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Late Pleistocene Deposits at Wing, Rutland

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LATE PLEISTOCENE DEPOSITS AT WING, RUTLAND

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CONTENTS

The context, lithostratigraphy and biostratigraphy of a series of Pleistocene deposits from Wing, Rutland, in the East Midlands of England are described.

The sequence of till, lake clays, compressed wood and moss peats and peaty silts is shown to occupy a small, closed basin cut deeply into the Jurassic bedrock. The basin appears to have been excavated by ice responsible for the deposition of Chalky Jurassic Till in the area, and this till lines the floor and sides of the basin.

Pollen and plant macrofossil analyses have provided a long and continuous record of vegetational and environmental history at the site and the deposits have been dated by pollen analysis to the Last (Ipswichian) Interglacial and early Devensian Glacial stages (pollen zones Ip II*b* to e De).

With certain reservations, the sequence is compared and correlated with other interglacial deposits in Britain.

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1. Introduction

This paper presents the results, interpretations and conclusions of an investigation into a series of Late Pleistocene deposits at a site in the East Midlands of England. The information obtained in the investigation has added considerably to the growing body of evidence for vegetational and environmental history in the Last (Ipswichian) Interglacial and the early stages of the succeeding Devensian glaciation. The particular circumstances of these deposits have, moreover, enabled a detailed reconstruction to be made of at least local changes in vegetation and environment through a large part of Late Pleistocene time. The investigation has drawn on the evidence of litho- and biostratigraphy, with especial study of pollen and plant macrofossil remains.

2. Site context

The presence of a peat, apparently of interglacial age, in a deep basin at Wing, was first established during a site investigation carried out in 1974 by Ground Engineering Ltd, on behalf of the Anglia Water Authority. This investigation took place in preparation for the construction of a Water Treatment Plant, associated with the nearby Empingham Reservoir (Rutland Water). The discovery of organic deposits was communicated by Mr T. Power of Ground Engineering to Professor R. G. West, F.R.S., who initiated this study. Much of the material examined was made available through the good offices of Mr Power, in particular the continuous core ('B'), 4 in† in diameter, on which most of the palaeobotanical analyses were carried out.

The village of Wing, which is only a few hundred metres west of the interglacial site, lies in the former county of Rutland (now an administrative subdivision of Leicestershire), within the triangle formed by Melton Mowbray to the north, Stamford to the east and Corby to the south (figure 1). The site is located at National Grid Reference SK899026, at an altitude of about 119–121 m (400 ft) O.D. Like most villages in this area, Wing is perched on an interfluve, a position that reflects the local solid geology. The two streams bounding the interfluve are the River Chater to the north, and a small and unnamed tributary of the Chater to the south. These form part of the characteristic series of roughly parallel, eastward-flowing streams draining into the Welland across this part of the belt of Jurassic strata in the East Midlands. The interfluves here are rather flat-topped, with a somewhat sharp change in slope to the valley sides; the latter slopes are typically flattened to slightly convex, a feature related to large-scale superficial structures within the subdrift geology (see §5). In the vicinity of the interglacial site the valley floors are about 50 m below the tops of the interfluves and are occupied by streams which are, for much of the year, scarcely more than ditches, a metre or so in width.

The solid geology encountered in this area is part of a broad series of escarpments formed upon alternating hard and soft strata of Jurassic age. About Wing, the rather resistant Inferior Oolite has been extensively removed to expose the easily eroded Upper Lias Clay beneath, and the former now appears as a series of outliers, separated from the main outcrop to the east through dissection by the Rivers Nene and Welland and their tributaries.

The extent of the cover of drift upon these rocks is extremely limited in the area under consideration, although to the north, west and south there are nearly continuous sheets of boulder clay on the relatively high ground of the Lincolnshire–Leicestershire (Rutland) border,

† 1 in ≈ 2.54 cm.

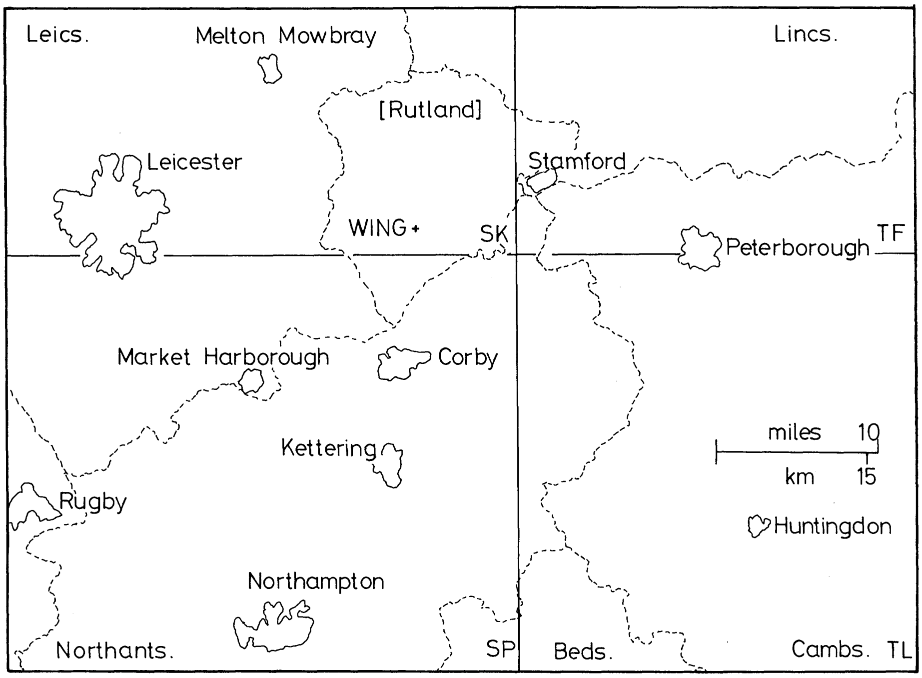

Figure 1. Site location; map shows position of Wing, with county boundaries, major towns in the East and 100 km National Grid squares.

on the Lias uplands between Melton Mowbray and Oakham, and on the Northamptonshire Heights.

Unfortunately, no complete and detailed account of the drift geology of Rutland has been produced since Judd's (1875) memoir.

3. Lithostratigraphy

The lithostratigraphy of the drift deposits at Wing has been elucidated by means of a number of borehole logs made available by Mr Power, and supplemented with numerous hand borings by the author. The positions of these borings are shown on the site plan, figure 2, on which a simplified stratigraphic sequence for each station has been rendered by means of a different symbol. This conveniently indicates the approximate extent of the till at the surface, and the approximate area of the drift-filled basin where the organic deposits were recorded. Extensive augering along the critical eastern margin has shown the basin to be closed and some 100 m in diameter; to judge from the site-investigation borings, the western margin appears to be bounded by a wall of solid, if very much weathered, ironstone.

The considerable depth of the basin is shown in the section, figure 3, where in borehole 42 the Lias was proved at a depth of 102 m o.d., the ground surface at this point being 118.8 m o.d. Thus the minimum thickness of clay to have been excavated during the formation of the basin is of the order of 13–14 m, with a cover 3–4 m thick of ironstone also removed.

The great depth of the basin, the limited amount of basal fill available for examination and the evident variations in the detail with which the site-investigation borehole logs were completed have all necessitated gross diagrammatic simplification of this lowermost part of the lithostratigraphy. Although sequences from the margins of the basin were more readily studied,

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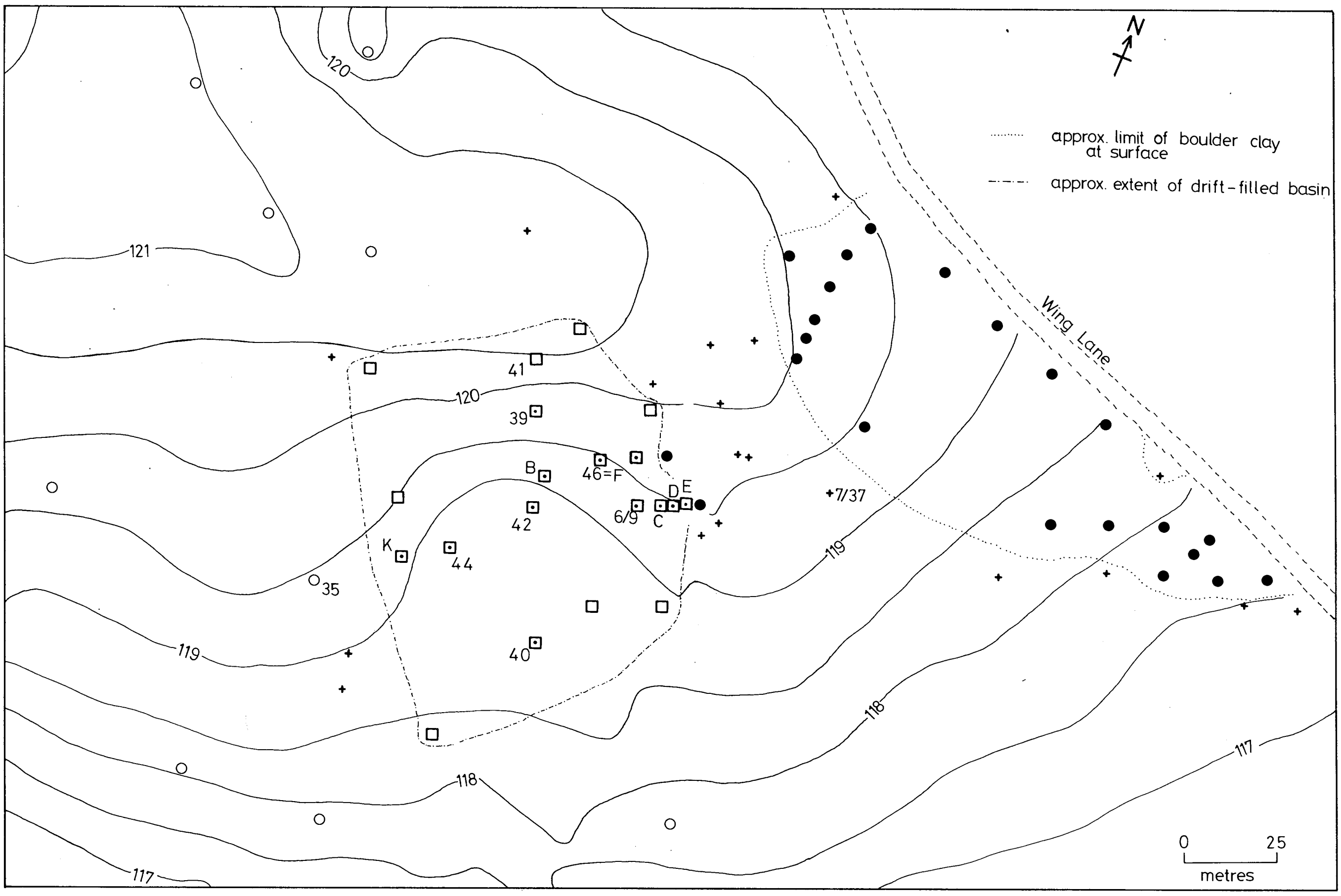

FIGURE 2. Site plan, showing position of boreholes made during site investigation in 1974 and hand borings by the author in 1975–7. The symbols for each station show the kind of stratigraphy encountered. Only those mentioned specifically in the text or shown in figure 3 are numbered: open circles, weathered solid ironstone overlaying Lias clay; crosses, strongly weathered ironstone over clay; squares, basin fills over Lias clay (spot indicates organic deposits proved); closed circles, till over ?solid ironstone.

it was soon apparent that there were enormous lateral as well as vertical variations in lithology, and this has also made detailed graphical representation difficult. The section, figure 3, shows a number of lithological units, which can best be described by considering in turn sequences from the centre and margins of the basin.

(*a*) *Central sequence*

The floor of the basin appears to be blanketed by a continuous sheet of boulder clay, almost certainly contiguous with that near the surface at the northeastern margin of the basin. At depth, this till consists of a stiff, dark blue to grey clay, with abundant crushed chalk and some flint fragments, oolitic limestone, ferruginous sandstone and occasional Jurassic fossils such as belemnites and *Gryphaea*. (N.B. A detailed lithological description for the central core 'B' is given in the appendix, with a key to sediment symbols used in the pollen and plant macrofossil diagrams.)

With the till has been grouped a series of coarse, unsorted deposits, consisting in part of the till just described, but with concentrations of shelly debris, greenish unweathered ironstone, and oolitic shelly limestone. This material may represent solid rock within the till that has not been

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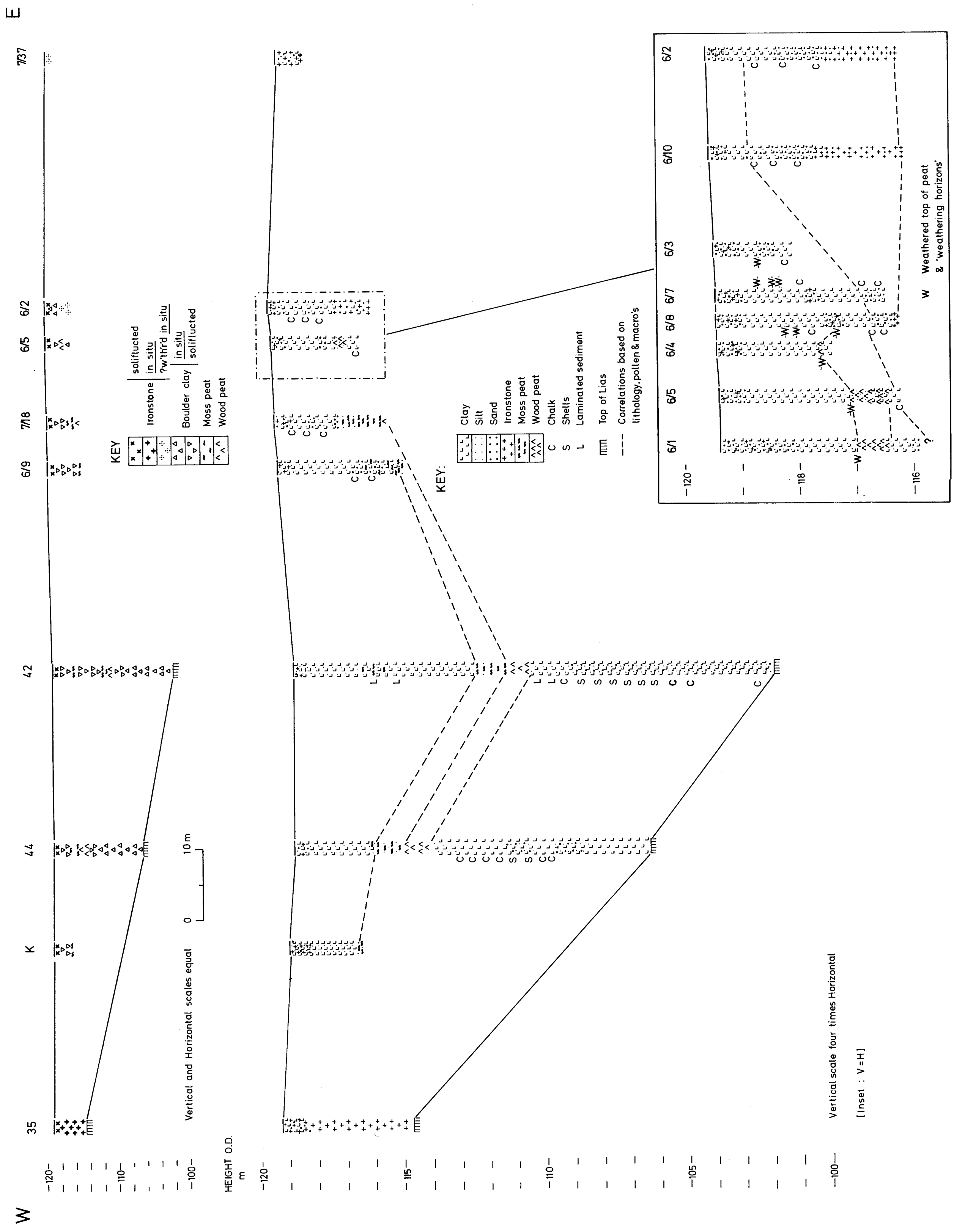


FIGURE 3. Section, east–west, across the basin; lithostratigraphy greatly simplified. The inset, bottom right, shows detail of borings at the critical eastern margin.

greatly broken up (and therefore has probably not travelled very far) or it may have slumped into the basin from the walls of solid rock present at the time of excavation. The presence of shelly debris, probably from the Upper Estuarine Series (which does not outcrop in the vicinity of the site) perhaps supports the former explanation.

Immediately above the uppermost of these coarse deposits, in both borehole 'B' and borehole 42, there occurs a well sorted, silty calcareous clay which has the colour and stiffness of the clay matrix of the underlying till yet lacks all but a few very small fragments of chalk, limestone and ironstone. In the core from borehole 42, moreover, fine laminations with a regular gradation of particle size (varves) were observed, suggesting seasonal inwash and settling of fine sediment from the sides of the basin into a lake of some depth. The most likely source for this clay would have been from till mantling the upper slopes of the basin, and this would also account for its highly calcareous nature.

Towards the top of the laminated clay, a new series of laminations was observed, though here the alternation was of silt and 'peat', the latter consisting largely of debris from forest trees. Countable quantities of pollen (indicating the local presence of mixed oak forest) were obtained from the clay just beneath the first peat layers. Thus there appears to be a very abrupt start to the interglacial part of the sequence. This will be discussed further in §5.

The 'wood peat' that succeeds the laminated peat–clay has a thickness of nearly 1 m at the centre of the basin, although here, as throughout, the organic deposits have been greatly compressed by overlying clays. Besides the abundant leaves, twigs, buds and fruits of a variety of thermophilous trees, the basal part of this peat is characterized by a number of aquatic taxa indicating sedimentary rather than sedentary deposition, while the stratigraphic sections suggest a water depth at the centre of the basin of at least 5 m. The lower part of the wood peat in core 'B' is somewhat sandy or silty, but the inorganic component diminishes upwards through the stratum.

The extreme compression of the peat at the centre of the basin means that subtle changes in peat lithology have not been recorded; however, from close examination of the sediment during the plant macrofossil analyses, it is clear that the next major unit within the peat is dominated by the remains of 'brown mosses' characteristic of fens and the margins of lakes (see §5). The brown moss layer grades imperceptibly into a peat rich in remains of *Sphagnum* and *Eriophorum vaginatum*, with an increasing component of birch (*Betula*).

Above this layer marked by birch remains, the peat becomes composed almost purely of *Sphagnum* material, though still highly humified. Silt begins to appear in the record within this peat, and the character of the sediment gradually changes from a silty detritus peat to a peaty silty clay (see appendix). The clay becomes pronouncedly calcareous and, moreover, exhibits various changes in colour, composition and calcareousness through the upper 5.5 m sequence of this unit at the centre of the basin. Two particular horizons merit specific mention. The first is a series of laminations at a depth of 4–5 m in core 'B', also recorded at equivalent depths in borehole 42. Although they show no internal particle size gradation, it is likely that these laminations, which vary greatly in colour and in thickness, are attributable to seasonal inwash of material from the sides of the basin, with variations in the source material and strength of erosion accounting for the observed changes from one lamination to the next. Within the laminated sediments, slump and microfault structures were recorded; these probably resulted from the increasing load of overlying clays upon the still unconsolidated sediments below.

The lake did eventually fill completely, and the uppermost sediments of the fill now present are increasingly coarse-grained silty to sandy clays with fragments of chalk and, in the top 3 m, weathered ironstone. These clays are characterized by a blue–grey/red–brown mottling, which may be the result of weathering from the modern land surface. The mottling serves to identify the second separate unit within the upper clay sequence, and it has been particularly useful in delimiting the extent of the basin at a stage immediately prior to its final infilling. Across the mottled clay is a thin mantle (usually less than $\frac{1}{2}$ m thick) of stiff red–brown sandy clay rich in ironstone fragments, and it has clearly been derived from the weathered solid ironstone in the area. This presumably represents solifluxion after the filling of the lake during the early part of the Last Glaciation. It is the typical topsoil of the area, mapped as hillwash by the Geological Survey and found to extend into the valley floors, across the outcrop of the Upper Lias Clay.

(*b*) *Marginal sequences*

At the eastern margin of the basin, hand augering revealed a series of clays and peat resting upon unweathered till, the latter being taken to be continuous with that under the central basin-fills (figure 3). The till in these marginal borings was generally found to overlie red–brown ironstone gravel, which in turn overlay unweathered greenish gravel apparently also derived from the ironstone formation. It was not possible to penetrate this gravel, however, and it remains uncertain whether it represents the top of the solid, *in situ* ironstone exposed before the deposition of the till, or, alternatively, massive ironstone within the till sheet; the circumstances of the solid geology and the borehole records from the western side of the basin suggest that the former explanation is more likely.

The till is succeeded above by a stiff blue–brown silty clay, and this, in turn, by a soft, olive–brown, silty clay, which becomes peaty and eventually grades into a silty, well humified peat. Pollen and plant macrofossils from these clays and peats indicate a correlation with the basal wood peat of the central sequence (figure 3).

The thickness of organic sediment at the edge of the basin is, of course, very much less than at the centre, and it thins to become little more than a blackish 'weathering horizon', composed of usually only 10 to 20 cm of finely divided, amorphous, black material. In some borings, more than one such horizon was proved. These may indicate, perhaps, a series of still stands in lake level, with the consequent formation of organic soils which later weathered *in situ*. Pollen analyses of some of these layers showed that they represented forest soils forming at a time of transition from oak- to hornbeam-dominated forest during the temperate part of the interglacial (§4(*b*)).

Inundation of the marginal peats was evidently part of the same general rise in water level experienced within the basin, and, as at the centre, silts and clays began to be deposited. In borehole 46, boulder clay seems to have slumped onto the peat with apparently little reworking, for there are lumps of chalk mixed with the peaty clay. Nearer the edge of the basin, however, the peat is covered by a bright blue sand and this, in turn, is covered by a similarly coloured, soft, plastic clay. The unusual colour may perhaps be attributed to a highly reducing environment at or after the time of deposition. Above the blue clay, the mottled clay already described for the central sequence is once more encountered, and it is succeeded in the top $\frac{1}{2}$ m by the sandy clay topsoil rich in ironstone material.

Finally, it may be mentioned that the weathering horizons in sequences marginal to those yielding weathered peat and the blue clays and sands were recorded between varying thicknesses of mottled clays with a characteristic blue–brown coloration. These clays are correlated with the upper, mottled clays from the central sequence.

4. Biostratigraphy

The following account outlines the results obtained in the various palaeobotanical analyses and presented in a number of diagrams. One again, the central and marginal sequences are considered separately. Throughout this section the following abbreviations have been adopted: a.p., arboreal pollen; n.a.p., non-arboreal pollen; m.o.f., mixed oak forest; p.a.z., pollen assemblage zone.

Figure 4 summarizes the pollen and plant macrofossil assemblage zones discussed below and shows their relation to the stratigraphy of core 'B'. Note that Latin names for native British vascular plants follow Clapham *et al.* (1962) and those for mosses follow Warburg (1963).

(a) *Core* 'B'

(i) *Pollen stratigraphy*

Samples for pollen analysis were taken from all parts of the 9.4 m long core, 'B', although only the section from 0.80 to 7.92 m yielded countable quantities of pollen and spores.

The record starts at 7.92 m, within the upper part of the grey silty clay, just beneath the first peat–clay laminations, where the spectra indicate the establishment of temperate mixed oak forest, typical of the Early Temperate phase of an interglacial vegetational cycle (*sensu* Turner & West (1968)).

The main pollen diagrams for core 'B', figures 5 and 6, have been divided into a series of local and regional pollen assemblage zones, following the scheme of West (1970). The local p.a.z. have been defined as follows.

local p.a.z.	depth/m	characteristic pollen types
W5	0.80–5.67	Gramineae – n.a.p. – Ericales – *Pinus*
W4	5.67–6.25	Gramineae – n.a.p. (mainly Compositae (Liguliflorae)) – *Pinus*
W3	6.25–6.88	*Carpinus* – *Betula* – (*Sphagnum*)
W2	6.88–7.30	*Carpinus* – *Quercus* – *Betula* (with *Tilia*, *Taxus*, *Ilex*)
W1*b*	7.30–7.68	*Quercus* – *Ulmus* – *Fraxinus*
W1*a*	7.68–7.92	*Quercus* – *Fraxinus* – *Acer* – *Hedera* (with *Betula*, *Pinus*, Gramineae)

These are correlated (see §6*a* and figures 4 and 10) as follows with regional p.a.z. of the Ipswichian temperate stage.

regional and local p.a.z.	depth/m	criteria for definition of zones
e De(W5)	0.80–5.67	at 5.67 m *Pinus* declines to levels of less than 20% of land pollen; zone dominated by Gramineae and other n.a.p.
IpIV(W4)	5.67–6.25	zone begins at marked decline in *Carpinus* and other trees, to be replaced by Gramineae and other n.a.p.
IpIII(W3)	6.25–7.03	zone dominated by *Carpinus*; begins where *Quercus* frequencies first exceeded by *Carpinus*
IpII(W1, 2)	7.03–7.92	zone dominated by *Quercus* and other m.o.f. taxa; base not recorded in pollen sequence

The local p.a.z. may be more fully described as follows.

Zone W1. The very local derivation of much of the pollen here, as throughout most of the

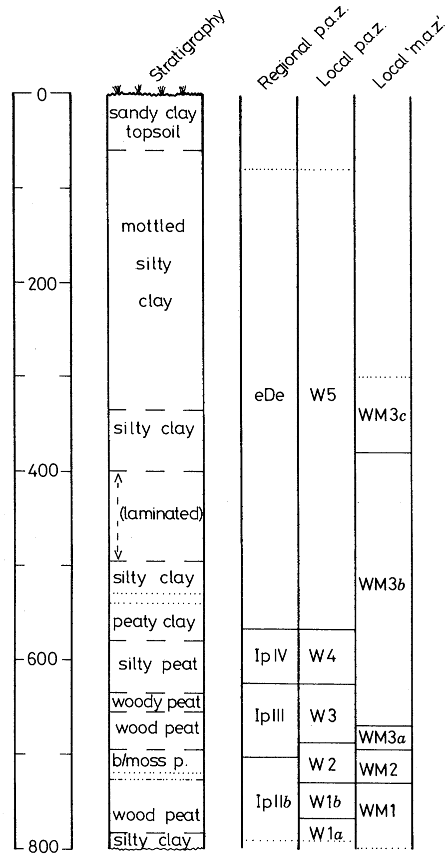


FIGURE 4. Correlation scheme for litho- and biostratigraphy at Wing (core 'B').

record, is reflected in the very high frequencies for the entomophilous taxa *Acer* and *Hedera*, with similar levels of *Fraxinus*. Although the last-named is wind-pollinated, it appears to be under-represented in pollen spectra. These three taxa occur at frequencies of about 20% land pollen (i.e. trees + shrubs + dwarf shrubs + land herbs, following the usual convention), and were occasionally recorded as 'clumps', although each clump of pollen was only scored as a single grain during the counts.

Quercus dominates these basal spectra, but it is rather less important in the section 7.68–7.92 m, which has been designated as a pollen subzone, W1*a*. Here, there are continuous curves for *Betula*, *Pinus* and Gramineae, at frequencies of about 10% land pollen, with slightly higher levels of other n.a.p. than in the subzone above. This presumably represents the vestiges of the 'pre-temperate' vegetational phase, dominated by birch, pine and herbs. All these taxa decline to trace percentages at levels above 7.68 m (subzone W1*b*), where there are considerable amounts (20%) of *Ulmus*; elm had hitherto been present only at trace frequencies.

Corylus and *Alnus* are both recorded at perhaps surprisingly low levels, but this trend continues throughout the diagram and will be discussed separately in §5. Another feature worthy of note here is the curve for pre-Quaternary microfossils, whose decline through zone W1 reflects the diminishing inwash of silt and clay from Mesozoic sediments in the till and solid rocks around the basin.

Zone W2. This zone is somewhat transitional, with continuously changing proportions of its major component pollen and spore taxa. However, there is a consistent assemblage, in qualita-

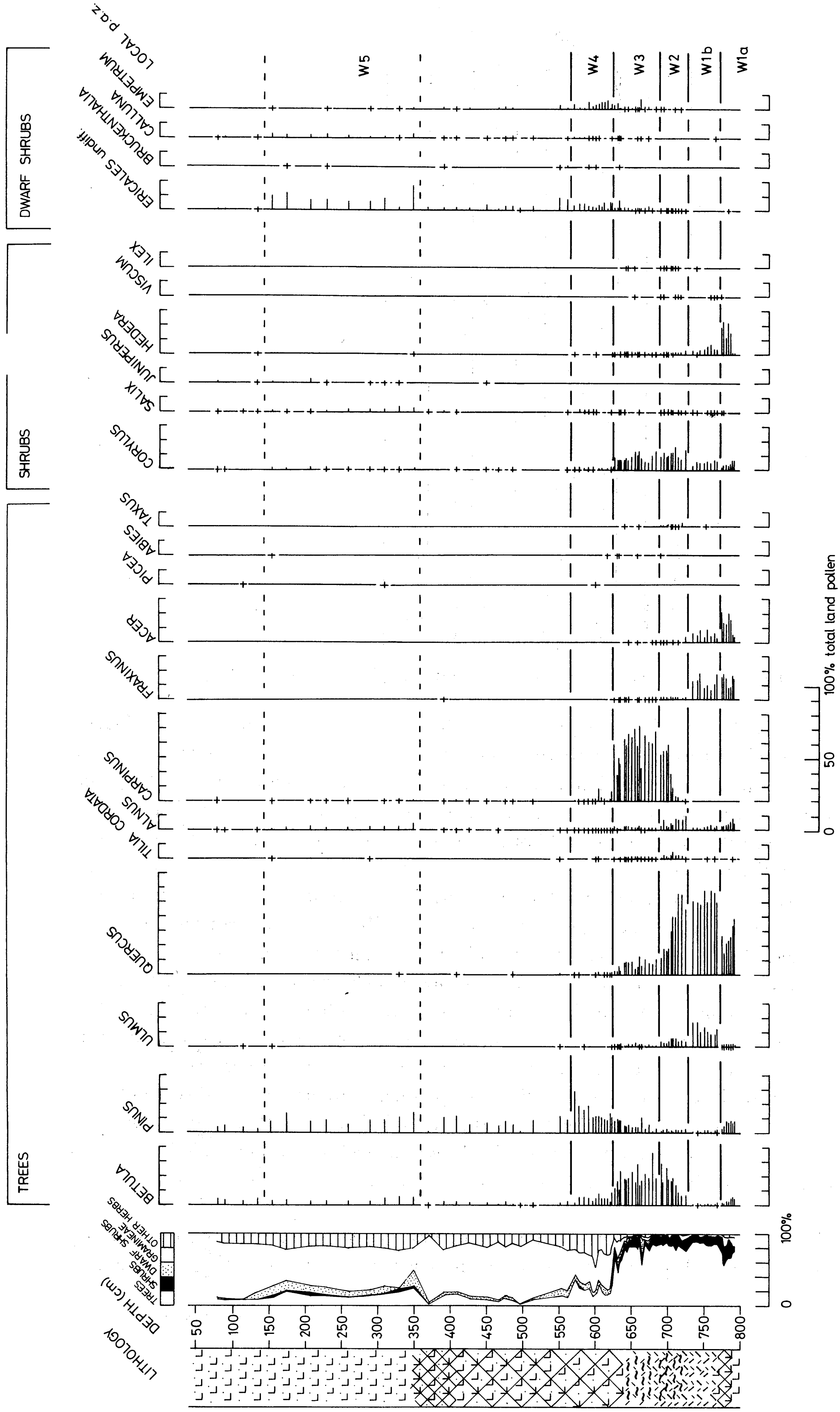


FIGURE 5. Pollen diagram for core 'B', showing woody taxa; + signifies taxa recorded at less than 1 % of the appropriate sum.

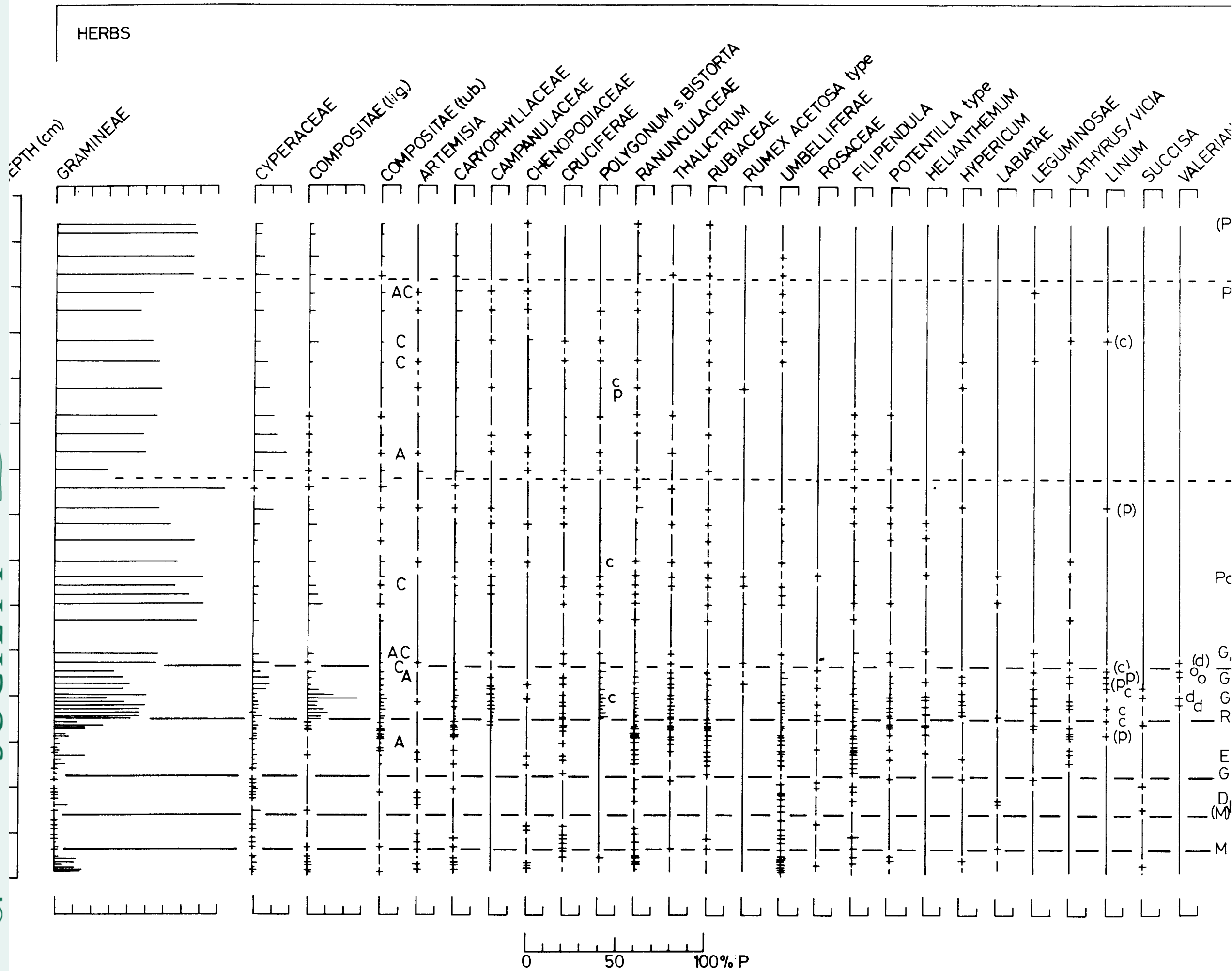
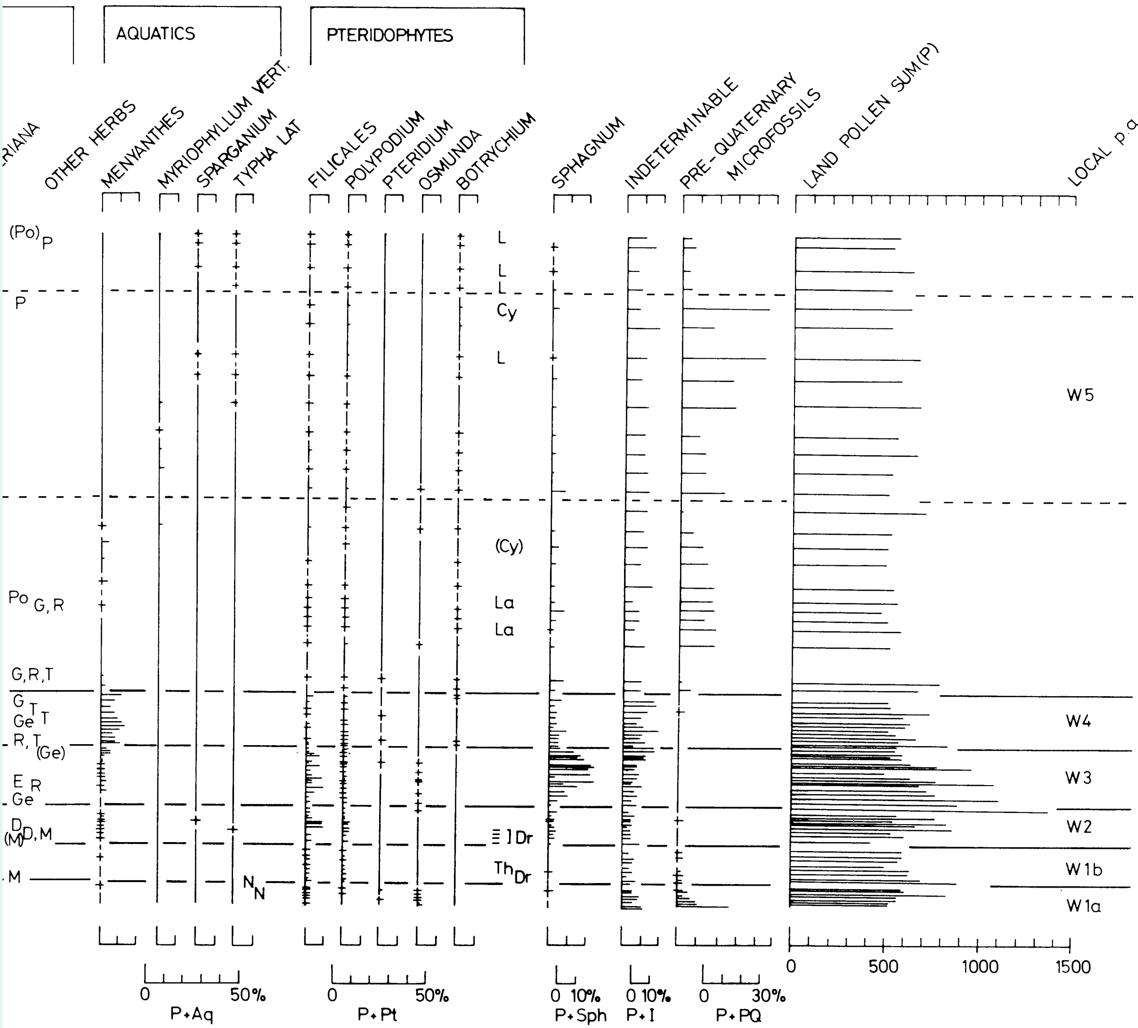


FIGURE 6. Pollen diagram for core 'B', showing herbs, aquatics, spores etc. Symbols as follows. Compositae (tub.): *Linum*: c, *L. catharticum*; p, *L. perenne* ssp. *perenne*. *Valeriana*: d, *V. dioica*; o, *V. officinalis*. Po, *Polemonium*; P, D, *Drosera* cf. *rotundifolia*; M, *Mercurialis perennis*; N, *Nuphar*; L, *Lycopodium* sp.; La, *L.* cf. *annotinum*; Cy, *Cyst* Sph, *Sphagnum* I, indeterminable; PQ, pre-Quaternary; brackets denote a tentative identification; + signifies



): A, *Arctium*-type; C, *Cirsium*-type. *Polygonum* section *Bistorta*: c, *P. convolvulus*; p, *P. persicaria*-type, P, *Plantago* sp.; R, *Rubus chamaemorus*; T, *Trifolium*; G, Gentianaceae; Ge, *Geranium*; E, *Epilobium*; *ystopteris fragilis*; Dr, *Dryopteris filix-mas*-type; Th, *Thelypteris palustris*; Aq, aquatics; Pt, Pteridophytes; ies taxa recorded at less than 1% of the appropriate pollen sum.

tive terms, of *Quercus* and other m.o.f. taxa (which all decline through the zone), and *Betula*, *Carpinus* and *Sphagnum* (which all increase). Small but persistent frequencies are recorded for pollen of *Tilia* (probably all *T. cordata*-type, cf. Andrew 1971), *Ilex* and, more sporadically, *Taxus*.

Also recorded for the first time in this zone are pollens of Ericales, including *Empetrum*, and a further indication from the pollen spectra of the development of acid peat in the basin is given by *Drosera* cf. *rotundifolia*, from two levels.

Zone W3. *Betula*, *Carpinus* and *Sphagnum* all reach their highest frequencies in this zone, although *Quercus* persists at levels of about 10%, with smaller contributions from *Ulmus* and *Tilia*. At the end of the zone, however, all the tree taxa decline (with the exception of *Pinus*) and spectra become dominated by Gramineae and other n.a.p. Levels of Ericales also increase.

Zone W4. The apparently abrupt change from spectra dominated by trees and shrubs to those where herbs and grasses prevail is most striking; it occurs over only 4 cm, between 6.23 and 6.27 m, although the extreme compression of the peat must, to some extent, exaggerate this. Besides frequencies of 40–50% Gramineae, the n.a.p. component of these spectra comprises taxa such as *Polygonum* section *Bistorta*, Compositae (Liguliflorae), Ranunculaceae, Rubiaceae, Umbelliferae, *Filipendula*, *Linum* spp., *Valeriana* spp. etc. (see figure 6). *Menyanthes* becomes a prominent feature of the otherwise rather small aquatic pollen assemblage at this time.

Zone W5. Throughout this zone, Gramineae pollen dominates the spectra, with frequencies of at least 70–80%. There are consistently small percentages of *Pinus* and *Betula*, but, in general, the tree pollen component is now much diminished, and shrubs are scarcely represented. There is a further increase in Ericales, however, to levels of 10–20%, while the variety and abundance of herbaceous pollen types noted in the previous zone is now rather reduced. Although there is a series of samples between 1.40 and 3.60 m, where the frequencies of *Alnus*, *Salix*, Ericales and Cyperaceae all increase, this has not been designated as a separate subzone; it is shown on the diagrams (figures 5 and 6) by pecked lines. The curve for pre-Quaternary microfossils is established once more, at the start of this zone, where the first traces of inwash of mineral sediments are recorded.

(ii) *Plant macrofossils*

As far as possible, a continuous sequence of samples for the analysis of plant macrofossils was taken from core 'B'. This was particularly desirable in view of both the richly organic nature of much of the material and the extreme compression of the peats. Thus, most of the samples were from contiguous slices, 5, 10, or 15 cm thick.

The record for plant macrofossils begins with the basal sample at 7.94–8.00 m; this comes from the silty clay immediately beneath the wood peat (described above, §3) and a little below the lowermost polleniferous sediments. The very low concentrations of macrofossils here could not, unfortunately, be compensated for by increasing the sample size, since the rapid changes in lithology dictated the use of only thin slices from the 4 in diameter core. The upper limit for identifiable remains at reasonable concentrations is at 3.00 m, above which, although still polleniferous, the clays did not contain sufficient fruits and seeds etc., in samples of even as much as 500 g, to make macrofossil analyses practicable.

The results of the macrofossil analyses are shown on the diagrams (figures 7–9) and in table 1. The diagrams are constructed in a way broadly similar to that for pollen, already discussed, though the taxa are grouped differently, and the data are expressed in one of two forms: fruits and seeds are shown as numbers of individuals per unit mass (here 100 g) of sediment, while the results for mosses and certain other types of remains are presented on a six-point scale of abundance.

Note the following abbreviations that appear on these diagrams and in table 1: Ceratophyllum sub., *Ceratophyllum submersum*; Pot., *Potamogeton*; Myriophyllum s./v., *M. spicatum/verticillatum*; Ranunculus bat., *R.* subgenus *Batrachium*; Eriophorum vaginatum (scl.sp.), *E. vaginatum* (sclerenchyma spindles); Camptothecium ser./lut., *C. sericeum/lutescens*; a., achene; an., anther; b.sc., bud scale(s); c., caryopsis; fr., fruit; fgts, fragments; lvs, leaves; m., mericarp; per. segs, perianth segments; s., seed(s); spga, sporangia.

The diagrams have also been subjected to a simple zonation following similar principles to those used for pollen diagrams. This has, of course, only created local assemblage zones, which can have little or no regional significance; they have been defined as follows.

local m.a.z.	depth/m	characteristic taxa
WM3*c*	3.00–3.80	*Carex* spp., herbs of open ground
WM3*b*	3.80–6.70	*Potamogeton* spp., *Nitella*-type, *Ranunculus* subgenus *Batrachium*, Ericales; a variety of herbs, mosses of acid peat
WM3*a*	6.70–6.95	paucity of taxa; *Eriophorum vaginatum* and *Sphagnum* predominate
WM2	6.95–7.30	*Menyanthes*, m.o.f. trees, *Betula*, *Carpinus* and 'brown mosses'
WM1	7.30–8.00	floating and floating-leaved aquatics, m.o.f. trees, corticolous/calcicolous mosses

The zones may be more fully described as follows.

Zone WM1. The basal zone has two main and contrasting components, terrestrial and aquatic. The latter is represented by floating-leaved types (*Nymphaea*, *Nuphar*), submerged types (*Ceratophyllum* spp.), and free-floating types (*Lemna*), with oospores of the calcareous alga, *Chara*, present in some quantity in the basal (calcareous) clay. The forest trees are well represented by their fruits, buds and often also by anthers; the most important taxa are *Acer*, *Fraxinus* and *Quercus*, with a smaller component of *Ulmus*. There is also a suite of mosses, of which some, e.g. *Antitrichia curtipendula* and *Neckera complanta*, are characteristically corticolous and may have growth on the boles of the forest trees. The 'marsh' taxa here, as throughout, are scarce; *Lycopus* is the only type to occur with any regularity.

Zone WM2. Although many of the taxa recorded for the previous zone, notably the trees and mosses, are still present here, a number of important new taxa appear and many others disappear. Thus, the aquatics of zone WM1 are replaced by *Brasenia schreberi*, which indicates that at least some open water was still present, and marginal aquatics are represented by *Dulichium arundinaceum* and *Menyanthes*. Taxa of damp mineral soils are no longer recorded, but there are the first occurrences of acid peat plants, notably *Drosera rotundifolia*, *Eriophorum vaginatum* and *Vaccinium oxycoccus*. The presence of *Sphagnum* is also firmly established, although the species concerned have not been determined. With the m.o.f. trees, *Taxus* (leaves and seeds), *Ilex* (fruitstones), *Betula* and, a little later, *Carpinus* now appear. There are few herbs, but the 'brown mosses' *Cratoneuron commutatum* var. *falcatum* and *Meesia longiseta* are prominent.

Zone WM3. Partly because of its length, this zone has been divided into three subzones.

Zone WM3*a*. The number in this subzone is small, with remains of *Betula*, *Eriophorum vaginatum* and *Sphagnum* dominating. While strong humification may have been responsible for this paucity of taxa, the abundance of remains of the three plant species mentioned suggest vegetation that was, in fact, species-poor.

Zone WM3*b*. In this next subzone, however, the assemblages of plant macrofossils are much

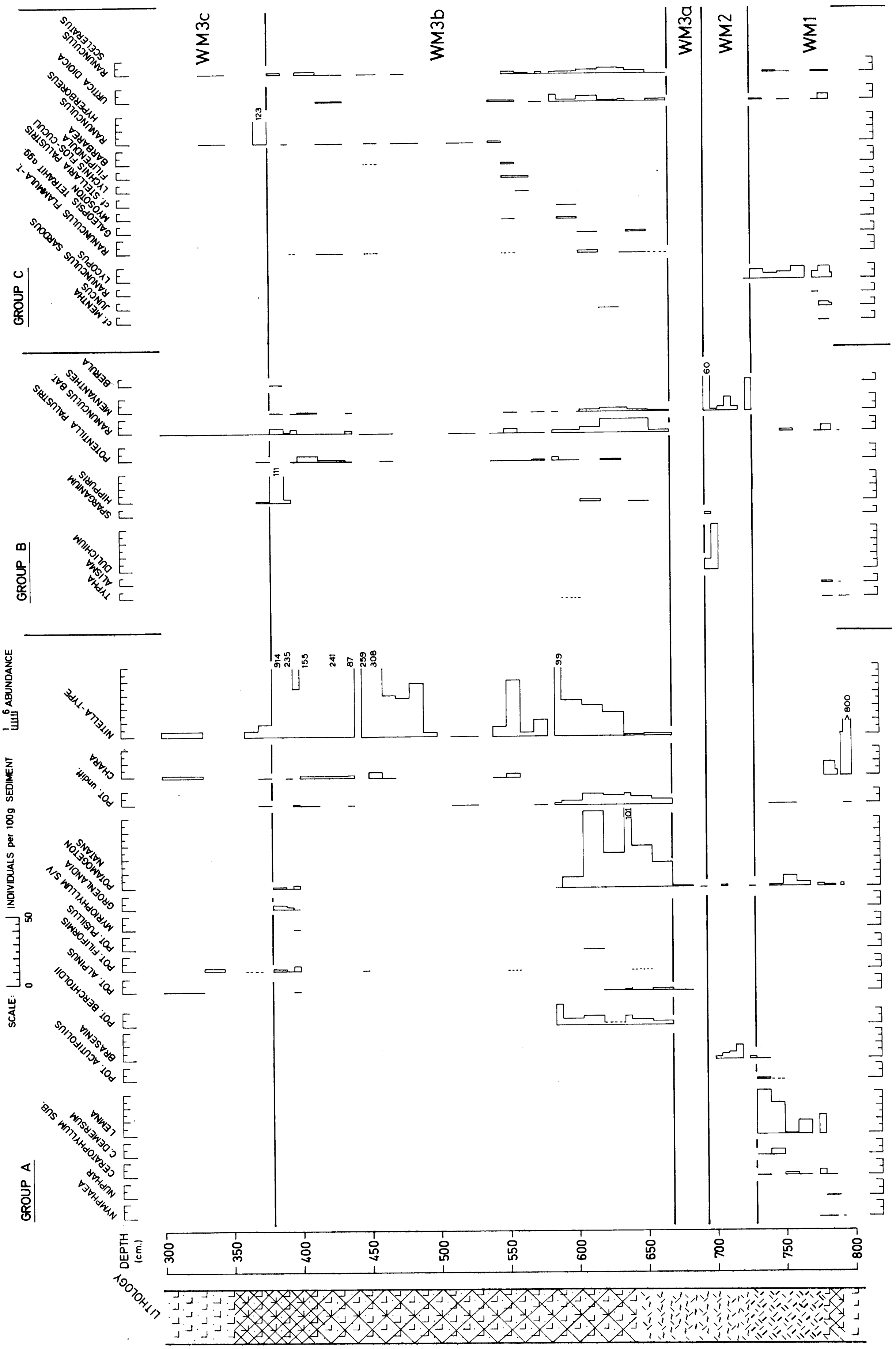


FIGURE 7. Plant macrofossil diagram (core 'B') for submerged or floating-leaved aquatics and plants of standing water (Group A), marginal aquatics (Group B) and plants of moist terrestrial habitats (Group C).

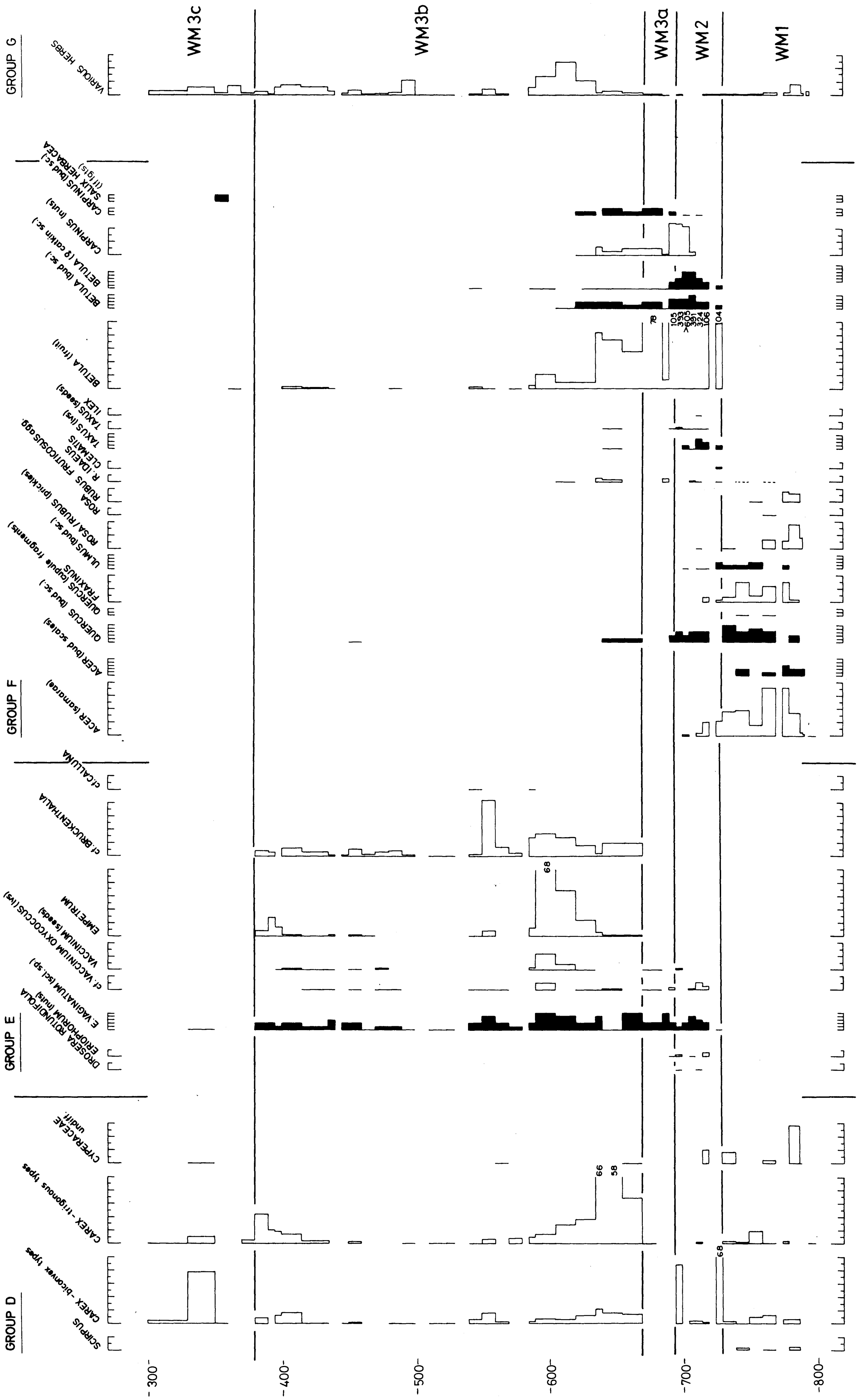


FIGURE 8. Plant macrofossil diagram (core 'B'): Cyperaceae, excluding *Eriophorum* (Group D), plants of acid peat substrates (Group E) and woody taxa, excluding dwarf shrubs (Group F).

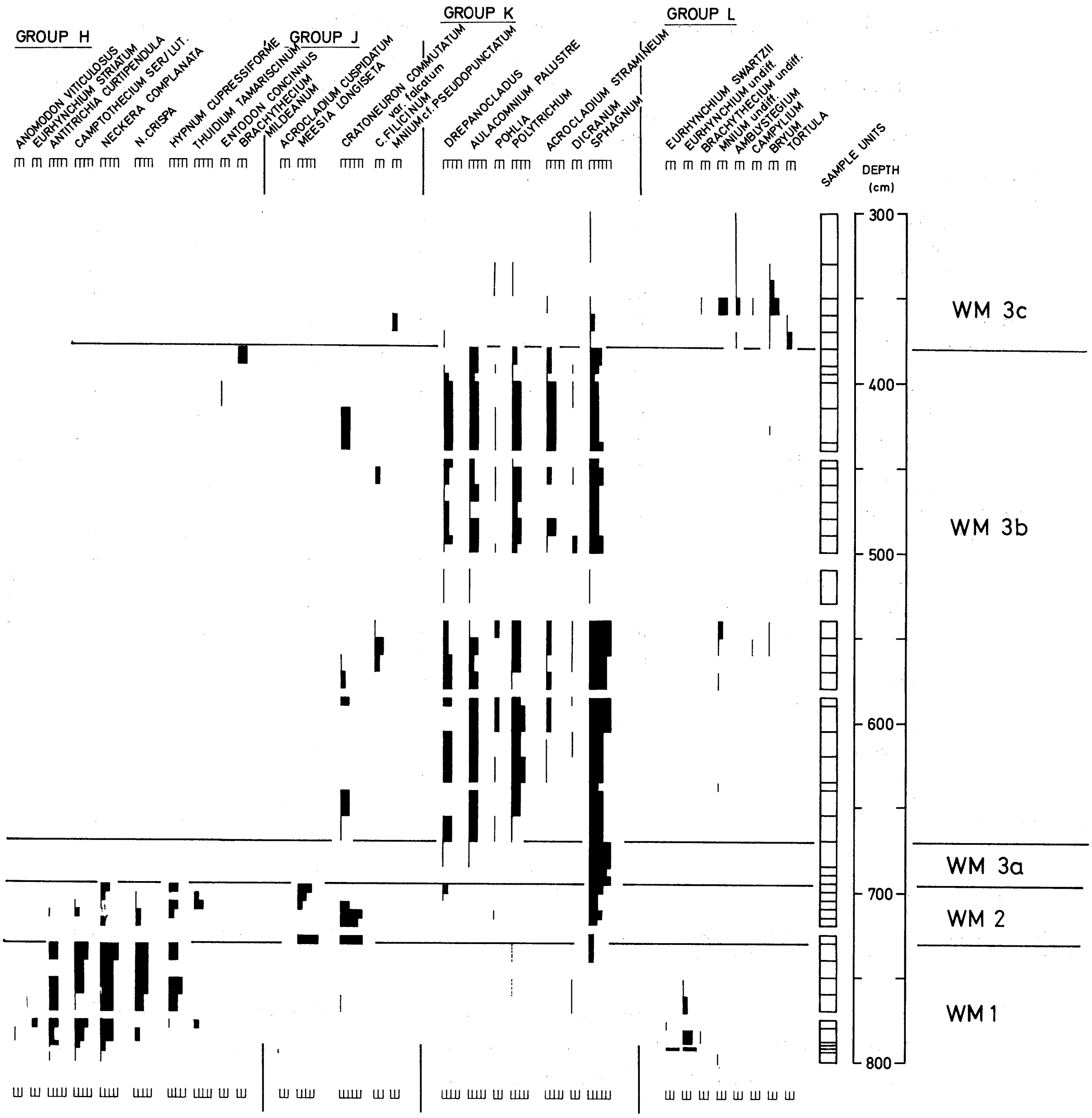


Figure 9. Plant macrofossil diagram (core 'B'): mosses of corticolous and/or calcareous habitats (Group H), mosses of marsh/fen (Group J), mosses of acid bogs (Group K) and ecologically indeterminate taxa (Group L).

less restricted. Aquatics are once more important, with large numbers of pyrenes of *Potamogeton* spp. and with *Nitella*-type oospores. There are nearly continuous histograms for the marginal aquatics *Potentilla palustris*, *Ranunculus* subgenus *Batrachium* and *Menyanthes*, and *Hippuris* is, briefly, important at the upper end of the zone. Herbs of damp ground are represented by *Ranunculus flammula/reptans*, *R. hyperboreus*, *R. sceleratus* and *Urtica dioica*, while *Carex* spp. are abundant towards the upper and lower ends of the zone. Acid peat taxa predominate throughout, with persistent records for *Eriophorum vaginatum*, *Bruckenthalia spiculifolia*, *Vaccinium* sp(p). and *Empetrum*. There is also a suite of mosses characteristically associated with *Sphagnum*, which is itself the major component of the organic fraction of the sediments representing this zone.

Table 1. Plant macrofossils from core 'B': Group G (dry land herbs)

depth/cm ... taxon	type of remains	WM3*c* (300–380)	WM3*b* (380–670)	WM3*a* (670–695)	WM2 (695–730)	WM1 (730–800)
Campanula rotundifolia L.	s.	+	+	−	−	−
Caryophyllaceae indet.	s.	−	+	−	−	+
Cirsium/Carduus sp(p). indet.	a.	+	−	−	−	+
Compositae indet.	a.	−	+	−	−	−
Cruciferae indet.	s.	+	+	−	−	−
Epilobium sp.	fr.	−	−	−	+	+
Filicales	spga	−	+	+	−	+
Gramineae indet.	c.	+	+	−	+	+
Hypericum sp.	s.	−	−	−	−	+
cf. *Leontodon* sp.	a.	+	+	−	−	−
Luzula sp(p).	s.	−	+	−	−	−
cf. *Marrubium vulgare* L.	n.	−	−	−	−	+
Moehringia trinervia (L.) Clairv.	s.	−	+	−	−	+
cf. *Mycelis muralis* (L.) Dum.	a.	−	−	−	−	+
Polygonum sp(p). indet.	fr.	+	+	−	−	−
P. section *Bistorta*	an.	−	+	−	−	−
Polypodium sp.	spga	−	−	−	+	+
Potentilla section *Potentilla*	a.	−	+	−	−	−
Primulaceae indet.	s.	−	+	−	−	−
Ranunculus section *Ranunculus*	a.	−	+	+	+	+
R. parviflorus L.	a.	−	−	−	−	+
Rumex sp(p). indet.	per. seg.	+	+	−	−	−
	fr.	+	+	−	−	−
Saxifraga sp. indet.	s.	+	−	−	−	−
Solanum cf. *dulcamara* L.	s.	−	−	−	−	+
Sonchus asper (L.) Hill	a.	−	−	−	−	+
Stellaria graminea L.	s.	−	+	−	−	−
Stellaria sp(p). indet.	s.	−	+	−	−	+
Taraxacum sp(p). indet.	a.	−	+	−	−	−
Umbelliferae indet.	m.	−	−	−	−	+
Viola sp(p). indet.	s.	+	+	−	−	+

Abbreviations for the types of remains are given in the text; + indicates that one or more individuals were recorded for the appropriate macrofossil zone.

Zone WM3*c*. Once again, this is a zone with sparse macrofossil assemblages; *Salix herbacea*, *Rumex* sp(p)., *Saxifraga* sp. and a number of mosses probably indicative of inorganic rather than acid peat substrates are all recorded, albeit in very small numbers.

(*b*) *Marginal sequence*

(i) *Pollen stratigraphy*

A number of samples from some of the cores marginal to the basin were analysed for pollen to permit correlation across the basin. Only two cores provided contiguous sequences of samples, however, namely cores 46 and 'C' (from the hand-augered boring 7/18).

The results for the two short sections available from core 46 indicate that the upper (3.00–3.45 m) can be assigned to pollen zone W4 of the main sequence, having spectra dominated by Gramineae, n.a.p., *Pinus* and *Carpinus*. The lower (4.50–4.95 m) yielded *Quercus–Betula–Carpinus* assemblages and has been referred to zone W2.

In core 'C', samples were taken from the humified peat and from the blue sand and clay immediately above it. The sequence shows that the basic record proved for the centre of the basin is here repeated in a much condensed form. This presumably reflects slow sedimentation

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at the edge of the basin, or perhaps, rather, the net deposition of only a small amount of sediment under a regime of continual erosion and deposition. The only taxa new to the pollen record here are *Frangula* and *Thelycrania sanguinea*; the latter is also represented in the macrofossil record from the marginal deposits.

(ii) *Plant macrofossils*

More detailed analyses of the cores just discussed were made for plant macrofossils, partly in an attempt to increase the list of taxa recorded and thence to provide a more complete picture of the types of vegetation in the vicinity of Wing during the period represented by the deposits. However, these marginal deposits were often heavily humified and only a few new taxa were recorded: *Ajuga* cf. *reptans*; cf. *Crepis* sp.; *Euphorbia* cf. *platyphyllos*; *Populus* sp.; *Potamogeton crispus*; *P. pectinatus*; *Prunus* cf. *avium*; *Thelycrania sanguinea*; and *Valeriana* cf. *dioica*.

The detail of the central core further permits broad correlation of these marginal sequences by plant macrofossil assemblage zones, in a similar way to that of those for pollen. Thus, core 46 provided assemblages comparable with those described for zones WM2 and WM3*b*, agreeing with the independent correlation based on pollen evidence. Similarly, from core 'C', zones WM1, 2 and 3 could be discerned.

Cores 'D' and 'E' (borings 6/1 and 6/5 respectively, see figure 3) were also examined for plant macrofossils and both proved that the peaty clay in these extreme marginal sequences belongs to zone WM1 (pollen zone W1 or Ip II). Unfortunately, the overlying heavily humified peat in core 'D' was virtually devoid of identifiable remains; this suggests that it was at some time a subaerial surface, possibly a forest mull soil, which was inundated by the blue sand and clay, dated from core 'C' to W4/5 times. As mentioned before, it is likely that the black weathering horizons, recorded from sequences marginal to cores 'C', 'D', 'E' and 46 discussed above, may represent lateral extensions of this forest soil onto the drier flanks of the basin, which were not inundated until the very latest stages of the basin infilling, and were then probably sealed by solifluxion.

5. Vegetational and environmental history

The peculiar circumstances of the deposits at Wing have permitted a close examination of lithostratigraphy and palaeobotany, from which the following interpretation and reconstruction of vegetational and environmental history has been made. It is necessary first, however, to consider the possible mode of origin of the basin and then to discuss the course of its infilling.

It is clear, from the dimensions and proportions of the basin at Wing (about 100 m in diameter and as deep as 18 m at the centre), that no inconsiderable agency must have operated in its formation. From the presence of till on the floor of the basin, a subglacial origin appears the most likely. However, it is certainly not a subglacial channel in the strict sense, for it is roughly circular and is closed by solid rock on all sides, and it is quite unlike the much larger, linear subglacial channels described from areas to the north (see, for example, Rice (1962)), which are regularly drift-filled. On the other hand, the basin does not have the form of a subglacial pot or kettle.

Of the other possible explanations for the origin of the basin, that of a ground-ice depression or kettle-hole can be discounted since the basin is cut directly into solid rock, albeit heavily weathered ironstone and easily eroded Lias clay. Consideration has also been given to the hypothesis that the basin represents a 'gull' or fissure opened up in the solid rock and associated with Pleistocene climatic and physiographic changes. Gulls are a common feature of the superficial geology of this part of the East Midlands of England, and have been described and had their origin discussed by Hollingworth *et al.* (1944), by Kellaway & Taylor (1952) and, more recently, by Kellaway (1972) and by Horswill & Horton (1976). These too are linear features, however, and those observed by the author in sections exposed by the construction work at Wing were all no larger than a metre or two in width and depth, although some were of considerable length.

Whatever the mode of formation of the basin at Wing, the first stage in the record for environmental history is represented by the basal sequence of till and 'slump' deposits denoting the debris left by the ice that was presumably responsible for the excavation of the basin. As indicated in §3, most of this material is unsorted and was thus probably deposited quickly and from a nearby source. There were at least two episodes of deposition in quiet, possibly deep water, however; the upper is indicated by the laminated silty clay immediately beneath the lowest peats in the central sequences. At the edge of the basin at this time, erosion rather than deposition seems to have occurred.

The sudden appearance, above this clay, of organic debris indicative of Early Temperate vegetation and climate remains somewhat enigmatic. It seems unlikely, in view of the presence of the laminated clay and alternating peat–clay laminae, that there was ever any delay in sedimentation caused, as noted at sites outside Britain, by the late melting of a concealed block of ice within the basin. In particular, there is no organic 'trash layer', often associated with such a feature. The absence of a fossil record for the early part of the interglacial cycle must then be attributed to a paucity of vegetation in the area of the basin and to the thin distribution of what potential fossil remains were incorporated into the lake deposits. On the other hand, the sudden appearance of Early Temperate vegetation may reflect a short time interval between the amelioration of climate following the glacial period and the immigration of thermophilous trees into the region.

Besides the abundance of thermophilous trees indicated by the pollen and macrofossil records from these basal peaty clays, there is also some evidence for the vegetation of the lake itself, with floating-leaved macrophytes (*Nymphaea*, *Nuphar*), submerged aquatics (*Ceratophyllum* spp., *Potamogeton* spp.) and free-floating taxa (*Lemna*). If the occasional records of aquatics from the marginal cores can be taken as evidence of at least shallow water at those points, then there must have been some 5 m of standing water at the centre of the basin. The scarcity of marsh plants may be a result of shading by overhanging trees, although the rather steep slopes of the basin margin may have limited the area available to telmatic taxa between the aquatic and terrestrial zones.

Acer, *Fraxinus* and *Ulmus* all appear to have been important constituents of the mixed oak forest that was established at this time, with oak dominating. *Hedera* is also, most unusually, well represented in the pollen record. Since ivy flowers only in the sun (Clapham *et al.* 1962), these high frequencies may reflect the gap in the tree canopy afforded by the lake basin, although it is possible that much of the pollen reached the basin from above-canopy turbulence (the C_c component of the pollen rain, cf. Tauber (1965)), from plants flowering in the tree tops. The absence of *Hedera* fruits can readily be explained by their softness and rapid decay when fresh.

Viscum was evidently also present in the forest around the basin at this time, while something of the shrub layer is suggested by the records if *Thelycrania sanguinea*, *Frangula*, *Rosa* and *Rubus*

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(including detached prickles of one or both of the two last-named taxa). It is worth remarking here that levels of *Alnus* and *Corylus* pollen remain low throughout the sequence, neither plant being represented by macrofossils. *Corylus* may have been present as an understorey shrub, flowering (and thus pollen production) of which was suppressed through shading, while the topographic context of the site may suggest that *Alnus* was confined to the river valleys bounding the interfluve. The chalky till mantling the interfluve might, moreover, have favoured the growth of *Acer* at the expense of *Corylus* and *Alnus*.

Although the fossil record clearly indicates a continuum of gradual change in the vegetation in and around the lake, it is possible to define the next stage in the sequence as a phase of acid mire development. The character of the peat changes, with the prevalence of the 'brown mosses' *Cratoneuron commutatum* var. *falcatum*, *Meesia longiseta* (for a fuller account of this taxon see Hall (1978)) and *Drepanocladus* spp. These are characteristic of mesotrophic mires such as 'poor fen', but the increasing component of *Sphagnum* (unfortunately not identifiable to species) indicates that acid conditions were becoming established. The cause of this may be that the supply of bases from the underlying till around the basin had been cut off by the growing blanket of organic matter forming during the Early Temperate phase. This, together with surface leaching at the edge of the lake, where a marginal moss–sedge fen was probably now established, would have favoured the colonization of parts of the peat by *Sphagnum* after which autogenic processes of acid peat accumulation would have been initiated.

The aquatic flora appears to have become restricted during the earlier part of this transitional phase almost to *Brasenia* alone. This plant, the 'pink water-shield', is no longer indigenous to Europe, but is characteristic of acid lakes and pools in areas of mire in North America today, and this fits well with the interpretation of gradual acidification of the lake. Later on, sedimentation and peat accumulation evidently proceeded so far as to exclude all bodies of open water in the basin; at this stage of overgrowth or *Verländung*, *Sphagnum*, *Betula* and *Eriophorum vaginatum* seem to have formed a continuous community across the basin. In the early stages of the mire development, several marginal aquatics were recorded, including *Menyanthes*, *Sparganium*, *Carex* spp. and the 'three-way sedge', *Dulichium arundinaceum*. The last-named, like *Brasenia*, is a 'Tertiary relic' in this interglacial period; both taxa are discussed further by Hall (1978). Acidophiles are also recorded at this time, notably *Empetrum*, *Drosera rotundifolia* and *Vaccinium oxycoccus*.

A brief discussion of this *Verländung* and subsequent *Versümpfung* is appropriate here. Similar Late Temperate acid mire development has been noted by, for example, von der Brelie (1954) and Jessen & Milthers (1928), from Eemian deposits in N.W. Europe. Von der Brelie indicated that *Flachmoortorf* was characteristically formed during the m.o.f.–hazel zone (his zone VI*b*, equivalent to zone *f* of Jessen & Milthers and Ip II*b* of the British scheme) and also during the hornbeam–spruce and the spruce zones (VII*b* and VIII, *i.e.* late *g* and early *h*, zone Ip III). However, *Hochmoortorf* developed where the climate had an Atlantic rather than a Continental aspect. Jessen & Milthers, by contrast, provide a table (Jessen & Milthers 1928, p. 361) illustrating the various kinds of lake overgrowth at many of their Danish sites. *Verländungen* occurred at different times through the interglacial cycle, from zone *d* (equivalent to Ip I*a*) to zone *i* (late Ip IV). In most cases, the overgrowing peat was formed by *Sphagnum* or '*Hypnum*' (presumably a *Braunmoos* such as *Cratoneuron* or *Drepanocladus* spp.), though there were also wood peats and, in one instance, *Scheuchzeria* peat.

The subsequent inundation or *Versümpfung* of such peats, thought to be due to climatic

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deterioration rather than to changes in local hydrology, usually occurred in zone *i* (late zone Ip IV) and involved the deposition of highly humified *Sphagnum* peats and clay muds. This is a good parallel for the record at Wing, where the zone III *Sphagnum* peat is overlain by a progressively more silty humified detrital *Sphagnum*-rich peat, although the *Versümpfung* here appears to have begun somewhat earlier in the interglacial cycle than it did at many of the Danish sites.

Birch woodland seems to have flourished in the area of the basin during zone III times, but the surrounding forests were probably dominated by *Carpinus*, pollen and macrofossils of which form a very considerable component of the assemblages from the *Sphagnum* peat. With *Carpinus* there grew *Tilia*, *Ilex* and *Taxus*, at least in the earlier stages of the transition from m.o.f. to hornbeam forest, and it is interesting that both leaves and seeds of yew were recorded, suggesting that this tree may have been growing close to, if not actually upon, the mire. Although it is characteristic of steep slopes on chalk and limestone in Britain today, the fossil record (cf. Godwin 1975, p. 115) indicates its former abundance in fen woods before draining and agriculture destroyed these habitats.

As remarked elsewhere, the paucity of macrofossils of taxa other than birch, cotton-grass and *Sphagnum* in the record of core 'B' from about 6.70 to 6.95 m is taken to represent the stage of maximum *Verländung*, Rather abruptly, at 6.70 m there is a dramatic expansion of aquatic taxa (figure 7); once again, the compression of the deposits may be partly responsible for this sudden change observed in the pollen and macrofossil diagrams. It is evident that areas of open water were once more established and that the water was sufficiently base-rich to support calcareous charophytes, oospores of which are well represented here. A possible explanation for the change is that increased precipitation raised the water table within the basin, flooding the lower, wetter parts of the growing peat surface to produce bog pools, with drier hummocks supporting the dwarf shrubs that are recorded in some quantity at this time.

The increased circulation of base-rich waters in the basin is also attested by the appearance of a number of taxa that are characteristic of the 'lagg stream' of raised bogs: *Hippuris*, *Potentilla palustris* and *Menyanthes*, besides the various *Potamogeton* spp. Moreover, there is a gradual increase in the silt content of this by now largely sedimentary, detrital peat.

It is clear that these hydrological changes are related to climatic change, for they are concomitant with the end of the phase of thermophilous forest vegetation as indicated in the pollen diagram. At 6.27 m there is an apparently abrupt change in the pollen spectra, from assemblages dominated by trees and shrubs to those where grasses and other herbaceous types prevail. Even allowing for the compression of the record, this must have been quite a sudden event, and it corresponds roughly with the first inwash of mineral sediment onto the peat. As mentioned above, this inwashing was probably responsible for the perpetuation of basin infilling, through the steady compaction and compression of the peat under the ever increasing load of silt and clay.

The vegetation present at this stage of climatic deterioration and soil erosion probably comprised a regional pine–birch woodland (although these trees appear not to have been important locally, perhaps due to the rather exposed, hill-top position of the site) with large areas of acid peat. This may have been blanket peat, for there is evidence of the ombrogenous mire taxon *Rubus chamaemorus*, as well as a suite of mosses such as *Polytrichum* sp(p)., *Aulacomnium palustre* and *Acrocladium stramineum*. The last-named is a plant confined to oligotrophic mires in Britain today and Watson (1968) suggests that in some bogs it is restricted to areas that receive some mineral enrichment. At Wing, the earliest occurrence of *A. stramineum* is just after the first indications of inwash of inorganic sediment into the basin.

The peat taxa *Bruckenthalia*, *Empetrum* and *Vaccinium* sp(p). are also present through this phase of vegetational development. The first of these, discussed further by Hall (1978), is now confined to the Balkan Mountains of southeastern Europe, yet it was apparently widespread in northwestern Europe at the end of the Last Interglacial and in Early Devensian interstadial times. It appears to occupy habitats similar to those of *Calluna vulgaris* in Britain today and its success in the past may have been at the expense of heather (which is but poorly represented in the record at Wing).

Besides peatland vegetation, areas of herb-rich grassland must have been present around the basin, for there is an abundance of pollen and macrofossils of grasses, sedges and herbaceous plants, indicative of a treeless landscape. In particular, Compositae (Liguliflorae-type pollen reaching very high levels in zone W4), *Polygonum* section *Bistorta* and families such as Ranunculaceae, Rubiaceae and Umbelliferae are all well represented. Among the macrofossils (table 1) there are persistent records for *Campanula rotundifolia* and *Ranunculus* section *Ranunculus*, with many other taxa recorded only as single individuals. It seems likely that these plants would have become established on the somewhat unstable soils around the lake, where erosion had removed the blanket of peat and exposed the underlying chalky till. The silty clays in this upper part of the sequence are certainly very calcareous at some horizons, and, towards the top, small fragments of chalk appear, so that the source of the material seems unequivocal.

Little can be said of the changes in the local vegetation once open water was again established in the basin, and in regional terms it appears that a treeless grassland community continued throughout the period recorded by the upper 5–6 m of the deposits. Evidence for local marsh vegetation is provided by the records for *Hippuris*, for various marsh and aquatic species of *Ranunculus* and for *Carex* spp. Further climatic deterioration is attested by the appearance of *Ranunculus hyperboreus* and *Salix herbacea* in the macrofossil assemblages. The former is today characteristic of moist clay and, occasionally, enriched soils or small pools in northern and montane Scandinavia, northern Iceland and Siberia. Tralau (1963) cites records for it in numerous Weichselian, and some pre- and post-Weichselian sites in Denmark, Germany and Russia, while Godwin (1975) indicates that its history in Britain covers all the cold stages since the Baventian. *S. herbacea* is also discussed by Tralau; it is an artic–alpine shrub and the pollen of *Salix* recorded from zone W5 at Wing is probably of this taxon, although a few leaf fragments only were obtained from one macrofossil sample. With these indicators of a cold climate is a number of mosses not identified further than genus, but likely to be taxa associated with bare soil and rock (figure 9), and consistent with the interpretation of increasingly disturbed soils with erosion and perhaps cryoturbation and solifluxion. As stated earlier, it is likely that the top 3 m of clay at the centre of the basin was largely deposited through solifluxion in a periglacial climate, for it merges into coarse, unsorted, ironstone-rich, gravelly clay in the top 80 cm.

The major features of the foregoing account of vegetational and environmental history are summarized in table 2; this table is not exhaustive, but serves to emphasize differences in the various parts of the basin.

Table 2. Stages in vegetational–environmental history in and around the basin at Wing

phase	basin: central	basin: marginal	area surrounding basin: 'local'	area surrounding basin: 'regional'
5	re-establishment of lake; Characeae and *Potamogeton* spp.	marsh vegetation on shallow sides of basin; *Hippuris*, *Ranunculus hyperboreus*	treeless grassland with dwarf-shrubs and a variety of herbs; ?blanket peat with Ericales and *Rubus chamaemorus*	
4	raised bog with *Eriophorum vaginatum* and Ericales; pools with *Potamogeton* spp.	?lagg stream, with *Potentilla palustris*, *Menyanthes*, *Hippuris*	decline of *Betula*	decline of *Carpinus* forest
3	*Verländung* of *Betula–Sphagnum* mire across basin		main expansion of *Betula*	expansion of *Carpinus*
2	*Brasenia*	?floating sedge–moss mat with *Dulichium*, *Menyanthes*, *Carex* spp.	transitional forest with *Ilex*, *Taxus*, *Tilia* and *Carpinus* replacing mixed oak forest taxa	
1	*Lemna* floating-leaved and submerged aquatics	narrow belt of marsh vegetation with *Typha*, *Alisma*	forest–lake margin with shade-tolerant herbs of moist soils	mixed oak forest with *Quercus*, *Ulmus*, *Acer* and *Fraxinus*

6. Dating the deposits; correlation and comparison with other sites

(a) *Dating*

If the framework for Pleistocene chronology in Britain proposed by Mitchell *et al.* (1973) is accepted, only the Hoxnian and Ipswichian interglacials need be considered for the comparison with the deposits at Wing. The present interglacial deposits clearly post-date a till that can only be of Anglian or Wolstonian age. Moreover, there is no evidence to support the definition of a new interglacial stage.

The following criteria have been used to assign the polleniferous deposits to the Last (Ipswichian) Interglacial and Early Devensian glacial:

(i) the importance of *Acer* and *Quercus* in the Early Temperate phase (*sensu* Turner & West 1968; pollen zone Ip II);

(ii) the scarcity of *Alnus* throughout;

(iii) the relative unimportance of *Tilia* and *Taxus* across zones Ip II and III;

(iv) the very marked expansion and predominance of *Carpinus* in zone Ip III;

(v) the virtual absence of *Picea* and *Abies*, and the total absence of *Pterocarya*, *Vitis*, *Azolla* and 'Type X'.

Although most of these points can easily be argued against individually, their coincidence suggests that the dating to the Ipswichian is probably secure.

Comparison with continental interglacial pollen records further supports this, for the diagram from Wing shows some close similarities to published Eemian sequences from Holland, Denmark and northwestern Germany. In particular, the 'well marked phases of forest development' (Phillips 1974, p. 596) exhibited by most Eemian pollen diagrams are matched by the sharply defined changes in spectra in the diagram for Wing.

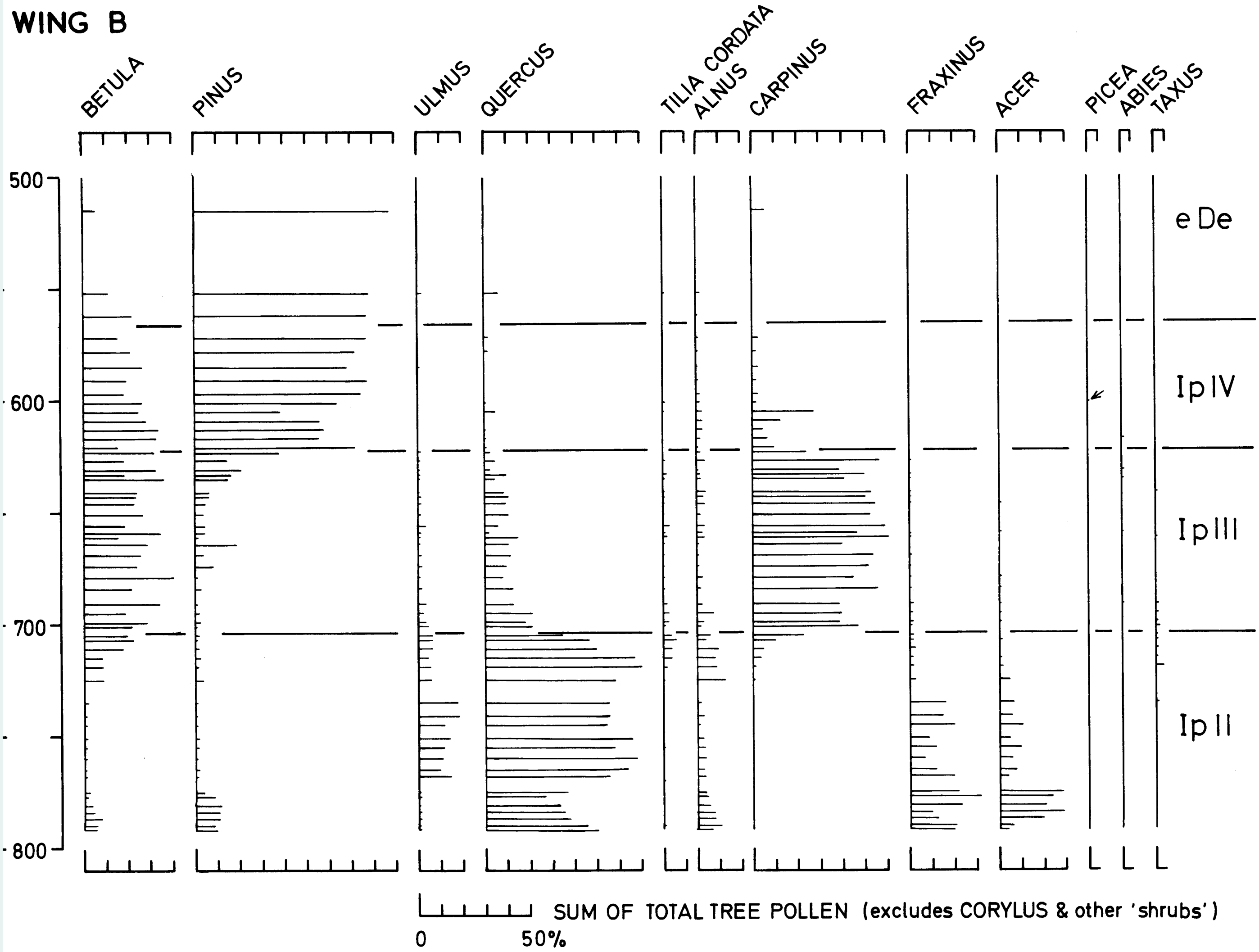

FIGURE 10. Tree pollen diagram for part of core 'B'.

(*b*) *Correlation and comparison with other sites in Britain*

A comparison of this kind may perhaps best be made by considering individual pollen zones representing broadly contemporaneous phases of the climatic and vegetational cycles encountered in interglacial and associated deposits. A diagram (figure 10) covering the lower part of the sequence, in which tree taxa alone are shown, is provided to aid comparison with other sites, where the sum of tree pollen rather than land pollen has been used as the basis for calculations.

Zone Ip II

As the pollen diagrams from Wing indicate, the pollen record begins after the establishment of m.o.f. vegetation characteristic of the Early Temperate stage of the interglacial. The obscurity of *Pinus* in the record, even allowing for the over-representation of locally produced pollen of m.o.f. taxa, and the presence of *Corylus*, albeit at unusually low frequencies, permit a correlation with subzone II*b* of the Ipswichian (zone *f* of Jessen & Milthers (1928)).

For comparison, sites with broadly similar spectra (see figure 11) include Stone and Selsey

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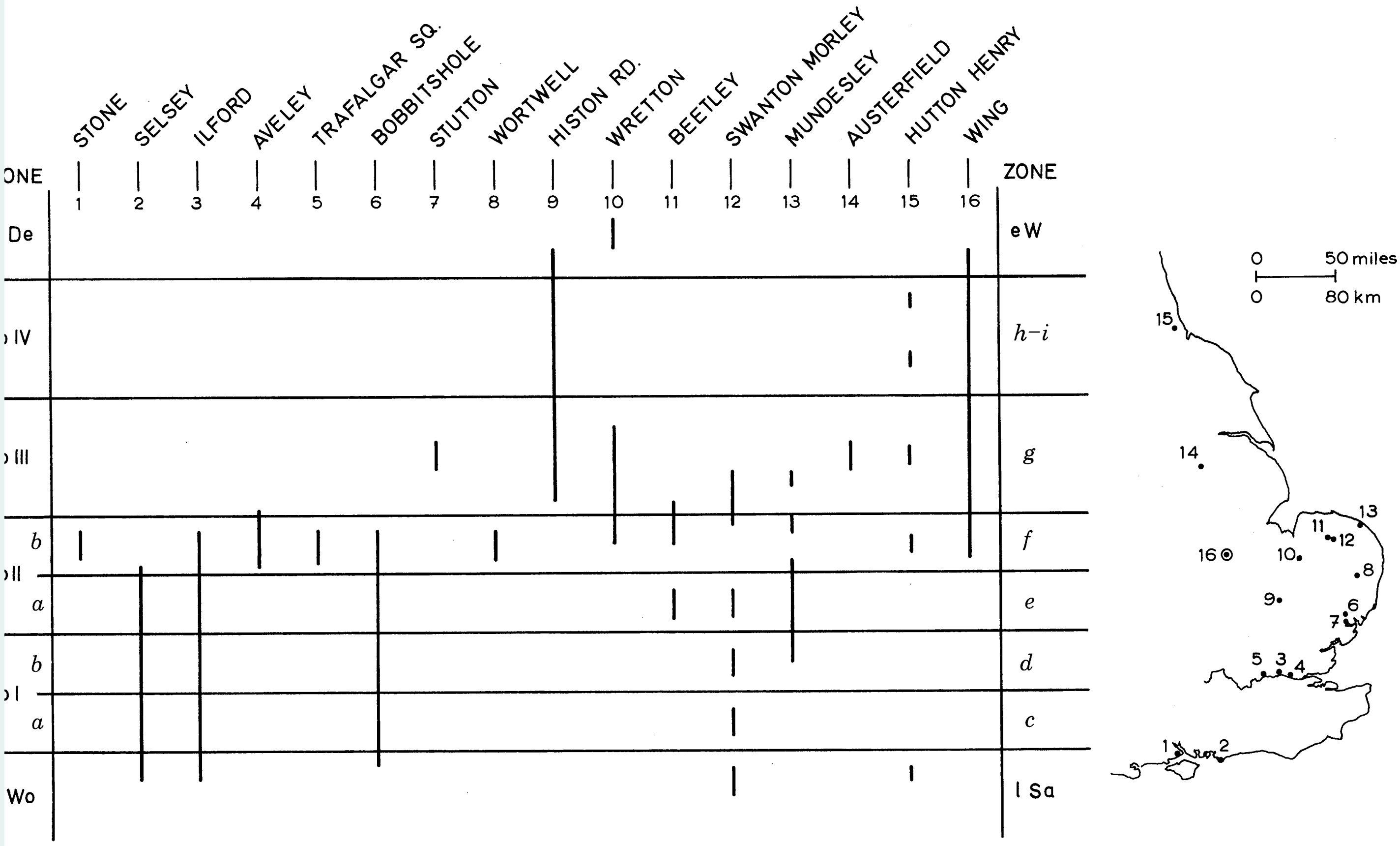

FIGURE 11. Map showing location of Ipswichian interglacial sites in Britain, with pollen zone range diagram.

(West & Sparks 1960), Ilford (West *et al.* 1964), Aveley (West 1969), Trafalgar Square (Franks 1960), Bobbitshole (West 1957) and Wretton (Sparks & West 1970); more recently, isolated spectra or short sequences have been described by Phillips (1976) from Beetley and Swanton Morley. These all show spectra dominated by *Quercus* and *Corylus*, the latter often at very high frequencies in terms of both tree pollen and land pollen sums. *Pinus* is usually well represented, but it seems likely that this reflects the depositional environment, where a greater proportion of a widely distributed pollen such as pine might be expected in fluviatile sediments than in the lacustrine deposits of a small enclosed hollow. Redeposition and inwash of pollen from upland areas may also have occurred in the fluviatile depositional environments of all these previously described Ipswichian sequences.

The only other thermophilous trees to occur at more than very low levels in other Ipswichian zone II*b* assemblages are *Acer* (reaching about 10% tree pollen at Bobbitshole and over 30% tree pollen at Trafalgar Square) and *Alnus* (see below). Although the latter is likely to be local over-representation from river-valley alder carr, it seems likely that *Acer* really was an important component of Ip II*b* vegetation. Much has been made of the records of *Acer monspessulanum* fruits from deposits of this age at Stone, Trafalgar Square and Swanton Morley, with tentative identifications from Selsey and Bobbitshole. These, taken with records of other taxa now native to Mediterranean areas, have been used as evidence for a climate with summers at least a little warmer than at similar latitudes today. All the macrofossils from Wing, however, were referred to *A. campestre*, the single species native to Britain in the Flandrian. Unfortunately,

Table 3. Average frequencies for '*Corylus*' pollen from various British Ipswichian interglacial diagrams (zone Ip II*b*)

	percentage a.p.	percentage (a.p. + n.a.p.)
Selsey	50	20
Stone	40	15
Trafalgar Square	200	45
Beetley	20†	5
Ilford	40	20
Wretton	60	25
Bobbitshole	60	40
Aveley	40	30
Swanton Morley (Phillips 1976)	20†	10
Swanton Morley (Coxon *et al.*, unpublished)	*ca.* 400	60
Wing	5	5

† Percentage (a.p. + shrubs).

pollen of these two species is not readily distinguished, so it cannot be established whether one or both were contributing to the marked *Acer* component noted above.

The behaviour of *Corylus* is less easy to discuss, since calculations of its percentage frequency have often been made with use of the sum of tree pollen (which as a rule excludes the count for *Corylus*), frequently producing values in excess of 100%. Even so, the importance of *Corylus* is quite clear. Table 3 summarizes the average frequencies for *Corylus* from a number of Ipswichian sites in Britain. It shows enormous variation, but emphasizes the low levels for hazel at Wing; moreover, the two independent pairs of figures for Swanton Morley indicate the type of variation that may be expected even at one site.

Two other tree taxa deserving of mention are *Tilia* and *Taxus*, both of which may be inadequately represented in the pollen record. Phillips (1974) has discussed the relative scarcity of pollen of *Tilia* in Ipswichian spectra, but, in the light of studies on pollen production and dispersal, it is likely that the values of 5% a.p. at Ilford, 9% a.p. at Aveley and up to 5% a.p. at Wing indicate the presence and even the importance of the tree in forests of zone II*b* times. Long-distance transport is unlikely to have occurred on a scale sufficient to account for these percentages, especially since pollen of lime is heavy, often remains in clumps at anthesis and seems often to travel only short distances from parent trees. Frequent records for *Tilia* at 10% a.p. from Hoxnian pollen spectra suggest that it was more abundant regionally during that interglacial.

The difference between the curves for *Taxus* pollen for the Hoxian and Ipswichian interglacials is much more marked, however, for yew reaches levels of 10–40% a.p. at Marks Tey (Turner 1970), Nechells (Kelly 1964) and Hoxne (West 1962), while there are only very low or trace frequencies from Ipswichian deposits. It appears from modern studies of pollen productivity and representation values that *Taxus* is a gross pollen producer, but that this may be greatly offset by the difficulty of identifying the pollen, especially where conditions of preservation are less than perfect.

Phillips (1974) has also discussed the erratic behaviour of *Alnus* in Ipswichian pollen assemblages. At Austerfield (Gaunt *et al.* 1972) and at Wretton (Sparks & West 1970) it reaches frequencies of over 50% a.p., although at comparable fluviatile sites where it might have

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Table 4. Comparison of average percentages for *Carpinus* pollen from various British interglacial sites

Hoxnian, Ho III		Ipswichian, Ip III	
Hoxne	less than 5%	Wretton	50–60%
Marks Tey	less than 10%	Aveley†	30%
Barford (Phillips 1976)	less than 5%	Histon Road	40%
Nechells	traces only	Hutton Henry	50%
Hatfield	none recorded	Wing	50–70%

† Only basal part of zone Ip III established at Aveley.

flourished, only small percentages are recorded. It is characteristically an abundant taxon of the Hoxnian temperate stage and it may be suggested that this reflects the regional importance of alder in that interglacial.

Lastly, mention may be made of *Ulmus*, high frequencies for which at Wing are evidently somewhat exaggerated by local over-representation, for bud-scales of the genus were also recorded. No fruits were recovered, though this is not unexpected in view of their delicate structure and ready degradation. Previous authors have contrasted the expansion of *Ulmus* before *Quercus* in zone Ip II*a* with the converse for Ho II*a*. This is not quite consistent from site to site, however, and seems likely to vary with local soil and topographic conditions as well as with vagaries of dispersal and competition between these two trees and with forest vegetation already present in an area where immigration is taking place.

Zone Ip III

As figure 11 shows, there are few sequences that record the transition from zone Ip II to Ip III, and none hitherto has produced so long and continuous a record as that from Wing, where this and one or two later pollen zone boundaries may be discerned.

Zone Ip III deposits are recorded from Histon Road (Sparks & West 1959) and these provide the most useful comparison with those from Wing. Spectra from Swanton Morley are, with a single exception, taken from material adhering to unstratified large-mammal bones, and there are only isolated spectra from Hutton Henry (Beaumont *et al.* 1969) and Stutton (Sparks & West 1963) and short sequences from Aveley, Wretton and Austerfield. The designation of many of these spectra as zone Ip III was based on their high or very high *Carpinus* content; table 4 above contrasts figures for hornbeam pollen from a number of Hoxnian and Ipswichian sites. Hornbeam was evidently important if not completely dominant over much of lowland Britain in the Late Temperate stage of the Last Interglacial. From its occurrence at Hutton Henry and Austerfield, moreover, its range seems to have been considerably greater than in the Flandrian.

Picea and *Abies* are both scarcely represented in the pollen record from Wing and from other Ipswichian sites where zone III has been identified, yet both trees are characteristic of the Late Temperate phase of the Hoxnian and of the corresponding stage of the Eemian (correlated with the Ipswichian) of northwestern Europe. However, Phillips (1976) has shown that *Picea*, at least, can contribute as little as 3% to the tree pollen rain only a short distance from a parent tree, so that the values of 5% at Histon Road, Aveley, Austerfield, Wretton and Hutton Henry may be sufficient evidence for the presence of spruce in much of Britain at this time. Once again, the 'filtering' effect of the forest vegetation that appears to have grown around the basin at Wing may account for the trace frequencies of these two pollen taxa.

Zone Ip IV

Apart from that at Histon Road, the sequence from Wing is the only one to record the zone III–IV transition, placed where *Carpinus* and other thermophilous trees are replaced by *Pinus* (though the values for both *Pinus* and *Betula* in the tree pollen diagram, figure 10, are exaggerated by the calculation sum used) and by grasses and herbs. The diagrams from these two sites share a number of features, notably the marked decline in *Quercus*, *Carpinus* and *Corylus* (although in view of the type of local vegetation at Wing at this time, perhaps *Myrica* is more likely to have contributed to the Coryloid pollen component). These declines are concomitant with the re-expansion of *Pinus*, Gramineae and a diverse herbaceous pollen flora, especially Compositae. Recalculation of pollen data from the latest of the accounts of the deposits at Histon Road (kindly made available by Professor R. G. West) showed that the high levels of *Pinus* on the published diagram are in fact similar, in terms of the sum of land pollen, to those from zone W4 at Wing.

Zone e De

Other early Devensian pollen spectra have been published by West *et al.* (1974), from Wretton, and by Phillips (1976), from Swanton Morley. Those from the latter site showed very low frequencies of tree pollen (about 5 % *Betula* and even less *Pinus*), with Cyperaceae and Gramineae predominating. Spectra from Wretton are broadly similar, as are those from the upper clay sequence at Wing. Mention has already been made that the *Salix* curve from zone W5 at Wing may be due to *S. herbacea* and it is possible that the curve for *Betula* is due to *B. nana*. Some reworking of pollen and other fossil material is likely in the sequence of silty clays between 5.50 m and the end of the record in core 'B', but this appears to be slight to judge from the only very occasional traces of types such as *Carpinus*, which might be expected in some quantity if soils formed during zone Ip III were being reworked during zones Ip IV and e De. Although it is likely that the higher levels of *Salix* and *Alnus* between 1.40 and 3.60 m of the main sequence are not the result of reworking, there does not seem to be sufficient evidence to support the designation of a separate subzone. These spectra certainly cannot be thought of as recording an interstadial comparable with those at Chelford and at Beetley.

7. Conclusions

The following summary of conclusions can be made from the evidence obtained in this investigation.

The sequence of glacial and interglacial deposits established from borings at the site at Wing is shown to have accumulated in a small, deep, steep-sided basin. The basin, which is closed, appears to have formed as a result of ice action, though its exact mode of formation remains uncertain. It is lined with Chalky Jurassic Till and is thus associated with an important phase of ice activity in this area.

Study of litho- and biostratigraphy has elucidated much of the local vegetational and environmental history in and around the basin, through the greater part of an interglacial stage and continuing into the early part of a subsequent glacial period. The record of vegetation begins abruptly with the establishment of mixed oak forest around the basin and of a diverse aquatic flora in the lake occupying it. This gradually changed through the temperate parts of the interglacial to give hornbeam-dominated forest with an acid mire (raised bog) supporting birch, cotton-grass and *Sphagnum* within the basin. As climatic deterioration ensued, the basin once more contained a lake with a rich flora fed by nutrients from inwashed mineral sediments, denoting increased run-off and the degradation of the forest soil. Further from the basin, there was probably blanket peat with sparse pine–birch woodland and a number of dwarf shrubs, in particular *Bruckenthalia*. Further climatic deterioration led to treeless, tundra-like vegetation and the rapid infilling of the basin by soliflucted clays from its flanks, so that the biological record ceases at some time in the early stages of a glacial period.

Although comparison with other sites has been made difficult by the unusual depositional circumstances in this small basin at Wing, pollen stratigraphy dates the deposits to the Last (Ipswichian) Interglacial and early Last (Devensian) Glacial, with a long and continuous continuous sequence spanning pollen zones Ip II*b* to e De. On this basis, the underlying Chalky Jurassic Till is dated to the Wolstonian glaciation, and, moreover, it was probably deposited late in that cold stage.

This sequence of deposits provides one of the longest and most complete records for the Ipswichian and Early Devensian in Britain, albeit a record of local rather than regional vegetational and environmental history.

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Appendix

Lithostratigraphy of core 'B' (all depths in metres)

ground level: 119.25 m o.d.

0–0.60	red–brown, crumbly, sandy clay topsoil with abundant ironstone fragments
0.60–3.35	red–brown to brown/grey-mottled to grey silty clay with small fragments of chalk below 0.80 m; small ironstone fragments in places; grades through 3.35 m to
3.35–4.00	grey–brown silty clay, tending to part along thin laminae of somewhat coarser material; some fine organic material, especially in the section 3.68–4.00 m
4.00–4.95	grey–brown silty clay with laminations variable in thickness, colour and lithology; microslump and microfault features visible in places
4.95–5.30	sample disturbed during coring; material available consists of contorted grey–brown silty clay with a little organic detritus and some weak laminations; the section 5.30–5.40 m is missing
5.40–5.80	rather crumbly interbedded silty peaty clay and silty clay peat, giving a streaked appearance in vertical section
5.80–6.35	well humified silty *Sphagnum* peat, becoming less silty below; peat compressed, its texture firm
6.35–6.55	as above, but with a woody component; inorganic content virtually absent
6.55–6.95	highly compressed humified wood peat

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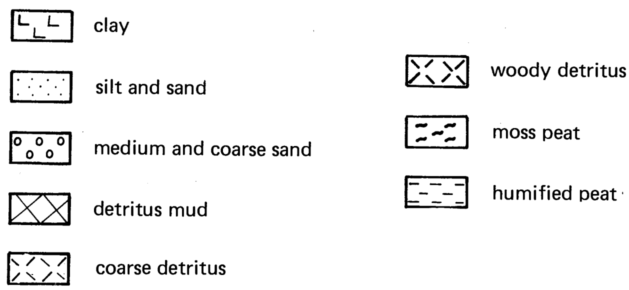

FIGURE 12. Sediment symbols used in pollen and macrofossil diagrams.

6.95–7.20 fissile, compressed woody–herbaceous peat with 'brown mosses'

7.20–7.25 not recovered

7.25–7.84 highly compressed, fissile to crumbly, woody peat with some micaceous silt and fine sand towards the lower end; at 7.84 m, a rather sudden change, with laminations, to peaty, silty clay

7.84–8.20 stiff, silty, calcareous grey clay, with some coarse organic detritus towards the top; below, almost pure silty clay with occasional reddish and blackish specks; some obscure laminations through 8.10–8.20 m

8.20–8.40 coarse, chalky sandy detritus in a grey clay matrix

8.40–8.90 olive–grey clay with occasional fine silty partings; this section of core disturbed and stratification difficult to discern

8.90–9.90 a mixture of various lithological types, including stiff, grey, chalky clays (?Chalky Jurassic Till) and greenish grey to reddish brown sandy clays with chalk and large clasts (to 5 cm diameter) of ?unweathered ironstone; some sharp lithological boundaries, but the nature of the cores (as 45 cm lengths with 5 cm disorientated samples between them) does not facilitate description.

The section 9.35–9.40 m consisted of the following types of material, mostly occurring as angular clasts in a grey plastic clay matrix: calcareous sandstone with shelly fragments (?L. Lincs. Lst.); iron-rich oolitic limestone (?Northampton Sand Ironstone); fine-grained calcareous sandstone; fine-grained grey clay, weathering brown on exposure, and with reworked fragments of shell and ?carbonaceous clay; chalk; shelly detritus (?Upper Estuarine Series).

A rather similar assemblage of rock types was recovered from 9.85–9.90 m, along with a crinoid stem segment and some coal-like material, the latter probably derived from the Lower Estuarine Series.

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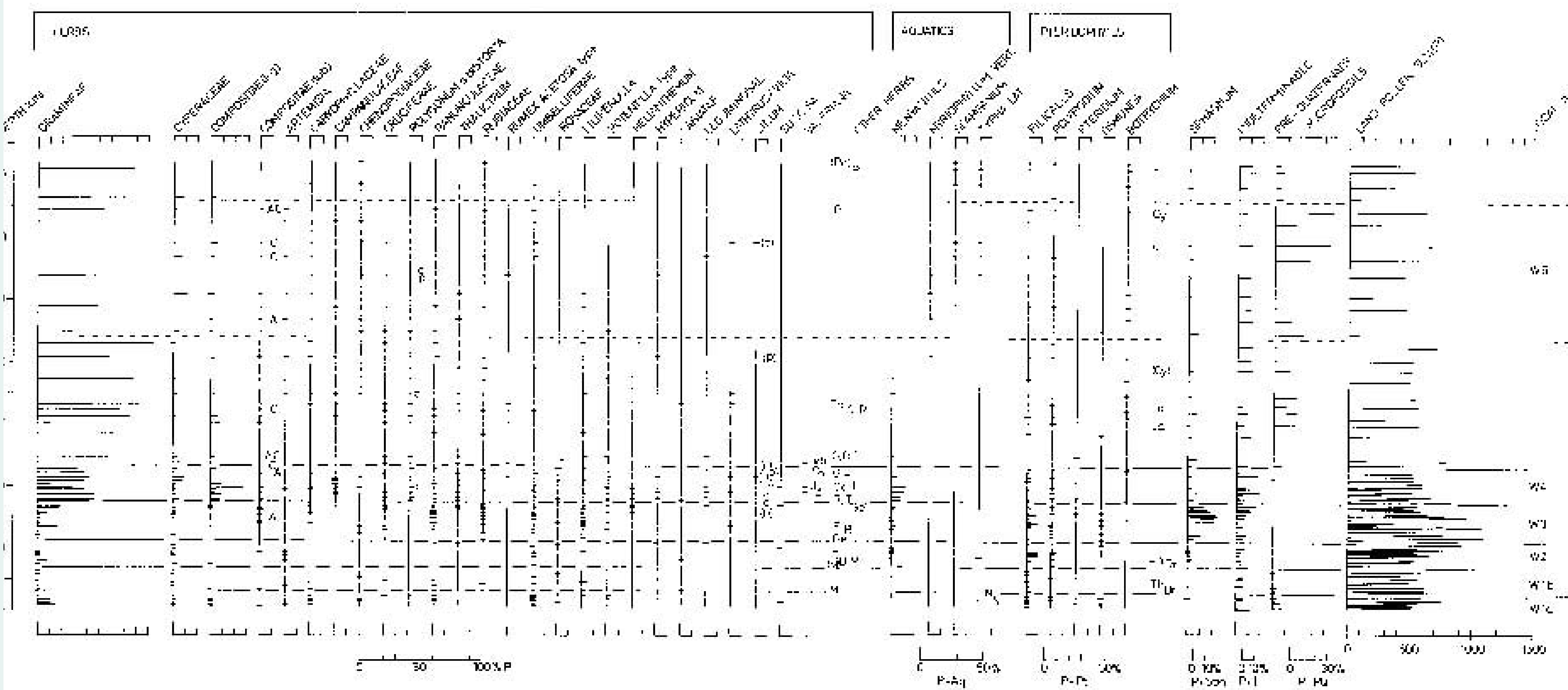

FIGURE 6. Pollen diagram for core 'B', showing herbs, aquatics, spores etc. Symbols as follows. Compositae (tub.): A, *Arctium*-type; C, *Cirsium*-type. *Polygonum* section *Bistorta*: a, *P. amphibium*; p, *P. persicaria*-type. *Linum*: c, *L. catharticum*; p, *L. perenne* ssp. *perenne*. *Valeriana*: d, *V. dioica*; o, *V. officinalis*. Po, *Polemonium*; P, *Plantago* sp.; R, *Rubus chamaemorus*; T, *Trifolium*; G, Gentianaceae; Ge, *Geranium*; E, *Epilobium*; D, *Drosera* cf. *rotundifolia*; M, *Menyanthes trifoliata*; N, *Nuphar*; L, *Lycopodium* sp.; La, *L.* cf. *annotinum*; Cy, *Cystopteris fragilis*; Dr, *Dryopteris filix-mas*-type; Th, *Thelypteris palustris*; Aq, aquatics; P, Pteridophytes; Sph, *Sphagnum*; I, indeterminable; PQ, pre-Quaternary; brackets denote a tentative identification; — signifies taxa recorded at less than 1% of the appropriate pollen sum.