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The Late Devensian Vegetation of Ireland

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Phil. Trans. R. Soc. Lond. B 1977 **280**, 273-293
doi: 10.1098/rstb.1977.0110

Phil. Trans. R. Soc. Lond. B. **280**, 273–293 (1977) [273]
Printed in Great Britain

The Late Devensian vegetation of Ireland

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[Pullouts 1 and 2]

The vegetation of the Late Devensian period in Ireland is reviewed. New investigations at Ballybetagh, Co. Dublin, Dunshaughlin, Co. Meath, Glenveagh, Co. Donegal and Poulroe, Co. Clare, are reported. A sequence of phases of vegetation development for the Dublin region is described and regional variation elsewhere in Ireland discussed. Pollen influx values for two Late Devensian sites in southeastern Ireland are reported. A case is made that the *Juniperus–Empetrum* phase between 12400 and 12000 B.P. was the warmest phase of the Late Devensian. The reason for absence of birch woodland in late-glacial Ireland is discussed. Evidence for widespread soil erosion at the end of the *Juniperus–Empetrum* phase is presented. The occurrence of a corrie glaciation at Lough Nahanagan in the Wicklow Mountains in the *Artemisia* phase is documented. A radiocarbon chronology for events in the Late Devensian of Ireland is proposed.

1. Introduction

(*a*) *Review of the literature*

The formal system of stratigraphic nomenclature now in use in Britain and Ireland names the Last Glaciation the Devensian and defines the Late Devensian as the time from 25000 to 10000 years ago (Mitchell, Penny, Shotton & West 1973). The Late Devensian thus includes the time when the ice sheets of the Last Glaciation first accumulated and spread to their greatest extent, their subsequent melting and disappearance and a final phase with fluctuating climate which lasted from about 13000 to 10000 years ago. As nothing is known about the Late Devensian flora and vegetation of Ireland before about 13000 years ago it is convenient to recognize this last phase as the 'Late-glacial period', while recognizing that this is an informal name which lacks exact definition. At 10000 B.P. the Flandrian (Postglacial) period begins.

The first clear identification of a Late-glacial deposit in either Ireland or Britain was the investigation of the bogs at Ballybetagh near Dublin by Jessen & Farrington (1938). At the northwestern bog at Ballybetagh Jessen's excavations showed that a lake deposit which contained bones of the extinct Irish giant deer, *Megaloceros*, lay between two stony layers which he identified as solifluxion earths. Jessen drew attention to the similarity between Ballybetagh and the well-known site at Allerød in Denmark where there was clear evidence of a Late-glacial climatic oscillation. His subsequent investigations showed that Late-glacial deposits are very common in Ireland. In 1949 Jessen's comprehensive account of his work in Ireland was published by the Royal Irish Academy at whose invitation his Irish researches had begun. His splendidly argued and presented paper (Jessen 1949) has been regarded as authoritative, and later studies in Ireland have used his work as a standard against which to measure their conclusions. Jessen concluded that three zones could be identified in the Late-glacial period. It is useful to quote his summary of his tripartite scheme:

Zone I. The older *Salix herbacea* period. The information that is yielded by examination of the plant remains and of the sediments in the lakes suggests that Ireland was covered by an open tundra-like vegetation of a limited number of species and was subject to solifluxion.

Zone II. The Late-glacial *Betula* period or Allerød period. Ireland was an oceanic sector of the sub-arctic Birch region of north-west Europe. There were copses of birch (*Betula pubescens*) and stretches of open country, which in the west were covered by heaths rich in *Empetrum* and elsewhere by a vegetation of grasses and herbs whose character cannot be closely defined.

Zone III. The younger *Salix herbacea* period. The vegetation was clearly more northern in character than in the preceding period, though oceanic influence was maintained. The tree growth was even more restricted but birch copses may have survived in sheltered localities. Solifluxion was a common phenomenon and the country for the most part carried an open tundra-like vegetation with patches of sub-arctic heaths containing, among other plants, *Salix herbacea*, *Dryas octopetala*, with in the northwest much *Empetrum nigrum*.

Parallel with Jessen's studies, his pupil G. F. Mitchell showed that fossils of both *Megaloceros* and the reindeer occur predominantly in the upper part of Zone II and that it could be argued that they had become extinct in Zone III (Mitchell 1941 *a*; Mitchell & Parkes 1949). Both Jessen and Mitchell determined large numbers of Late-glacial plant macrofossils. This work is summarized, and the Irish Late-glacial flora compared with the modern vegetation of south-facing morainic slopes in Swedish Lapland by Mitchell (1954).

In the early work of Jessen and Mitchell only a limited range of pollen types was identified. In particular, *Juniperus*, which proved to be a very important member of the flora, and many herbaceous species were not recognized. As the range of pollen determinations was extended, a simple tripartite scheme for the Late-glacial was found to be inadequate. Zone II proved to be more complex than had been believed, and the pollen zones could not be equated exactly with the sedimentary units. Authors attempted to redefine the pollen zones (Watts 1963) or to interpolate new transitional zones numbered I–II and III–IV (Singh 1970). Craig (1973) abandoned Jessen's zones completely and used a local zonation system only.

A number of pollen diagrams exist in which *Juniperus* and herbs were identified to a modern standard. Watts (1963) published three diagrams of major taxa from sites in western Ireland, while A. G. Smith and his colleagues at Queen's University, Belfast, published several detailed studies (Smith 1961; Morrison & Stephens 1965; Singh 1970). Smith (1970) reviewed Ireland's Late-glacial vegetation and climate. In southwestern Ireland a detailed pollen diagram is available from Muckross, Killarney, Co. Kerry (Vokes 1966). Craig (1973) has investigated two sites in the southeast, Coolteen, Co. Wexford, and Belle Lake, Co. Waterford, making use of absolute pollen counting procedures. These sites and others referred to in the text are located in figure 1.

(*b*) *The present review – some general considerations*

In an effort to make this review as objective as possible, information from Ireland has been considered in isolation, so that the account is uninfluenced by stratigraphic or climatic conclusions reached in other countries. The reason for this approach is the belief that premature emphasis on correlation may obscure real differences between regions. In Ireland the numerous Late-glacial deposits make it possible to choose sites for study where sedimentation has been rapid and a high resolution of stratigraphic detail can be obtained. This is held to be particularly important in the establishment of a satisfactorily detailed account of the regional development of vegetation.

The review presents new site investigations but its objective is not to consider these in great detail, but to use them in conjunction with the published literature to illustrate a number of interesting aspects and problems of Ireland's Late-glacial vegetation (see § 5). The system of pollen zones introduced by Jessen (1949) for the Late-glacial and early Flandrian is abandoned here. As a framework it does not fit, and cannot be adapted to fit, present-day knowledge of the pollen stratigraphy. Unfortunately, the very numerous plant macrofossil records from the period have been referred to one or other of Jessen's zones. This does not mean that the records are unusable, but they cannot be related to modern pollen diagrams. It will be necessary in the future to prepare seed diagrams (Watts & Winter 1966) from the Irish Late-glacial to show the exact relationship of macrofossil records to pollen profiles. In abandoning Jessen's zones, difficult problems of procedure and principle arise in deciding whether, or how, to zone pollen diagrams. The procedures adopted are discussed in the succeeding paragraphs.

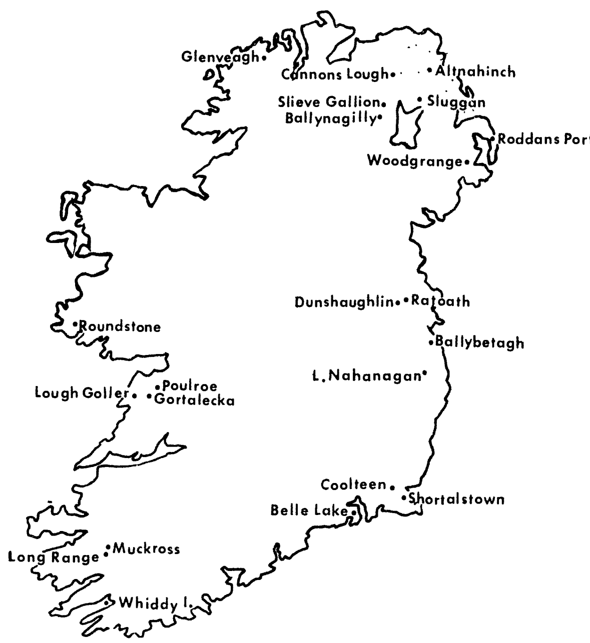

FIGURE 1. Sites referred to in the text.

The diagrams were first divided into local pollen zones. Local zones refer to one site only. Each zone is given a number and a combination of letters which identifies its site. The zones are defined by their pollen composition only. The importance of giving primacy to local pollen zones is that they are defined without giving any consideration to the pollen record at other sites so that they preserve information about local variation. This reminds us that vegetation was not homogeneous in the past and that the investigation of differences between sites may reveal the variability of vegetation cover in the past and its relation, then as now, to factors of history, soil and local climate. Pollen diagrams from one region tend to be very alike and common features are usually more striking than differences. As a second stage local pollen zones which were very homogeneous from site to site were considered to belong to an 'assemblage zone'. Assemblage zones are defined by a characteristic composition of fossil pollen. They can be mapped in time and space (American Commission on Stratigraphic Nomenclature 1961; Cushing 1967). Assemblage zones may begin at different times locally and last for varying periods. They do not provide a basis for time correlation which must depend on radiocarbon-dated profiles. The assemblage zones were named and defined (table 1). For convenience in

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Table 1. Pollen assemblage zones and chronology of the Late-glacial period in Ireland

informal names used in text for pollen assemblages	most important pollen types	sites at which identified	approximate duration in radiocarbon years B.P.	chronological subdivision of Late-glacial (Late Weichselian) period in northern Europe (in Pennington 1975)	
the *Corylus* assemblage	*Corylus* (hazel)	Wo, Be, Co, Ro	begins 9000		
the *Betula* assemblage (*Betula* or birch phase)	*Betula* (tree-birch), often with *Salix* (tree-willow) and *Dryopteris* (fern)	Wo, Be, Co, Ro, Mu, Dl, Bb	9500–9000		
the *Juniperus–Filipendula* assemblage	*Juniperus* (juniper), often with *Empetrum* (crowberry) and *Filipendula* (meadow-sweet)	Wo, Be, Co, Mu, Dl, Bb	10000–9500	Flandrian	
the Gramineae–*Rumex* peak	A peak of Gramineae (grass), often with *Rumex* (dock)	Dl, Bb	10200–10000		10000
the *Artemisia* assemblage (*Artemisia* phase)	Variable amounts of *Artemisia* with Caryophyllaceae, often with *Salix* (dwarf willow), *Armeria*, *Koenigia*, *Sedum rosea*	Wo, Be, Co, Ro, Mu, Dl, Bb	10800–10200	Younger *Dryas*	
the Cruciferae peak (crucifer peak)	More than one genus of Cruciferae	Wo, Be, Co, Ro, Dl, Bb	10900–10800		11000
the Gramineae assemblage (Gramineae or grass phase)	Gramineae, often with frequent *Helianthemum* and Umbelliferae	Wo, Be, Co, Ro, Mu, Dl, Bb	12000–10900	Allerød	11800
				Older *Dryas*	12000
the Hippophaë peak	Hippophaë, pollen and leaf hairs	Dl, Bb	*ca.* 12000		
the *Juniperus–Empetrum* assemblage (*Juniperus–Empetrum* phase, Juniper phase)	*Juniperus*, often with *Empetrum*	Wo, Be, Co, Ro, Mu, Dl, Bb	12400–12000		
the *Rumex–Salix* assemblage	*Rumex*, usually with *Salix* (dwarf willow)	Wo, Be, Co, Ro, Dl, Mu, Bb	13000–12400	Bølling	13000
the pre-*Rumex*-phase flora	Gramineae, much secondary pollen	Wo, Ro	13000	Middle Weichselian	

Wo, Woodgrange; Be, Belle Lake; Co, Coolteen; Ro, Roddans Port; Mu, Muckross; Dl, Dunshaughlin; Bb, Ballybetagh.

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discussion the names are as short as possible. This procedure is 'informal' in the sense of the Code of Stratigraphic Nomenclature but the formal naming of a type site and more detailed diagnosis and nomenclature are premature in the present rapidly changing state of knowledge. Formally named assemblage zones may well, because of their rigidity, be less useful than a loosely defined informal scheme. Table 1 contains a tentative chronology for the assemblage zones. These dates should be understood to be no more than very crude estimates of means, the true values of which will vary from site to site by amounts varying from decades to centuries.

In principle it may be doubted whether pollen zone boundaries should be drawn at all. Pollen diagrams are complex records of alternating periods of stability and of change in vegetation. Zone boundaries imply that discrete homogeneous units can be identified within pollen diagrams, but this is not the case, because it ignores transitions which may occupy significant periods of time (Watts 1973).

There is an obvious analogy to a basic problem of vegetation science. Is the nature of vegetation such that its stands can be regarded as discrete units and be classified on the basis of degrees of similarity of their floras, the view of classical plant sociology (Westhoff & van der Maarel 1973) or is each stand continuously variable in space and time, as Gleason (1926) maintained, and therefore unclassifiable? In the author's view (Watts 1973), Gleason's individualistic concept of the plant community is supported by the evidence of pollen analysis. In this strict sense the drawing of zone boundaries whether subjectively or by computer (Gordon & Birks 1974) in vegetation which is 'continuously variable in space and time' is a mistake because it is inconsistent with the character of the scientific evidence.

If one accepts that it may be convenient and practical, even with the reservation that it may be inexact scientifically, to delimit and classify stands (define and correlate pollen zones), then the process of zoning pollen diagrams becomes like the practice of plant sociology. Local pollen zones, or the spectra of which they are composed, become analogous to the relevés or real local records (quadrats) of plant sociology, and the delimitation of assemblage zones analogous to the definition of associations (a synthetic or artificial concept) from the data of relevés assembled in association tables. The necessity to present large quantities of data in a manageable form suggests that local pollen zones, based on actual data and subsequently united into synthetic assemblage zones, may be pragmatically the best way to make the information contained in pollen diagrams accessible in summary form.

2. Pollen diagrams from Ballybetagh and Dunshaughlin (Figures 2, 3)

(a) *The sites*

A re-investigation of Ballybetagh seemed desirable because it is a classic site but lacks a satisfactory modern pollen diagram. Dunshaughlin has already been studied by Mitchell (1940), but also lacks a modern pollen diagram.

Ballybetagh lies at the edge of the Dublin Mountains at an altitude of about 250 m. The three bogs described by Jessen & Farrington (1938, p. 207) overlie boulder clay of the Last Glaciation which is rich in limestone. The 'bogs' are really spring-fed marshes or fens covered by sedges, herbs of shallow water and bryophytes. *Carex paniculata* is a prominent component of the vegetation.

Jessen's studies were carried out mainly on excavations in the northwestern bog. The middle bog of the three, Jessen's southwestern bog, had become famous because upward of 60 giant deer skulls and antlers had been excavated there during the nineteenth century, together with reindeer remains. Jessen considered this bog too disturbed by excavation for giant deer to be satisfactory for study, a very reasonable viewpoint when one considers that the site is only about 300 m long and 50 m wide. However, the author found no difficulty in sampling the middle bog with a Livingstone sampler and in finding undisturbed sediments in its centre. No evidence of nineteenth-century excavation was encountered and it is possible that excavations were limited to a small area or to the bog margin. Cores were obtained from the centre of the northwestern segment of the bog, about 30 m north of a mapped fence line (cores SW-1, SW-2, map in Jessen & Farrington 1938, p. 207). As the early Post-glacial sediments in the middle bog are peats with a strongly locally influenced pollen flora the pollen diagram is completed by a core from the northwestern bog, core NW-1, where the early Post-glacial facies is lacustrine.

Although the altitude of Ballybetagh at 250 m may seem low, it is close to the limit of cultivation at the edge of the Dublin Mountains; heath and bogland predominate from about 300 m. In contrast, Dunshaughlin is a drained lake basin lying at less than 100 m in the Central Plain northwest of Dublin in farming land of high quality over limestone-rich boulder clay. Differences in the pollen diagrams between the two sites probably reflect the poorer soil and more exposed situation of Ballybetagh. Drilling at Dunshaughlin was carried out about 30 m east of map point 29 (map in Mitchell 1940, p. 14).

(*b*) *The pollen sequence*

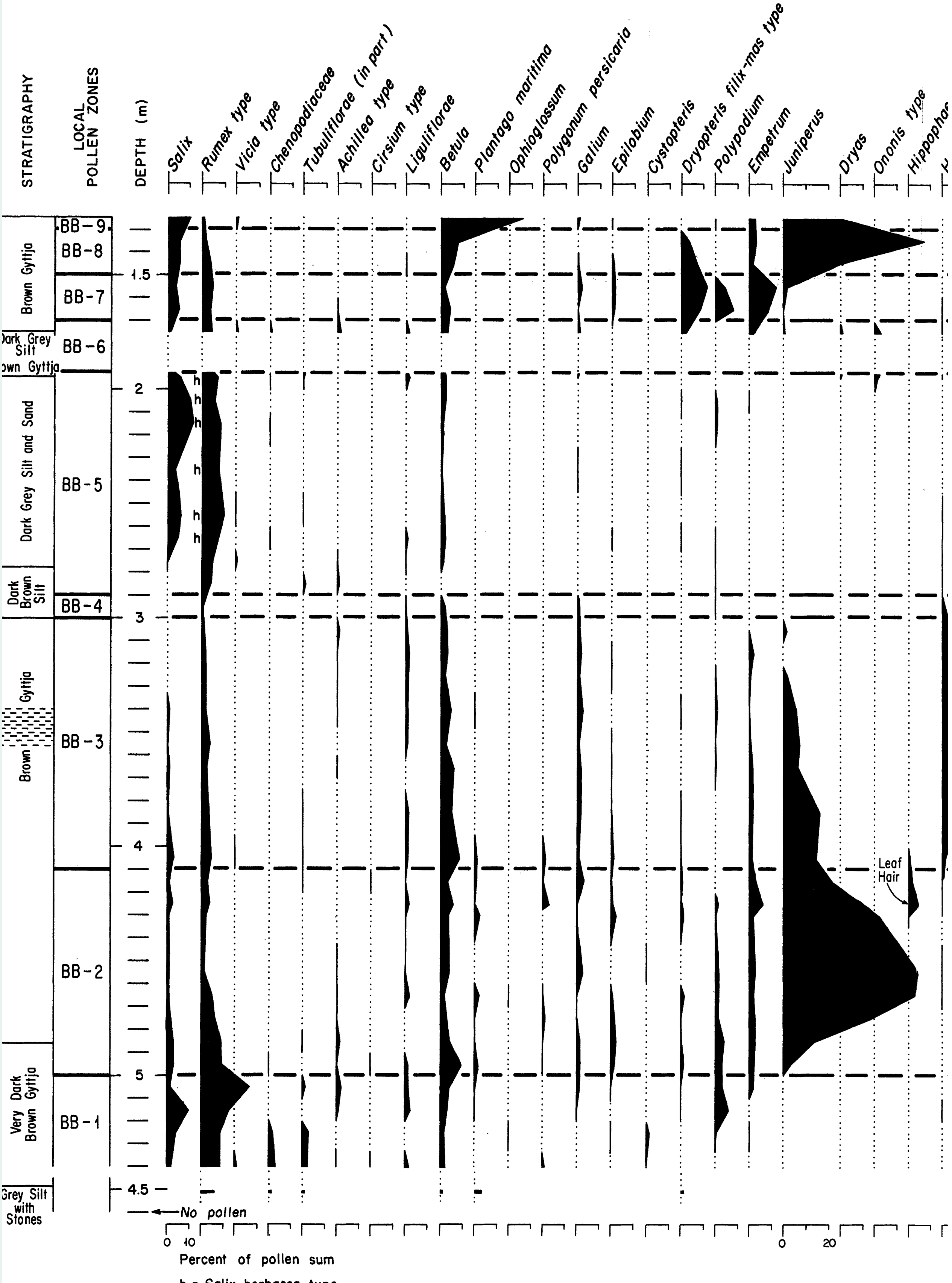
(i) The *Rumex–Salix* assemblage (dock–dwarf willow)

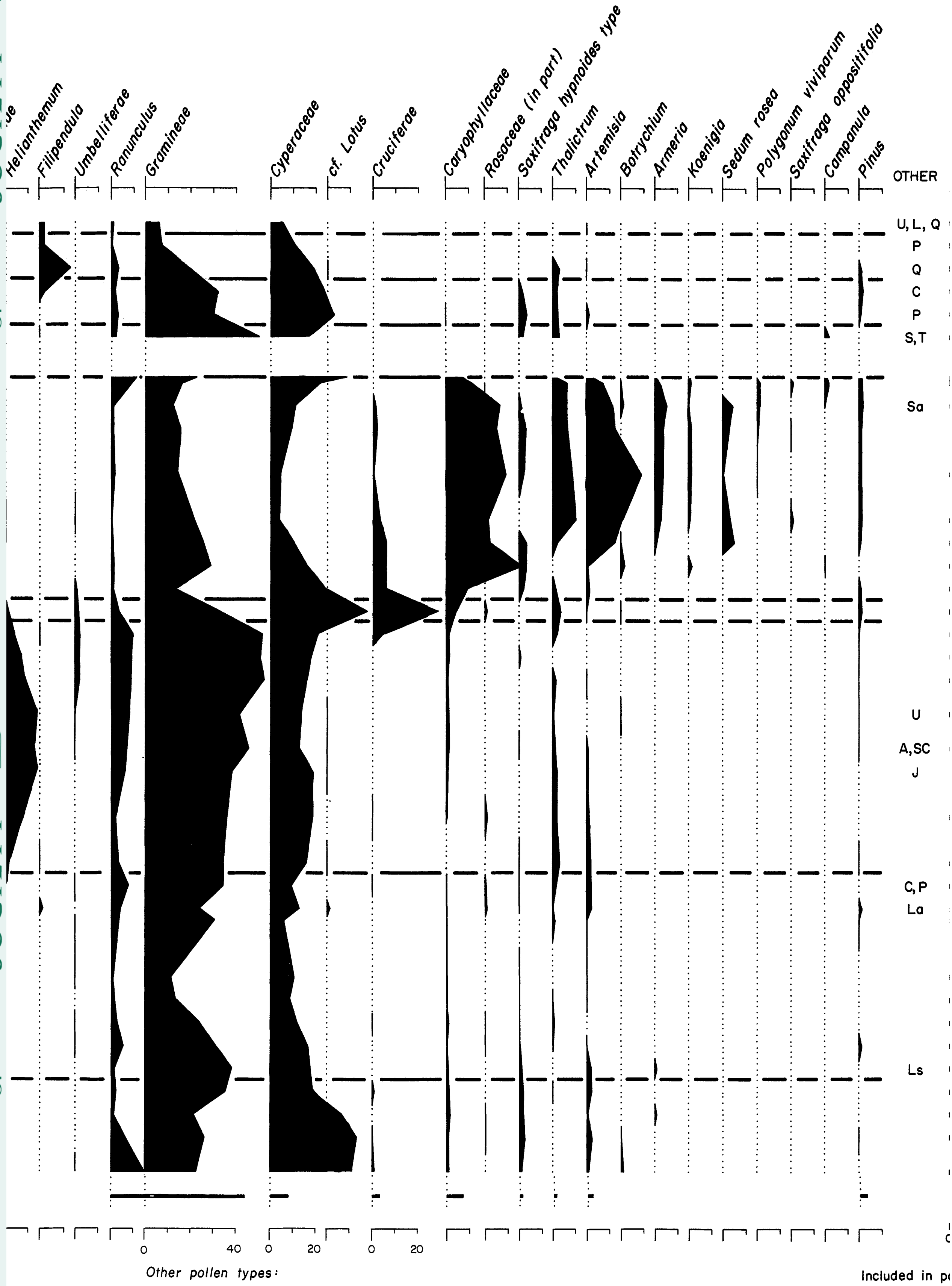
At the base of the Ballybetagh and Dunshaughlin profiles (figures 2 and 3) pollen of *Rumex* type makes up to 20 % of the pollen rain. *Rumex* type includes *Rumex acetosa*, *R. acetosella* and *Oxyria digyna*, all three of which occurred macroscopically at Ballybetagh (Jessen & Farrington 1938). *Salix*, probably *S. herbacea*, is frequent at the same time. At Ballybetagh a pollen spectrum in silt at the base of the profile has high percentages of grass pollen and relatively little Cyperaceae (sedge). This suggests that the earliest upland flora was largely grasses with dwarf willow, *Rumex* and some diversity of other herbs. The *Rumex–Salix* assemblage is found at all Irish sites that have been investigated in detail. It corresponds more or less with Jessen's Older *Salix herbacea* Zone (Zone I). Much detailed work on the pollen and macrofossil assemblages will be needed before the character of its vegetation can be defined satisfactorily.

(ii) The *Juniperus–Empetrum* (juniper–crowberry) assemblage

Juniperus and *Empetrum* appear at the end of the *Rumex–Salix* assemblage and become abundant immediately. Juniper contributes 60 % of the pollen rain at Ballybetagh, 60 % at Woodgrange (Singh 1970) and 70 % at Belle Lake (Craig 1973). The juniper scrub must have covered the landscape over large areas, much as gorse (*Ulex europaeus*) now does. At sites where it plays a smaller rôle percentages of 20–40 are recorded. *Empetrum* arrived before *Juniperus* at Ballybetagh, simultaneously at Dunshaughlin and Roddans Port (Morrison & Stephens 1965). In western Irish sites, especially at Long Range and Muckross, it arrived clearly before juniper and was already declining as juniper reached a peak. Its percentage values range from high values of up to 20 in southern and western Ireland and at Roddans Port to minor occurrences in other areas of northeast and southeast Ireland.

BALLYBETAGH County Dublin





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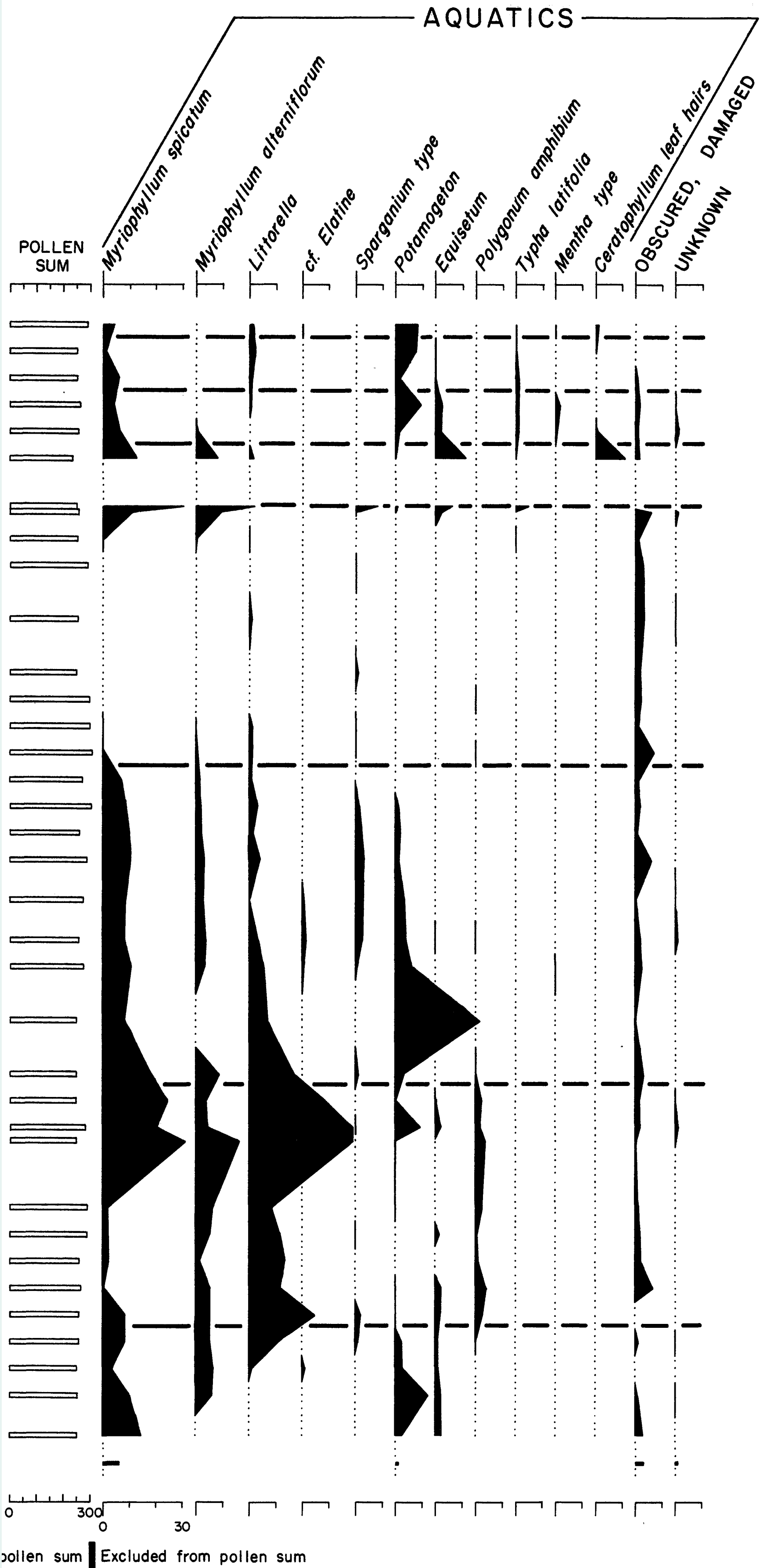

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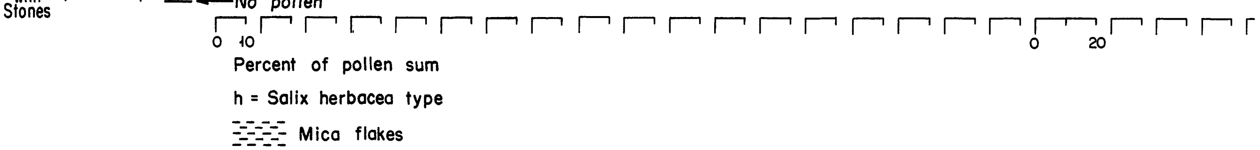
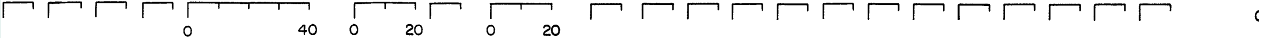

Stones
No pollen
0 10
0 20
Percent of pollen sum
h = Salix herbacea type
Mica flakes

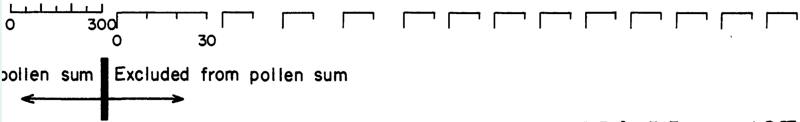


Other pollen types:

Included in p

A	Astragalus alpinus type	P	Plantago major type
C	Corylus	Q	Quercus
J	Jasione	Sa	Saxifraga aizoides
L	Linum	So	Sanguisorba officinalis
La	Lycopodium alpinum	T	Trifolium
Ls	Lycopodium selago	U	Urtica
		SC	Scrophulariaceae

FIGURE 2. Pollen diagram from Ballybetagh, Co. Dublin.



W.A. Watts 1976

UNSHAUGHLIN (Lagore), County

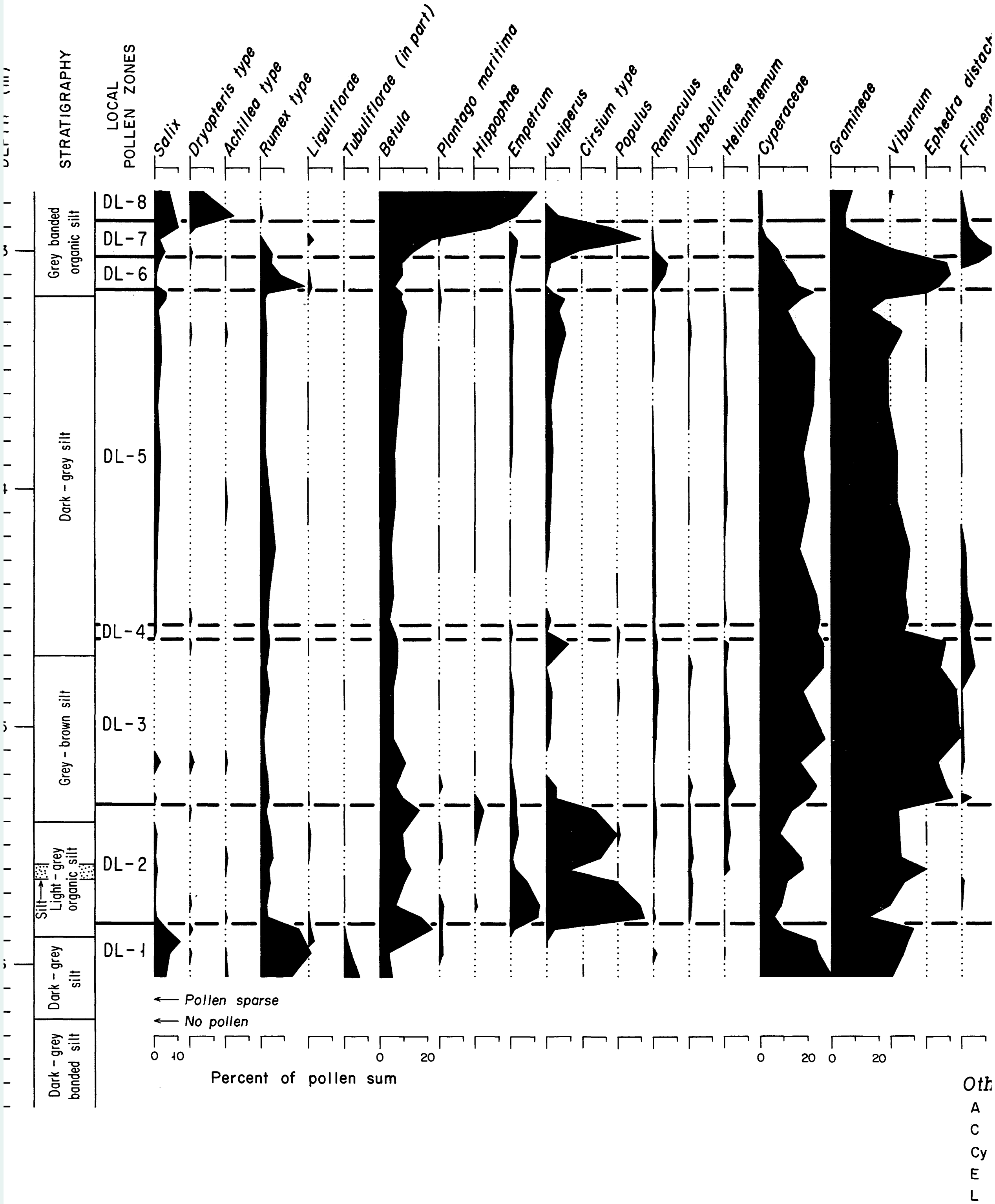
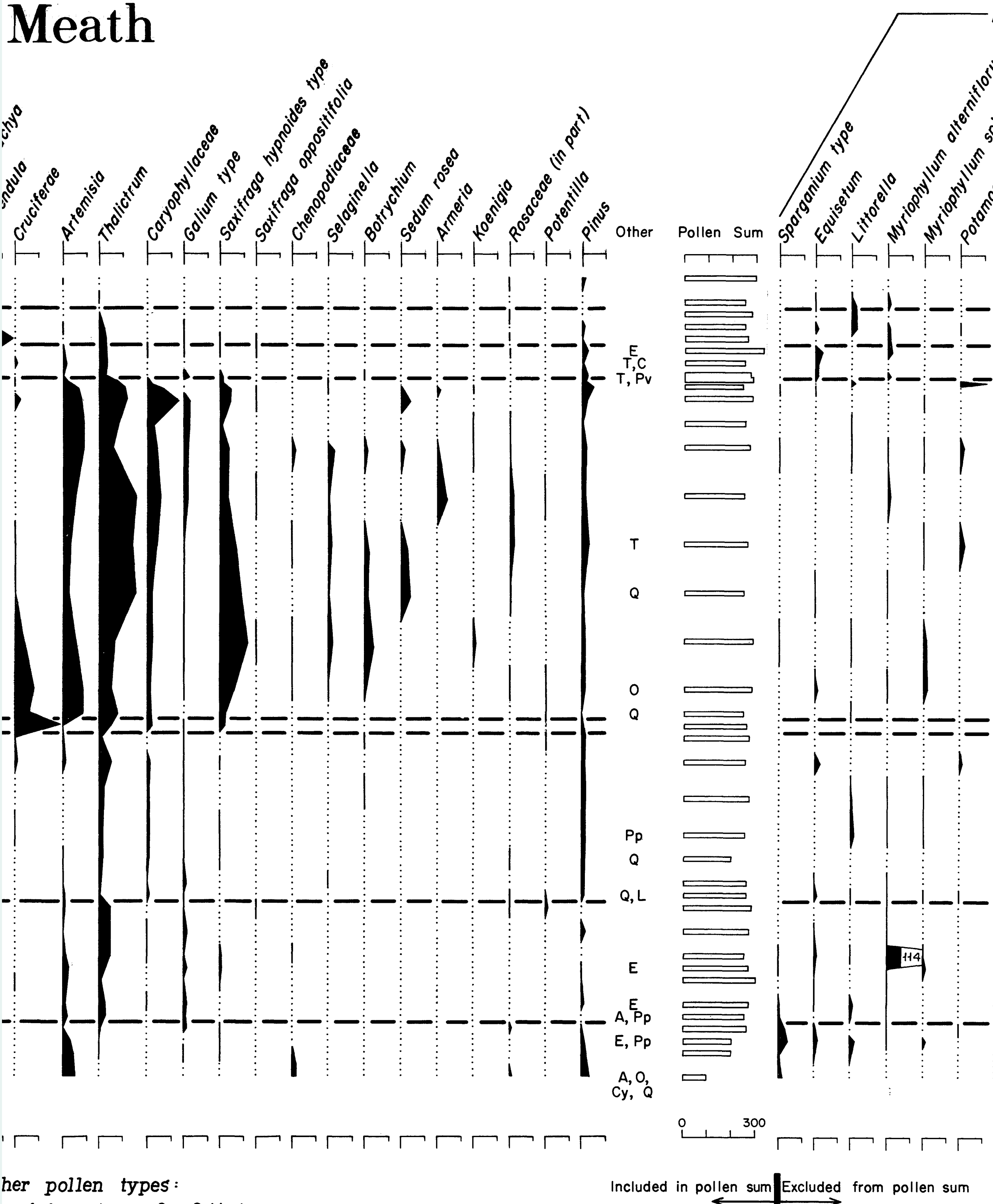


FIGURE 3. Pollen diag

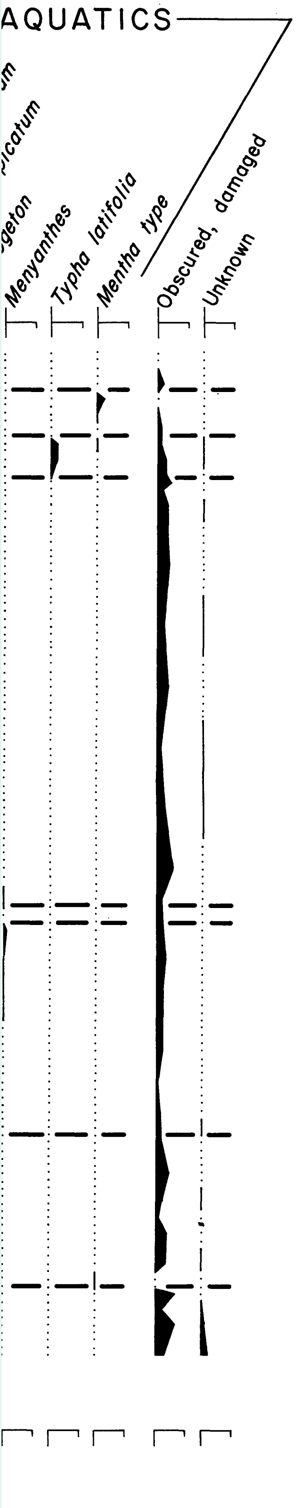
Meath



her pollen types:

	cf. Astragalus	O	Ophioglossum
	Campanula	Pp	Polygonum sect. persicaria
	Cystopteris	Pv	Polygonum viviparum
	Epilobium	Q	Quercus + Corylus
	Linum	T	cf. Trifolium

gram from Dunshaughlin, Co. Meath.



W.A. Watts 1976

A small but well defined peak of *Hippophaë* (sea-buckthorn) pollen is present and leaf hairs were observed at both Ballybetagh and Dunshaughlin at the end of the *Juniperus–Empetrum* phase. They are also recorded at Roddans Port (Morrison & Stephens 1965). The peak appears to be stratigraphically significant in the Dublin region, but elsewhere sea-buckthorn has been little recorded. It is recorded as a peak within the *Juniperus–Empetrum* assemblage in table 1, but is judged to be too small a feature to be given separate stratigraphic recognition.

(iii) The Gramineae (grass) assemblage

In this phase Juniper declines to low values and *Hippophaë* disappears. Grass supplies 50 % of the pollen rain. The most conspicuous associated taxa are *Helianthemum* and Umbelliferae. *Betula* is less frequent than in the preceding phase. The grass species involved are not known. There was some open ground, for mineral material continued to arrive in lakes. The assemblage of grass with low-growing genera such as *Helianthemum* and *Galium* suggests predominant short grassland with small herbs and shrubs and some stands of *Betula pubescens*. The birch occurs macroscopically. This was probably the habitat in which giant deer and reindeer flourished.

(iv) The Cruciferae (crucifer) peak

After the grass assemblage there is a brief peak of Cruciferae pollen. There is more than one type of crucifer pollen. At Ballybetagh Jessen identified *Cardaminopsis petraea* from 'zone III' and subsequently Mitchell (1953) added *Draba incana* and *Cochlearia officinalis* to the list. All three species occur relict on cliffs and base rich talus slopes in Irish mountains now. *Cochlearia* also occurs on seashores. The crucifer peak is very strongly developed at Ballybetagh, Dunshaughlin and Roddans Port (18–30 % of the pollen sum) and less strongly but clearly at Woodgrange (about 10 %). Elsewhere it has not been identified, so it is either a local phenomenon or it has not been observed because of too wide sampling. It appears to be a transitional phase from the grass assemblage to the next phase and probably indicates the beginning of the destruction of stable grassland by solifluxion in a deteriorating climate.

(v) The *Artemisia* assemblage

This phase is sharply distinct from all others in the Late-glacial. The most characteristic pollen types are *Artemisia* and Caryophyllaceae but at Ballybetagh, for example, *Sedum rosea*, *Armeria*, *Koenigia* and *Polygonum viviparum* are virtually confined to the zone, and pollen and leaves of *Salix herbacea* are frequent. *Thalictrum* pollen is common (*T. alpinum* was identified by Jessen at Ballybetagh) and at Dunshaughlin pollen of *Saxifraga hypnoides* type and spores of *Selaginella selaginoides* and *Botrychium* are characteristic. Elsewhere, there is a good deal of variation from site to site. *Artemisia* is not always abundant. High peaks occur at some sites with over 20 % of the pollen, at others the values may be as low as 1–2 %. At many sites the Cyperaceae increase in value and Gramineae decrease sharply, but at Ballybetagh both the Gramineae and the Cyperaceae decrease and at Dunshaughlin the Cyperaceae change little from the previous phase. The rôle of *Juniperus* and *Empetrum* in this zone is particularly interesting. They appear to have been under severe pressure from the climate, but to have been able to survive in favoured localities. Both species disappeared completely at Ballybetagh and Coolteen and were very much reduced or disappeared temporarily in the west and southwest. However, at Belle Lake and Dunshaughlin juniper continued to be successful and *Empetrum* survived at Dunshaughlin. There is no evidence to suggest redeposition of pollen from older assemblages.

There is evidence from Lough Nahanagan that mountain glaciers were temporarily re-established at this time and solifluxion seems to have been widespread (see § 5*f*). The phase corresponds approximately with Jessen's Younger *Salix herbacea* zone (Zone III).

(vi) The Gramineae–*Rumex* (grass–dock) peak

At the end of the *Artemisia* phase orderly organic sedimentation began again, and grass pollen was abundant briefly, associated with *Rumex* at Dunshaughlin and several other Irish sites, but not at Ballybetagh. In this brief phase very great changes must have taken place, for the characteristic pollen types of the *Artemisia* phase all disappeared or were greatly reduced and new taxa such as *Dryas*, *Ononis* type and *Trifolium* appeared fleetingly at Ballybetagh.

(vii) The *Juniperus–Filipendula* (juniper–meadowsweet) assemblage

Grassland was invaded in this phase by juniper, *Filipendula* and *Empetrum*. At Dunshaughlin *Filipendula* peaked first, while at Ballybetagh *Empetrum* was first and played a larger rôle, as is suitable for a mountain fringe habitat now with leached soils. Juniper reached high percentage values in this phase and was as abundant once more in the landscape as it had been in the early Late-glacial.

(viii) The *Betula* (birch) assemblage

In this phase tree birches came to dominate the landscape and replace juniper generally, as is particularly well seen at Dunshaughlin. This is the first more or less closed forest of the Post-glacial and is a suitable point to end consideration of the open landscapes of the Late-glacial and earliest Post-glacial period. Shortly afterwards *Corylus*, *Quercus*, *Ulmus* and *Pinus* appeared and initiated the forested Boreal period.

3. Pollen influx studies

Craig (1973) has carried out pollen influx studies at Coolteen and Belle Lake in southeastern Ireland. The pollen sequence is broadly similar to that at Ballybetagh. In the basal *Rumex–Salix* phase pollen influx is very low. In the succeeding juniper-dominated phase it is relatively high but falls again in the grass phase. An interesting result is that the influx of herb pollen of most genera is higher in the juniper than in the grass phase. The high grass values in percentage diagrams appear to be an artefact of the form of calculation used, rather than an expression of high cover of the landscape, for the grass pollen influx itself is less than in the juniper phase. In the *Artemisia* phase pollen influx is again higher than in the grass phase, a quite unexpected result, for most authors have held that the pollen rain of the *Artemisia* phase was probably an expression of sparse open vegetation. Craig's interesting data will require a thorough re-consideration of the Late-glacial plant cover if they are confirmed by further studies at other sites. Table 2 shows a comparison of Craig's data with data from Britain (Pennington 1975) and from the United States (Waddington 1969; Davis 1969; Craig 1972). Craig has shown that the pollen concentration and influx figures at Coolteen in the *Rumex–Salix* phase compare with the Late-glacial herb zone of the northern United States (the treeless vegetation between the forest margin and the ice sheet) but that the grass phase values are comparable to modern prairie. It is, however, well known that lake basins vary greatly in their characteristics as pollen traps, and that influx data may show great variability between different sites (Pennington 1973). This is clear from a comparison of the data from Blelham Bog (Pennington 1975) and from Coolteen. The Blelham values are all much lower, although the pollen concentration values are similar. Even taking this into account, vastly more pollen was sedimented at Coolteen in the *Artemisia* phase than in the comparable phase at Blelham. In view of this variability, caution should be used in making use of these data until more comparative data are available.

TABLE 2. COMPARISON OF POLLEN CONCENTRATION AND INFLUX VALUES FROM SEVERAL SITES

Coolteen (Craig 1973)			Blelham (Pennington 1975)			
local zone	pollen concentration (cm^{-3})	pollen influx ($cm^{-2}\,a^{-1}$)	local zone	pollen concentration (cm^{-3})	pollen influx ($cm^{-2}\,a^{-1}$)	approximate equivalent in Ireland
Co 1 *Rumex* phase	3.2×10^4	2×10^3	Ba	3.2×10^4	1.0×10^3	*Rumex–Salix* phase
Co 2 Juniper phase	21×10^4	50×10^3	Bb	10×10^4	2.5×10^3	*Juniperus–Empetrum* phase
Co 3 grass phase	15×10^4	15×10^3	Bd	7.5×10^4	1.5×10^3	Gramineae phase
Co 4 *Artemisia* phase	15×10^4	35×10^3	Bf	1×10^4	1×10^3	*Artemisia* phase

	Rogers Lake, Connecticut (Davis 1969)		Lake of the Clouds, Minnesota (Craig 1972)	
	pollen concentration (cm^{-3})	pollen influx ($cm^{-2}\,a^{-1}$)	pollen concentration (cm^{-3})	pollen influx ($cm^{-2}\,a^{-1}$)
Late-glacial herb zone	3×10^4	1×10^3	3 to 10×10^4	1.6 to 5×10^3

	Rutz Lake, Minnesota (Waddington 1969)	
	pollen concentration (cm^{-3})	pollen influx ($cm^{-2}\,a^{-1}$)
Post-glacial prairie	10 to 15×10^4	10 to 25×10^3

4. REGIONAL VARIATION IN VEGETATION COVER

While the Ballybetagh and Dunshaughlin pollen diagrams are very similar, there are differences in detail between the two sites which probably reflect the greater altitude of Ballybetagh, its more exposed site, and its poorer soils which have developed from calcareous boulder clay since the Late-glacial. The differences include the greater rôle of *Filipendula* and *Saxifraga hypnoides* type at Dunshaughlin and, at Ballybetagh, the relatively greater abundance of *Helianthemum* as well as the more distinct rôle of *Sedum rosea*, *Armeria*, *Koenigia* and *Saxifraga oppositifolia* in the *Artemisia* assemblage.

In western Ireland at Poulroe on bare limestone of the Burren Region, and at Lough Goller on infertile shales and sandstones, the same general development of vegetation can be seen as in eastern Ireland (figure 4). *Juniperus* plays a much larger rôle on limestone than on shale. *Empetrum* is more abundant at both sites than farther east. At these sites the early Late-glacial juniper peak is not as well developed as in eastern and southern Ireland and juniper is still present in the grass assemblage. Local presence is proved by the occurrence of a juniper needle in the sediments at Poulroe. Poulroe is of some interest because the relationship of macrofossils to the pollen diagram is known. *Betula nana* (dwarf birch) was frequent but *B. pubescens* (tree birch) is represented by several fruits and bract-scales in the grass assemblage. Birch was not abundant in the pollen rain. *Dryas octopetala* leaves are common at this site, as at other sites in the Burren. *Linum catharticum* is a common Late-glacial macrofossil at Poulroe and at Gortalecka (Watts 1963), and *Thalictrum minus* is also present in the Late-glacial of the Burren region.

So far, evidence for Late-glacial *Empetrum* heath in western Ireland has rested on the work of Jessen at Roundstone in western County Galway (Jessen 1949). The author has confirmed by resampling Jessen's site that *Empetrum* was frequent in the pollen rain of the Late-glacial and early Post-glacial even when *Juniperus* is also recorded. More recently pollen studies have been carried out by M. B. Telford at Glenveagh in northwestern Ireland as part of a Ph.D. thesis at Trinity College, Dublin. The Glenveagh site lies at low elevation in a high rainfall region largely covered by blanket-bog. The bedrock is granite.

The outstanding feature of the Glenveagh pollen diagram (figure 4) is the prevalence of *Empetrum* throughout the Late-glacial and early Post-glacial. *Empetrum* heath with grasses and sedges appears to have been the predominant Late-glacial vegetation at all times, including the *Artemisia* phase. The *Artemisia* phase has low percentages of *Artemisia* itself, and spores of *Lycopodium selago* and *Selaginella selaginoides* are frequent.

In the diagram the features which characterize Late-glacial pollen diagrams from eastern and southern Ireland can be distinguished to some extent. There is a *Rumex–Salix* phase and an early *Juniperus* peak. A silt horizon at 772 cm is correlated with a *Rumex* peak. This is the erosion phase referred to below (§ 5*e*). There is a weakly developed grass assemblage, culminating in a high percentage of *Betula* in one sample. Perhaps birch woodland was established locally for a short period. In the early Post-glacial successive peaks of *Rumex* with grass and *Filipendula* with juniper are very similar to the succession in eastern Ireland.

5. Aspects of climate and landscape in the Late Devensian

(*a*) *Reliability of evidence for the nature of the Late Devensian climate*

In the Late-glacial and Flandrian periods plant migration was universal, and is probably still taking place for many species. During migration species were under constant selection pressure to enable them to coexist with others, to occupy new habitats and niches and to adapt to different climates. The plant communities were restructured as new species immigrated and numbers adjustments took place (Watts 1973). It follows that species may not occupy their total potential range now because they are still migrating, they may differ genetically to some extent from their Late-glacial ancestors because of natural selection and they may occur in associations that did not exist in the Late Devensian. These considerations suggest that caution should be exercised in assessing past climates from present plant distributions. More reliable climatic evidence can be obtained from less ambiguous phenomena, such as the temperature of the ocean, the presence or absence of glaciers, geomorphological evidence of permafrost and solifluxion, the productivity of lakes at different times, and tree cover or its absence. The author doubts whether it is possible to state mean July temperatures for the various phases of the Late-glacial with much certainty of being correct, except within wide margins of error.

(*b*) *The main Late Devensian Glaciation*

Ireland was largely covered by ice at the height of glaciation (figure 5). An ice sheet of 400–500 m in thickness covered the Central Plain and through it the higher mountains which themselves bore corrie glaciers stuck out as nunataks. To the east the main ice sheet passed into a large ice mass filling the Irish Sea basin. In the southwest a local ice sheet covered the mountains of Kerry. A considerable area of southern Ireland, perhaps a fifth of the country, was free of ice and there were ice-free areas locally on the north and west coasts (Synge 1969). The ocean surface temperatures west of Ireland were comparable to those of eastern Greenland at present and there may have been floating ice. The Gulf Stream did not influence Ireland at that time, for 17000 years ago polar water extended to northern Spain (Ruddiman & McIntyre 1973). There seems no possibility that Ireland could have contained 'refugia' on its west coast for oceanic plants as suggested by Mitchell & Watts (1970). It is possible that the ice-free areas were isolated from the rest of Europe by ice sheets, although the floor of what is now the Celtic Sea may have provided a land bridge to Britain. Ice-free areas may have been a critical factor in the late survival of abundant large herbivores such as the giant deer, for there is no clear evidence that Palaeolithic hunters ever reached Ireland. Low sea level must have exposed substantial areas of the continental shelf (figure 5) and these were not invaded by the rising sea until after the Late Devensian, for freshwater deposits with Late-glacial pollen floras lie some 60 m below present sea level near Whiddy Island in southwestern Ireland (table 3, Stillman 1968).

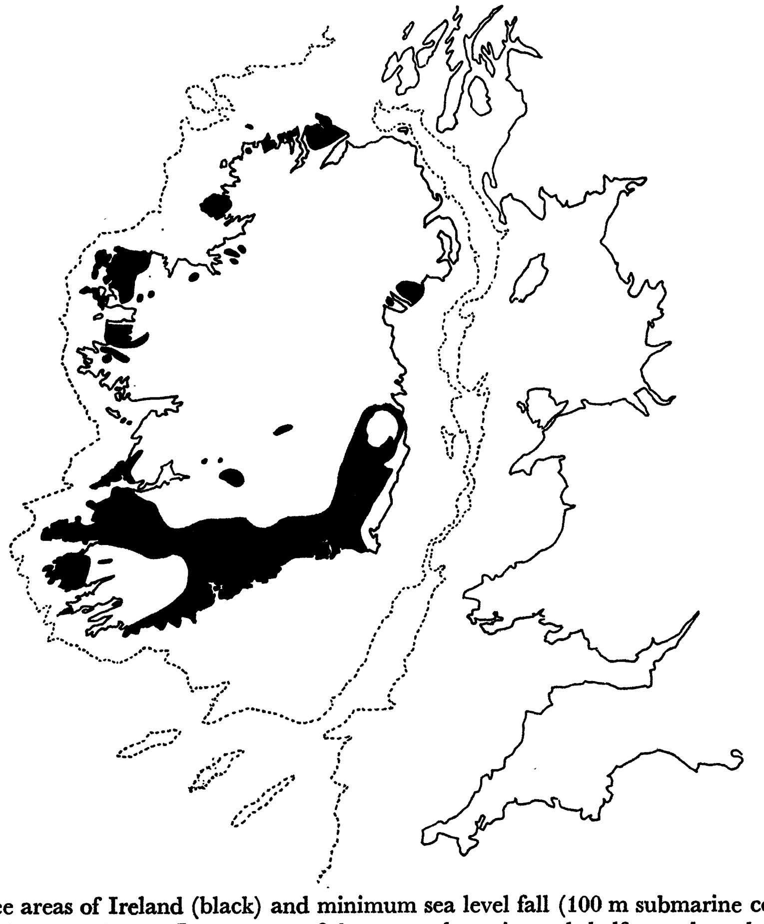


FIGURE 5. Ice-free areas of Ireland (black) and minimum sea level fall (100 m submarine contour shown as dotted line) about 17000 B.P. Large areas of the exposed continental shelf must have been ice-free.

(c) *The climate of the* Juniperus–Empetrum *assemblage*

The Late-glacial juniper assemblage is marked by several distinctive features. It has much the highest pollen influx values of the whole Late-glacial period, and this is contributed not only by juniper, but also by grasses and other herbs. At Coolteen the sediments of the period are very organic with 50 % loss on ignition in comparison with 10 % for most of the Late-glacial. This high productivity may also be observed at Dunshaughlin where whitish grey richly calcareous sediments mark the assemblage stratigraphically. At Roddans Port desmids are found early in the Late-glacial when juniper was frequent (Round, in Morrison & Stephens 1965), and a virtually identical species assemblage is found at Dunshaughlin in the juniper phase. There are numerous species of *Cosmarium* with species of *Staurastrum* and *Euastrum*. It might be argued that the productivity of the lakes and their rich algal floras reflected the interaction of a warming climate with availability of nutrients from unleached till, but the evidence that the upland flora was diverse and that there was a dense vegetation cover suggests that the climate was warm in summer with a long growing season. The success of juniper itself seems to point in this direction. Iversen (1954) explained survival of juniper in the Late-glacial of Denmark by the presence of adequate snow-cover in winter to protect flowering branches in periods of severe climate, with taller growth, free flowering and expansion in a more favourable climate when protection by snow was no longer necessary. In Ireland expansion can be explained by a completely favourable climate and absence or scarcity of competing trees and shrubs. The suggestion that the juniper phase was climatically the warmest of the Late-glacial may be supported by evidence from Britain that diverse Cladocera were present in the early part of the 'Allerød' and that the cladoceran fauna later became impoverished (Goulden 1964; Harmsworth 1968). As yet no evidence is available from Ireland on the stratigraphic occurrence of Late-glacial Cladocera. Coope (1970) and Coope, Morgan & Osborne (1971) have claimed that the evidence of fossil Coleoptera in Britain shows that the juniper phase was an exceptionally warm period. A coleopteran assemblage dated to 12160 ± 180 B.P. (I-4963) at Shortalstown, Co. Wexford, is said to suggest July mean temperatures of 15–16 °C, virtually the same as now (Coope, in Colhoun & Mitchell 1971). It is possible that many older macrofossil records of 'warmth-demanding' plants belong stratigraphically in the juniper phase, but this cannot be demonstrated. It makes new macrofossil studies tightly linked to pollen diagrams very desirable (cf. Watts & Winter 1966).

(*d*) *The grass assemblage and the* Betula *problem*

The failure of *Betula pubescens* (tree birch) to develop birch woodland or forest in the grass phase has been noted by several authors (Singh 1970; Craig 1973). *Betula nana* (dwarf birch) was frequent in the Irish Late-glacial, especially in limestone regions, but *B. pubescens* is also known from macrofossils at several sites (cf. Poulroe, Co. Clare) and must have been widespread. Why did it not form closed woodland or forest? Two explanations are possible. The climate may have been suitable for birch forest, but the trees were browsed very heavily by large herbivores, for at least the giant deer must have been extremely abundant. Alternatively, the climate was unsuitable, because of severe winds, low average annual temperatures and a short growing season. As in northern Scandinavia today, birch stands may have been confined to south-facing slopes or deep valleys protected by winter snow cover. *Helianthemum* cf. *canum* (Mitchell 1953), a species of southern distribution, was abundant in the grass phase. Its abundance seems inconsistent with the inability of birch woodland to develop, so that the overall character of the climate remains a puzzle. Although *Populus* cf. *tremula* (aspen) pollen is recorded from the grass phase, these records are regarded as uncertain at present, because single grains only have been found and there is a possibility of confusion with badly preserved pollen of other taxa. The first certain records of *Populus* date from the early Flandrian where both macrofossils and pollen are known (Jessen 1949; Smith 1961).

The development of vegetation at the beginning of the Late-glacial is strikingly parallel to the Early Flandrian. The Late-glacial may be characterized as an interglacial with deflected development. The juniper phase should have been succeeded by birch and other broad-leaved trees in a steadily improving climate. Instead, a deterioration began at about 12000 B.P. which was not reversed until the Early Flandrian.

(*e*) *Late-glacial erosion*

There is evidence from several sites that erosion characterized the time of transition from the juniper phase to the grass phase. This was already commented on by Watts (1963) and was first noticed by Mitchell (1941 *b*) at Ratoath, Co. Meath, a site close to Dunshaughlin and from which a modern pollen diagram very similar to that from Dunshaughlin is available (Peglar, in Mitchell 1976). Mitchell wrote 'minor climatic oscillations prior to this marked deterioration (Zone III) are possibly indicated by the two grey sandy layers that were traced in the lower chalk-mud over considerable distances'. At many Irish sites, and particularly noticeable in those with predominantly white calcareous lake-muds, a layer of inorganic material, often grey or blue-grey in colour and 2 or 3 cm only in thickness, occurs within a predominantly organic sediment. Such layers have been observed at Muckross, Gortalecka, Lough Goller, Glenveagh and Ratoath. The evidence is not so clear at Dunshaughlin and Ballybetagh where the thick sediments are more varied, but at Dunshaughlin the thick white calcareous muds of the juniper phase are interrupted by a dark silty layer and at Ballybetagh the grass phase is interrupted by somewhat brecciated sediment with large mica flakes. At Belle Lake there is no evidence of erosion, and it has not been observed at other sites with the exception of Coolteen. As it is a relatively minor phenomenon it may well have been disregarded as insignificant in some older studies.

At Coolteen there is very remarkable evidence of erosion. As the juniper phase came to an end sediments which were 50 % organic were succeeded by grey calcareous clays a metre or more in thickness with 10 % organic content. Curves for Na and K are available for the Coolteen profile. These show that if Na and K are expressed as a proportion of the total ash weight their highest values are found in the clays, providing evidence that unleached clay was washed into the basin by erosion.

The inorganic layers at other sites and the thick clays at Coolteen may be contemporary, but the evidence is disputable. At some sites silt layers occur before the end of the juniper phase (Glenveagh, Dunshaughlin), at some they mark the transition to the grass phase (Coolteen, Ratoath, Gortalecka) and at others they lie within the grass phase (Ballybetagh). Craig (1973) has argued that the juniper phase is of different duration at different places and this would explain the apparently variable ages of what might at first sight be a single climatically caused event. However, this cannot be regarded as certain and should not be relied on without further investigation. At Gortalecka, the silt of the erosion phase shows an *Artemisia* peak and at Glenveagh and Dunshaughlin *Juniperus* falls during the erosion phase in favour of *Rumex* and grass respectively.

While unambiguous evidence of a single phase of erosion remains elusive, it is clear that about the time of the end of the juniper phase many lake basins were affected by inflows of inorganic material. This could have any of a number of causes, solifluxion, exceptional precipitation causing sheet erosion, or low water levels with redeposition from shores.

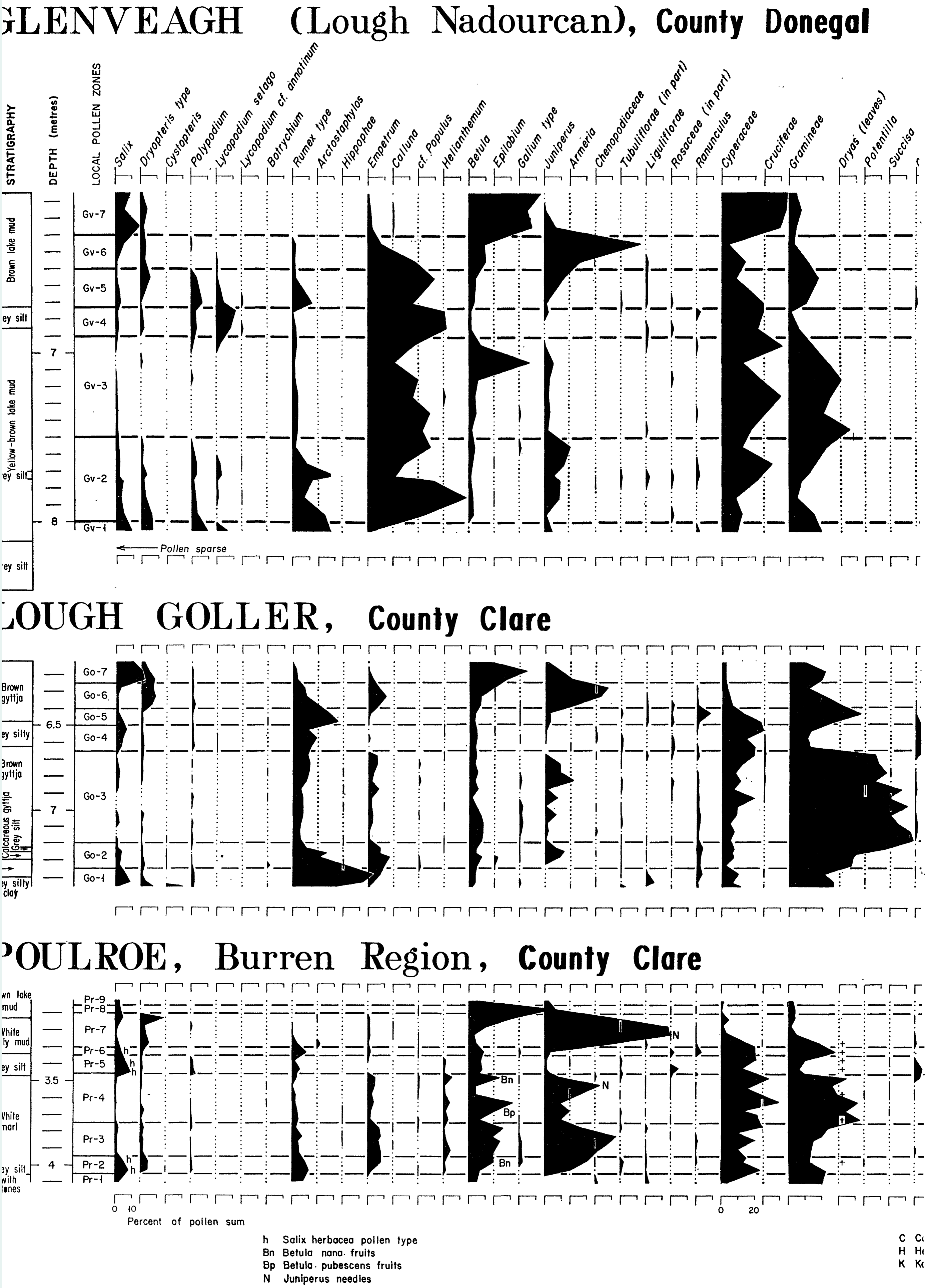
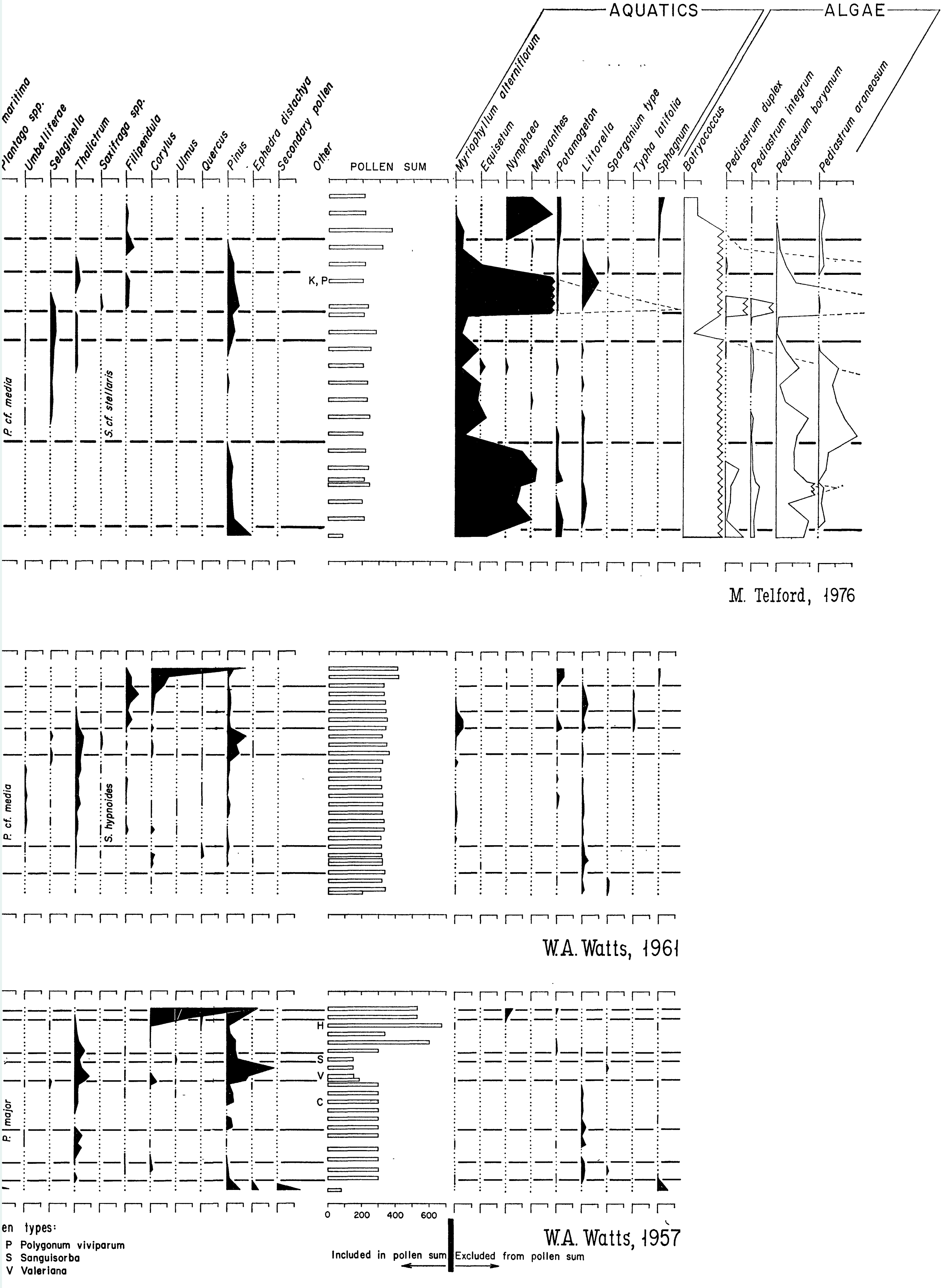


FIGURE 4. Pollen diagrams from Lough Goll



ulroe, Co. Clare, and Glenveagh, Co. Donegal.

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(*f*) *The Nahanagan glaciation and the* Artemisia *assemblage*

Lough Nahanagan lies at an elevation of 410 m in the Wicklow Mountains in mountain bogland above the tree limit. In 1968 the lake was drained temporarily in connection with a hydroelectric power scheme. As the water fell a substantial moraine of granite boulders appeared across the bottom of the lake. The moraine overlies and has pushed lake clays and silts and is overlain by brown gyttja. The stratigraphy was investigated by Dr E. A. Colhoun (unpublished). Organic lenses within the lake clays have yielded dates of 11600 ± 260 B.P. (Birm 321) and 11500 ± 550 B.P. (Birm 320). This places them within the Late-glacial grass phase which is confirmed by a pollen spectrum from one of the lenses. The moraine is covered by water-deposited silt of variable thickness but usually no more than 1 m thick. The silt passes up into fine black-brown organic lake deposits. It is barren of pollen in its lower part. At the top it contains a characteristic pollen spectrum of the *Artemisia* phase. Immediately above, in the first organic sediments, a strong development of the early Post-glacial juniper peak can be seen, perhaps surprisingly strongly developed in such an elevated and exposed site. The pollen spectra are presented in table 3.

Lough Nahanagan is a very important site within the Irish Quaternary, because it provides unambiguous evidence for corrie glaciation during the middle part of the *Artemisia* phase. The renewal of glaciation must have been of brief duration, perhaps 400–500 years at most, for it did not occupy all of the brief *Artemisia* phase (table 1). The glaciation is contemporary with the solifluxion of silt and stony deposits into lake basins throughout Ireland. Mitchell (1973) has claimed that the numerous fossil pingos of southern Ireland date to this period. Pingos which have been investigated do not contain sediments older than the earliest Flandrian and those which have been exposed in section by drainage ditches do not show evidence of older sediments. These observations support Mitchell's opinion. Yet it would be surprising if pingos dating to the main Devensian glaciation and containing older sediments cannot also be found, for the great majority of pingos occur in areas which were ice-free during the main glaciation.

The pollen flora of the *Artemisia* assemblage is the most distinctive of the whole Late-glacial in Ireland. It seems likely that its distinctiveness has been underestimated in the literature. Macrofossil records which are not properly related to pollen diagrams may have been placed in the assemblage in error, giving a false impression that 'temperate' or 'warmth-requiring' species were present. The likelihood that some macrofossils and pollen grains could have been redeposited from underlying Late-glacial deposits by solifluxion may have been overlooked. For example, reports of *Betula pubescens* fruits from 'Zone III' deposits in Ireland appear suspect because birch is infrequent in the earliest Flandrian. The true situation is probably that tree birch was present until late in the grass phase, then became extinct or extremely local and did not play an important rôle again until several hundred years of the Flandrian had passed. Then its population growth may have resulted entirely from new immigration. These considerations emphasize the need for detailed new studies of macrofloras in exact relationship to pollen diagrams (see § 1*b*).

Mercer (1969) has suggested that the cold *Artemisia* phase was a climatic anomaly confined to Europe, especially western and northern Europe, caused by increased ice in the North Atlantic resulting from the break-up of an extensive ice-shelf in the Arctic Ocean. Ruddiman & McIntyre (1973) provide evidence for a readvance of polar water from the Greenland/Labrador region towards the eastern North Atlantic at this time. While the cause of climatic cooling seems

TABLE 3. POLLEN COUNTS FROM LOUGH NAHANAGAN AND WHIDDY ISLAND

	Betula	*Juniperus*	*Salix*	Gramineae	Cyperaceae	*Rumex*	*Empetrum*	*Filipendula*	*Artemisia*	Other herbs	*Lycopodium selago*	Other pteridophytes	*Pinus*	*Corylus*	Other broad-leaved trees	Pollen sum	pollen assemblage or age
Whiddy Island (depth below sea level)																	
57 m (silty gyttja)	20.0	9.0	3.0	14.0	14.0	12.0	13.0	—	—	3.0	—	12.0	—	—	—	100	*Juniperus–Empetrum* assemblage
Lough Nahanagan (depth below mud-water interface)																	
325 cm (gyttja)	5.0	—	1.6	2.6	0.6	0.6	0.3	—	—	0.6	0.3	6.3	22.0	33.3	26.3	300	Flandrian
327.5 cm (silty gyttja)	23.0	0.8	10.4	10.9	1.7	1.3	1.3	0.4	—	1.3	—	36.3	10.9	1.7	—	230	*Betula* assemblage
330 cm (silty gyttja)	9.5	60.0	4.0	7.1	3.1	1.8	1.8	0.3	0.3	5.5	0.6	4.3	2.8	—	0.3	325	*Juniperus–Filipendula*
332.5 cm (silt)	5.4	0.8	3.4	28.3	11.0	3.0	5.9	1.3	1.3	6.8	14.3	11.0	7.6	—	—	237	Gramineae–*Rumex* peak
335 cm (silt)	3.3	0.8	3.3	4.2	24.4	0.8	1.6	—	7.3	9.8	4.9	24.4	11.4	—	—	123	*Artemisia* assemblage
(from organic lens in silt below Nahanagan moraine)																	
silty gyttja	3.7	16.8	1.1	28.0	17.9	8.6	1.1	—	0.4	6.3	4.9	11.2	—	—	—	268	*Juniperus–Empetrum* assemblage

to be focused on the northwestern North Atlantic, its effect is most strongly expressed on the Atlantic coasts of northwest Europe, and Ireland may have been more affected floristically than areas farther east.

(g) *Aquatic plants*

The Late-glacial aquatic flora is a rich one and new species have been added to the known list (Mitchell 1954) in recent years. *Elatine hexandra* is known macroscopically from the grass phase at Muckross, Killarney, and has been found elsewhere as pollen. *Ceratophyllum demersum* occurs early in the Late-glacial at Muckross and at Coolteen. At Coolteen *Potamogeton praelongus*, *P. pectinatus*, *P. crispus*, *P. pusillus* and *P. natans* all occur in the earlier part of the Late-glacial as, apparently, does *Typha angustifolia*. *Pilularia globulifera* megaspores were found in the *Artemisia* phase at Belle Lake. At Ballybetagh, pollen of *Polygonum amphibium* is frequent in the early juniper and grass phases.

It is interesting that the aquatics play their largest rôles at two points within the Late-glacial, at the beginning, and at the transition to Flandrian. In each case a warming climate and an abundant release of nutrients from fresh till surfaces may have resulted in high productivity. At the end of the *Artemisia* phase, in which aquatic plants were completely eliminated at many sites, a remarkable burst of growth took place in the aquatics. *Myriophyllum alterniflorum* was particularly successful as was *M. spicatum* but the short-lived success of *Typha latifolia* and, at Ballybetagh, invasion and vigorous growth by *Ceratophyllum demersum* also mark this phase, which was fully developed and, at some sites, completed before the Flandrian expansion of *Juniperus* began. The very rapid response of aquatics to climatic warming during the Late-glacial is also recorded for Denmark by Iversen (1954).

6. Radiocarbon chronology

The number of radiocarbon dates available for the Late-glacial in Ireland is not great. A series is available from Coolteen and Belle Lake in southeastern Ireland (Dresser & McAulay 1974; Craig 1973). Further series are available from Sluggan, Slieve Gallion, Ballynagilly and Altnahinch in northeastern Ireland (Smith, Pearson & Pilcher 1971*a*, *b*, 1973). The northeastern dates are from bog monoliths. Pollen diagrams have not yet been published for these sites. Dates from Roddans Port (Morrison & Stephens 1965) are not used here because of inconsistencies in the long series which apparently arise from complex sources of contamination (cf. discussion by Dresser in Smith, Pearson & Pilcher 1971*b*). The southeastern and northeastern dates are detailed in appendix 1. They are the source from which the chronology given in table 1 is derived. Other dates are referred to in the text as appropriate.

It is desirable that more dates should be obtained from the earliest Late-glacial. We do not know when the *Rumex–Salix* phase began. Dates as old as 13000 may be obtained but there does not seem to be any reason to expect older dates at present, although they are known from Britain (Pennington 1975). The duration of the grass phase is uncertain because D-111 is significantly younger than UB-227F. The older date is preferred because it is consistent with dates from outside Ireland for the beginning of the *Artemisia* phase. Dates for this event should be nearly synchronous because the vegetation changes were caused by a general climatic deterioration related to a readvance of polar water in the North Atlantic (Ruddiman & McIntyre 1973). The dates for the end of the *Artemisia* phase for northeastern Ireland appear young and D-108 is preferred. It is possible that there is a regional difference in age for this event but the clustering of dates from the northeast around 9500 for several events (cf. UB-297, UB-260, UB-411, UB-225F) suggests that there may be contamination from rootlet penetration or movement of humus in some of the bog monoliths. Some of the dates proposed in table 1 are speculative. As yet we do not know anything about the duration of the Crucifer peak or the transitional herb-dominated phases at the beginning of the Flandrian. Both Ballybetagh and Dunshaughlin are unsuitable for radiocarbon dating because of the probable presence of ancient carbon in their calcareous sediments. It will be necessary to obtain further series of dates from sites where the various possibilities of error are more limited, ideally from autochthonous sediments of a large fast-sedimenting lake in a non-calcareous region. It should be remembered (§ 1*b*) that the pollen assemblages which are the basis of stratigraphy are probably non-synchronous and that a uniform chronology is not to be expected. In this sense any outline chronology is an over-simplification that ignores the likelihood of at least small-scale variation in age for dated events from site to site.

7. Discussion

In Britain Late-glacial pollen diagrams differ substantially in detail from those from Ireland (Pennington 1975). The most important difference is that much of Britain seems to have been covered by birch woodland in the Irish 'grass phase' while in the Netherlands, for example, either birch or pine woodland was present throughout the Late-glacial and juniper was much less frequent. The distinctively Irish features are, (1) an open landscape, never forested, at most with local birch woodland patches, (2) a very large rôle for juniper in the vegetation, (3) a very distinctive flora in the '*Artemisia* phase', suggesting that the climatic deterioration from 10900 to 10200 B.P. may have achieved its strongest expression on Atlantic coasts in northwest Europe, (4) the survival of the large herbivores, no doubt correlated with the absence of man.

The early *Juniperus* expansion between 12400 and 12000 B.P. is seen as the period of warmest climate and highest productivity of land and aquatic vegetation in the Late-glacial. The succeeding grass phase probably represents a climatic deterioration with perhaps a shorter growing season and cold winds, but without large-scale solifluxion. It is natural to equate the *Juniperus* expansion with the Bølling oscillation of Denmark and the grass phase with the Allerød (Iversen 1954). In this case the erosion phase (§ 5*e*) becomes 'Zone I c'. In the author's opinion such a correlation is unjustified. The evidence for a climatic deterioration between 12000 and 11800 B.P. in Britain followed by a recovery has a very slight basis as yet (Pennington 1975). The evidence from Ireland suggests that the climate of the Grass phase was less favourable throughout than the climate of the *Juniperus–Empetrum* assemblage, in other words a permanent deterioration rather than a decline and recovery took place about 12000 B.P. Erosion which took place at about that time may be a series of unconnected local events reflecting a general reduction in vegetation cover.

While the abandonment of Jessen's tripartite zone system is plainly overdue, new investigations will be necessary to improve our understanding of Ireland's Late-glacial flora and climate. In particular new macrofossil studies are needed so that there is no room for doubt about the stratigraphic position of climatically significant species. The identification of the grass species of the grass phase is specially desirable. New information about the supposed 'climatic optimum' of the *Juniperus–Empetrum* assemblage may also come from studies of the Algae, Cladocera and sediments of that time in comparison with those of the grass assemblage.

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I would like to thank N. Allott, H. Lamb, J. Shackleton and other final year students at Trinity College for assistance in field work, A. J. Craig and M. Telford for making unpublished data available to me and G. F. Mitchell, F.R.S., H. E. Wright and H. J. B. Birks for assistance in the laboratory and the field and with discussion of the literature.

Appendix 1. Radiocarbon dates from Late Devensian and Early Flandrian deposits in Ireland

(1) *Southeastern Ireland*

D-109	Coolteen	12470 ± 155	upper part of *Rumex–Salix* phase
D-110	Belle Lake	12235 ± 160	transition from *Rumex–Salix* to *Juniperus–Empetrum* phase
I-5039	Coolteen	12390 ± 160	early in *Juniperus–Empetrum* phase
I-5038	Coolteen	12020 ± 180	near end of *Juniperus–Empetrum* phase
D-111	Belle Lake	10590 ± 185	end of Gramineae phase, transition to *Artemisia* phase
D-108	Coolteen	10210 ± 110	beginning of *Juniperus–Filipendula* phase
D-112	Belle Lake	9600 ± 135	early Flandrian *Betula* peak
D-107	Coolteen	9055 ± 95	end of *Betula* phase before *Corylus* rise
D-113	Belle Lake	9100 ± 130	rise of *Corylus* after *Betula* decline

Data from Dresser & McAulay (1974), Craig (1973).

(2) *Northeastern Ireland*

UB-229F	Sluggan	12470 ± 125	boundary of Zone I–II (equivalent to end of *Rumex–Salix* phase)
UB-447	Sluggan	11635 ± 160	lower Zone II
UB-446	Sluggan	10995 ± 160	middle Zone II
UB-227F	Sluggan	10945 ± 145	top of Zone II, just below III
UB-298D	Slieve Gallion	9660 ± 105	end of Zone III
UB-297	Ballynagilly	9595 ± 125	end of Zone III
UB-411	Altnahinch	9555 ± 135	end of Zone III, transitional to next zone
UB-444	Sluggan	9610 ± 130	early Flandrian *Juniperus* rise
UB-281	Slieve Gallion	9215 ± 75	middle of early Flandrian *Juniperus* peak
UB-225F	Sluggan	9475 ± 145	transition from *Juniperus* peak to *Betula* rise in early Flandrian
UB-260	Ballynagilly	9595 ± 80	fall of *Juniperus*, rise of *Betula* in early Flandrian
UB-419	Altnahinch	9045 ± 125	early Flandrian *Betula* maximum
UB-443	Sluggan	9360 ± 150	falling *Betula*, rising *Corylus*
UB-418	Altnahinch	8895 ± 115	beginning of *Corylus* rise

Data from Smith, Pearson & Pilcher (1971*a*, *b*, 1973). Zone numbers after Jessen (1949).

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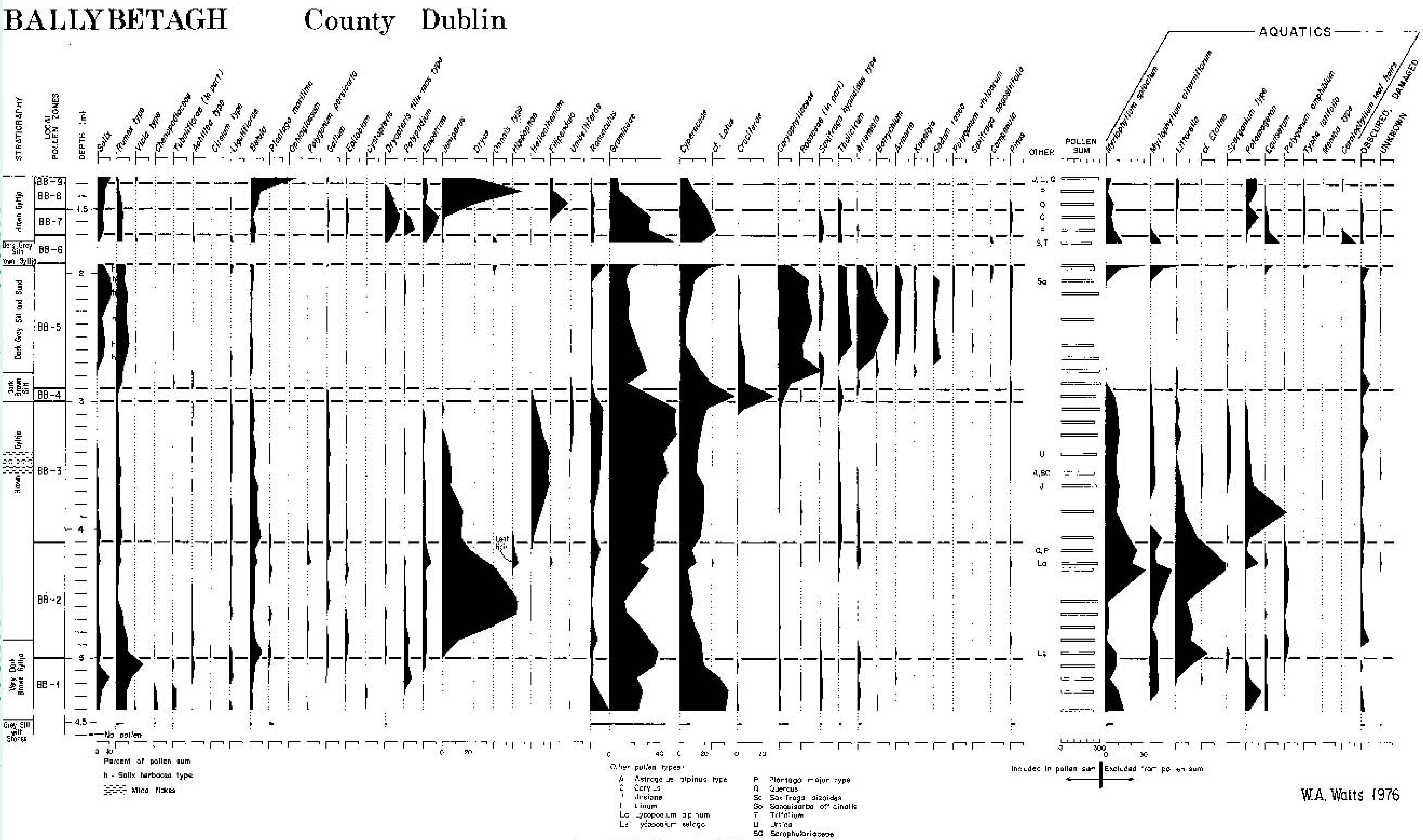

FIGURE 2. Pollen diagram from Ballybetagh, Co. Dublin.

DUNSHAUGHLIN (Lagore), County Meath

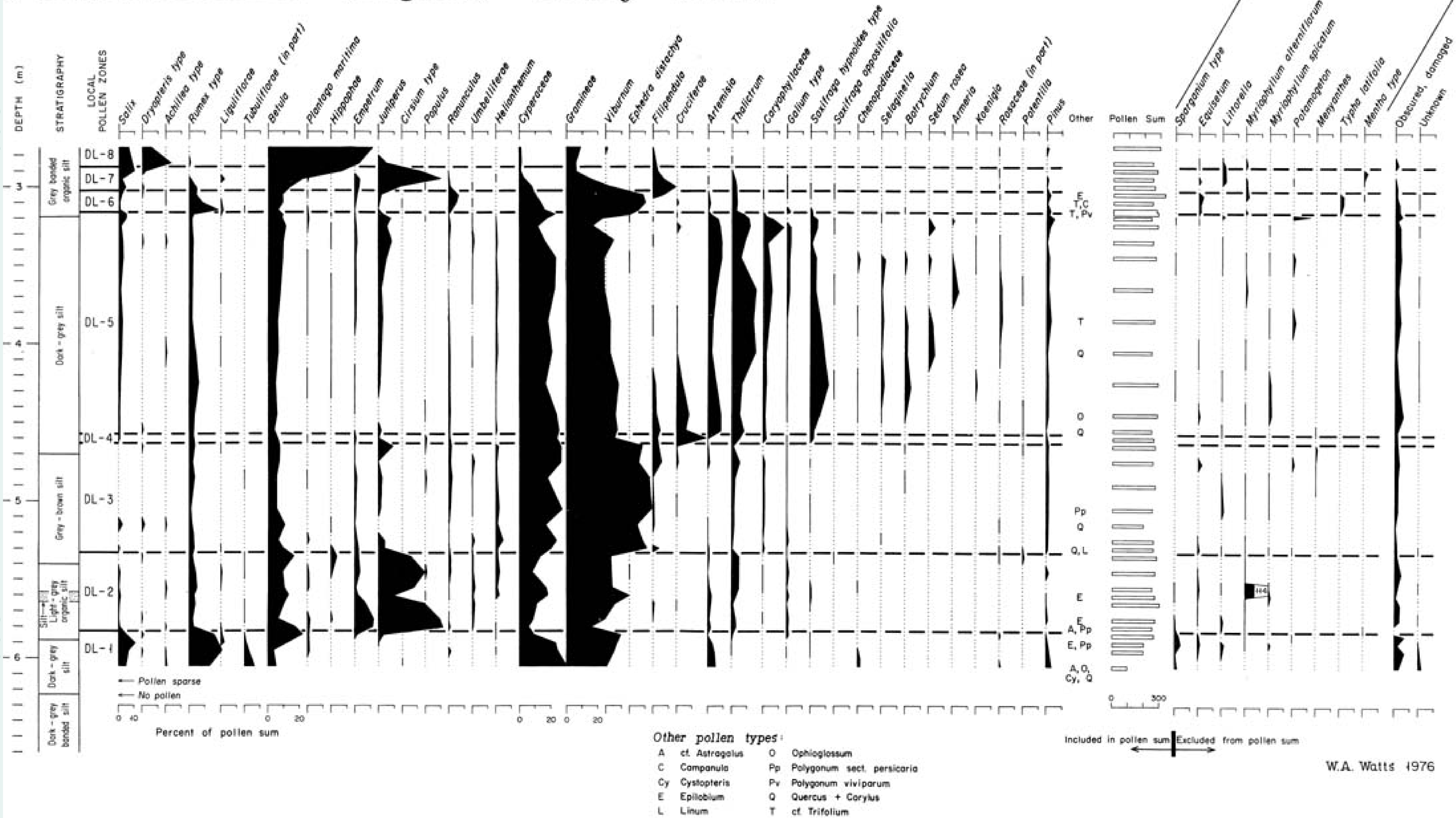

FIGURE 3. Pollen diagram from Dunshaughlin, Co. Meath.