 Compositae (Liguliflorae): although workers have referred this taxon to _Taraxacum spp._, according to Birks (1973) the type includes 13 genera and 32 spp.

25 _Cirsium/Serratula_ type: tricolporate echinate; > 35 μm; columellae visible beneath the tectum; includes _Cirsium_ (8 spp.), _Serratula_, _Saussurea_, _Arctium_ (2 spp.) and _Carlina_.

26 _Anthemis/Bidens_ type: as above; < 35 μm; no columellae visible beneath the tectum : includes _Anthemis_ (2 spp.), _Achillea_ (2 spp.), _Chrysanthemum_ (2 spp.), _Matricaria_, _Tripleurospermum_, _Bidens_ (2 spp.), _Pulicaria_ (2 spp.), _Eupatorium_, _Erigeron_ (2 spp.), _Bellis_, _Senecio_ (9 spp.), _Solidago_ and _Antennaria_.

27 _Artemisia_: no specific determinations could be confidently made. Within the genus types were separated during counting , of which _Artemisia_ 2 could hesitantly be described as _A. norvegica_: larger grain than normal; very thick exine with pronounced mid-colpal bulge; distinct colpi, more rounded grain than usual; verrucae/echinae more pronounced (compare

with Birks, 1973; p. 240). Webb (1977) described six types (A - F) on density and prominence of echinae, the appearance of the columellae and the porus shape. A. norvegica was placed in Type A together with A. pontica and A. borealis, from which it could not be distinguished. The grains counted showed great variability and, in the absence of suitable type material, this study combines all types under the generic name (5 native spp.).

AQUATICS

28 Isoetes: attempts were not made to separate species (cf. Godwin, 1975).

29 Myriophyllum undiff.: includes M. spicatum and M. verticillatum, with the former species dominating.

30 Utricularia: includes all 4 native spp.

31 Typhaceae undiff.: may include grains of Sparganium as no separation of these closely related taxon was made.

32 Potamogeton: includes both sections Eupotamogeton and Coleogeton.

SPORES

33 Thelypteris type: includes T. dryopteris, T. phegopteris, T. palustris, Asplenium marinum and Phyllitis scolopendrium (Moore and Webb, 1978).

34 Dryopteris type: includes D. dilatata, D. filix-mas, D. abbreviata, D. borrerii, D. aemula, D. carthusiana, D. cristata, Thelypteris robertianum, T. limbosperma and Cystopteris fragilis ssp. dickeana (Moore and Webb, 1978).

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