Pleistocene Vegetational History and Geology in Norfolk

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PLEISTOCENE VEGETATIONAL HISTORY AND GEOLOGY IN NORFOLK

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WITH AN APPENDIX ON THE NON-MARINE MOLLUSCA FROM SWANTON MORLEY

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[Plate 1]

CONTENTS

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Three Ipswichian Interglacial sites are described, at Mundesley on the northeast Norfolk coast, and at Beetley and Swanton Morley in central Norfolk. Two Hoxnian Interglacial sites are also described, at Barford and Dunston, again in central Norfolk.

Pollen diagrams from boreholes in channel sediments cutting the Contorted Drift at Mundesley span zones I*b* to III of the Ipswichian Interglacial, and a Devensian age for the Drift or for the ice movements producing the contortions must be discounted.

'Cannonshot' gravels at Beetley, considered to belong to the Wolstonian retreat, are overlain by organic layers indicating zone II of the Ipswichian Interglacial, and a Devensian interstadial. Interesting plant records include *Damasonium alisma* in the interglacial deposits, and *Picea abies* cf. ssp. *obovata* and *Bruckenthalia spiculifolia* in the interstadial beds. Fossils in organic deposits at Swanton Morley, late Wolstonian to early Devensian in age and pocketed in floodplain sands and gravels, include the exotic *Acer monspessulanum*, and mammalian bones referred to Ipswichian zone III.

At Barford, organic lake deposits of the Hoxnian Interglacial overlie Anglian boulder clay which lies in a deep channel in the Chalk. The organic beds, which are of late Anglian to Hoxnian zone III age, are overlain in turn by solifluction deposits and by a cannonshot gravel attributed to the Wolstonian retreat. The high non-tree pollen phase recorded at Hoxne and Marks Tey in subzone Ho II*c* is also found here. Pollen from lake deposits at Dunston indicates subzone Ho III*b* and zone Ho IV, and there is palynological evidence for widespread erosion in zone Ho IV.

1. Introduction

Until recently, relatively few Hoxnian and Ipswichian Interglacial organic deposits were known in Norfolk. These include the Hoxnian deposits in the Nar Valley (Stevens 1959) and the Ipswichian deposits at Wortwell and Wretton (Sparks & West 1968, 1970). In this paper, Hoxnian sites at Barford and Dunston, and Ipswichian sites at Beetley and Swanton Morley, all in central Norfolk, are described, as well as the Ipswichian deposits of the Mundesley River Bed on the east coast (figure 1).

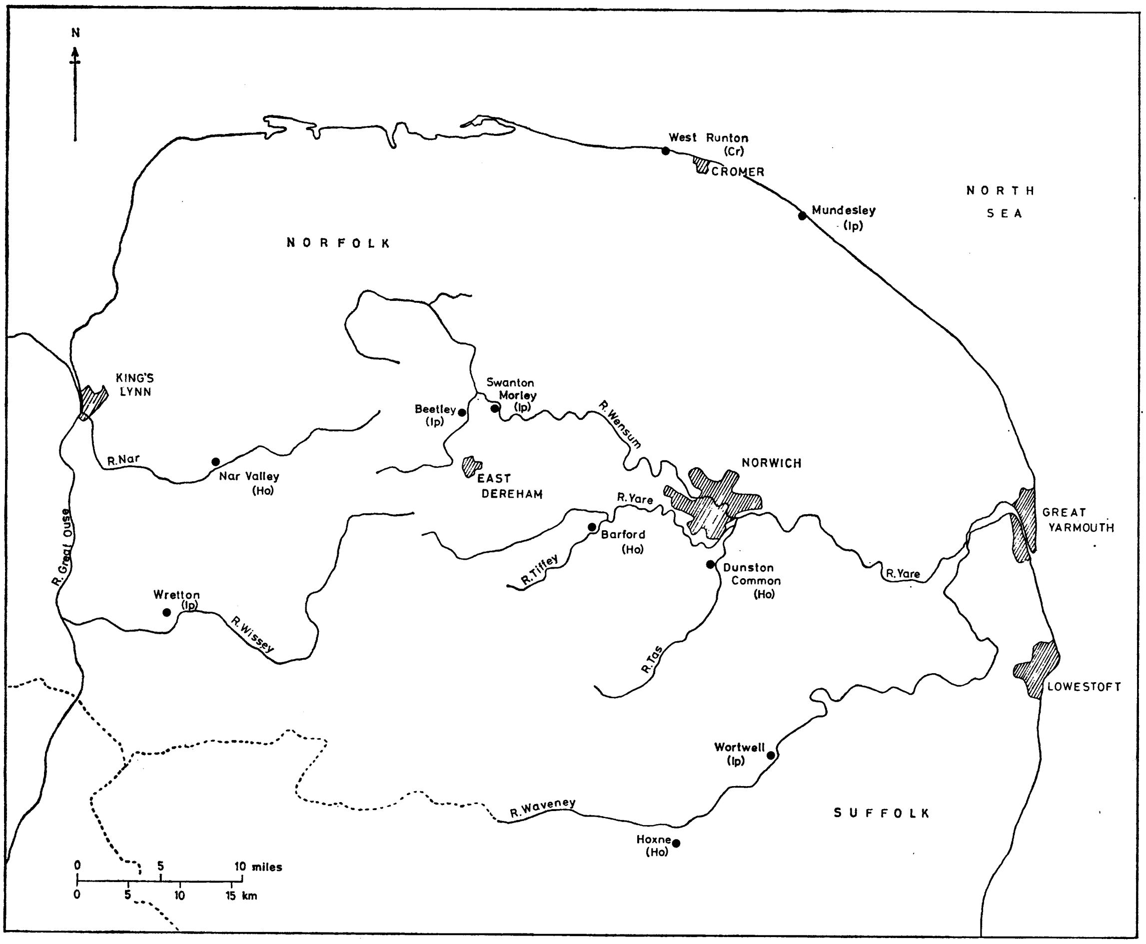

Figure 1. Interglacial sites in Norfolk. Ip, Ipswichian; Ho, Hoxnian; Cr, Cromerian.

The deposits at Beetley and Swanton Morley are in an area of extensive high-level gravels, the 'cannonshot' gravels, and similar gravels occur at Barford near Norwich. A detailed stratigraphical and palaeobotanical study of the deposits in each of the localities has made it possible to determine the age and relationship of the gravels and the underlying boulder clay, and the sequence of events in central Norfolk from the Anglian Glaciation onwards.

The stage names used here follow Mitchell, Penny, Shotton & West (1973), except in discussions of earlier literature, where the original nomenclature is retained. The current and earlier stage names and their equivalents in northwest Europe are given in table 1.

TABLE 1. CORRELATION TABLE FOR MIDDLE AND UPPER PLEISTOCENE SUCCESSIONS

stage	British Isles (Mitchell, Penny, Shotton & West 1973)	East Anglia (West 1963)	northwest Europe
Postglacial	Flandrian	Flandrian	Holocene
Glacial	Devensian	Weichselian	Weichselian
Interglacial	Ipswichian	Ipswichian	Eemian
Glacial	Wolstonian	Gipping	Saale
Interglacial	Hoxnian	Hoxnian	Holsteinian
Glacial	Anglian	Lowestoft	Elster

2. IPSWICHIAN INTERGLACIAL DEPOSITS AT MUNDESLEY

(a) *The original cliff sections and the* 1970 *boreholes*

The Mundesley River Bed was first described by Lyell (1840), and later by Prestwich (1861) and Reid (1882). This part of the Norfolk cliff sections has been concealed in the twentieth century, but was originally clearly exposed. The 'River Bed' consists of a series of gravels and organic beds lying in a broad channel which cuts through the glacial deposits (Contorted Drift, Sands and Second Till of Reid 1882; Third Till, Mundesley Sands and Second Till of Banham 1968), down into the Cromer Forest Bed Series. The organic beds are rich in plant and animal remains, and the nineteenth-century finds included seeds of *Ceratophyllum demersum* and leaves of *Salix* (Reid 1882), many insects and molluscs, several freshwater fish, *Emys lutaria* the European freshwater tortoise (Newton 1879), *Colymbus septentrionalis* the Red-throated Diver (Reid 1882), and various mammals including *Bos* sp. and *Elephas antiquus*.

The glacial sequence of northeast Norfolk is very complex and it is difficult to relate many of the phenomena seen in the cliff sections to particular glacial stages with any certainty. The gravels and organic layers of the Mundesley River Bed clearly post-date the Third Till and a firm dating of these deposits at least eliminates some of the possible interpretations of the stratigraphy.

Two boreholes were sunk in March 1970 in ground adjacent to the Ship Hotel at Mundesley (NGR: TG 315366). An auger was used for penetrating the gravels, and other cores were taken through the organic layers with a 10 cm (4 in) percussion corer.

The boreholes proved a sequence agreeing closely with the descriptions of Prestwich (1861) and Reid (1882) though the organic beds are considerably shallower in the boreholes (see appendix 1). The stratigraphy of the boreholes is shown in figure 2.

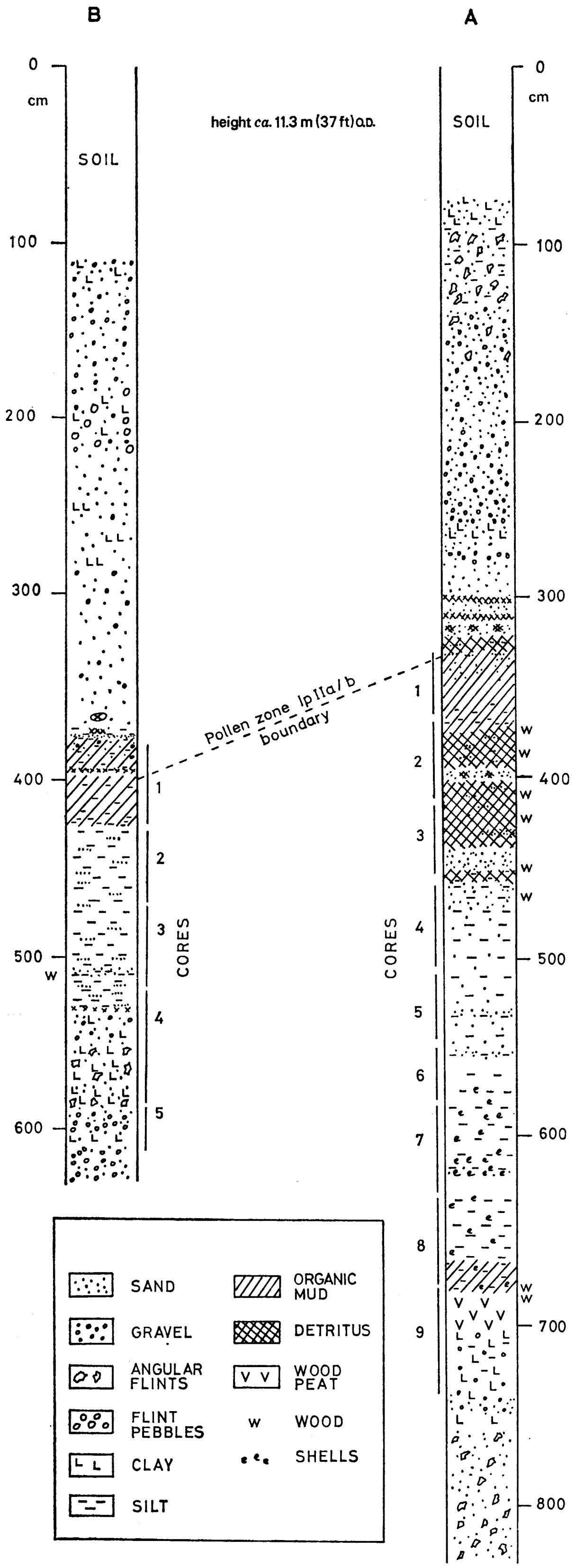

FIGURE 2. Stratigraphy of the 1970 Mundesley boreholes.

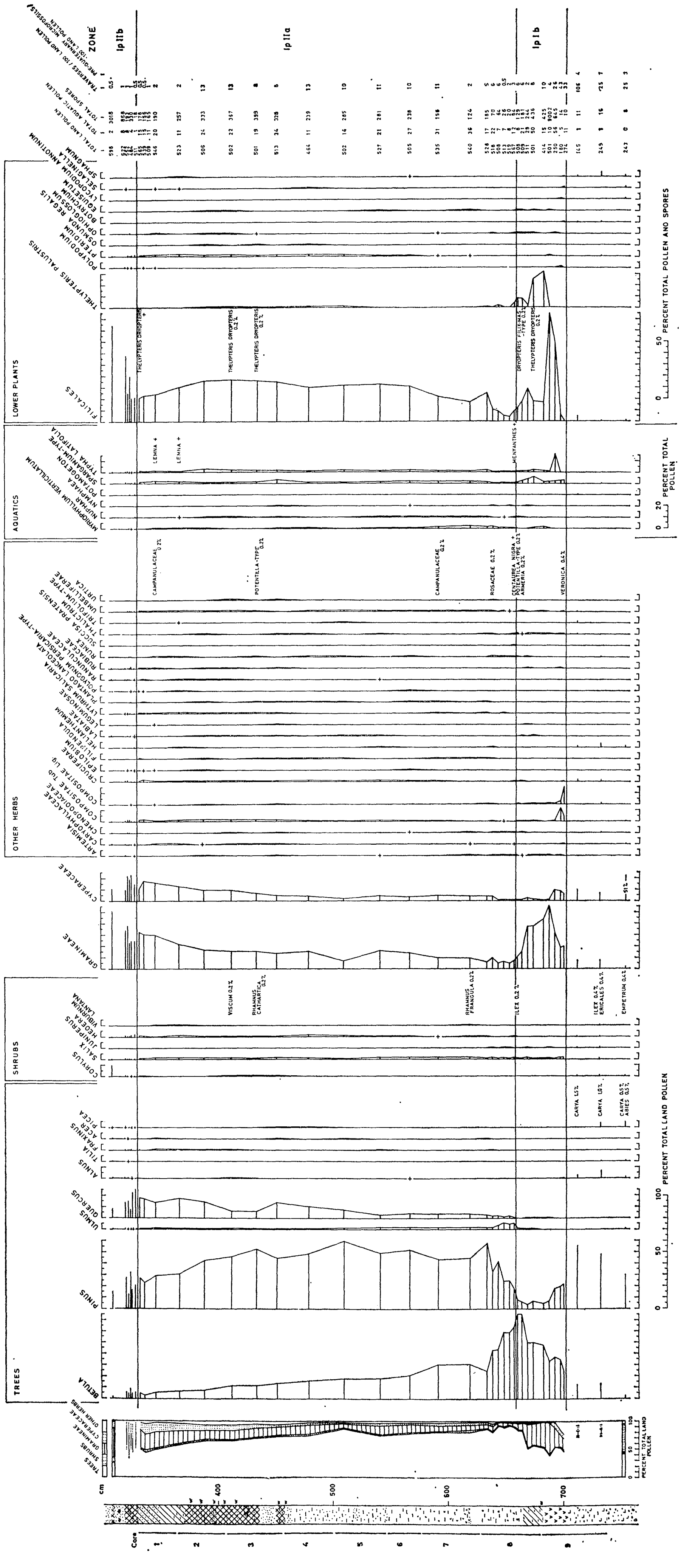

FIGURE 3. Pollen diagram from Mundesley borehole A.

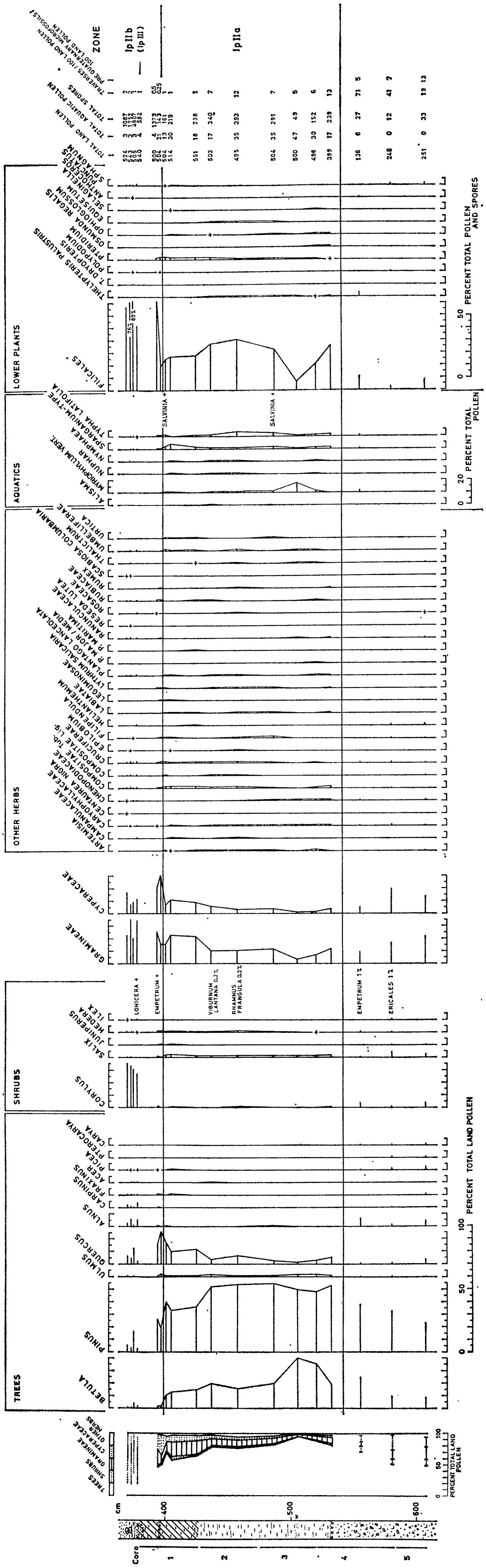

FIGURE 4. Pollen diagram from Mundesley borehole B.

(*b*) *The palaeobotany of the deposits*

(i) *Age of the deposits*

The pollen diagrams (figures 3 and 4) show the early part of an interglacial, which is considered to be the Ipswichian Interglacial for the following reasons: the long phase with high *Pinus* frequencies, though the length may be exaggerated to some extent by rapid sedimentation; the rise of *Quercus* to give a pine-oak phase; the early and low *Ulmus* maximum, before the main rise of *Quercus*; the characteristic *Carpinus*-dominated Late-temperate zone, seen in borehole MuB; the absence of *Abies* pollen; the virtual absence of *Tilia* pollen.

(ii) *Pollen zones*

At the base of the diagrams, the spectra are rather confused. *Alnus* and *Picea* pollen is present in some quantity, as well as pollen of *Carya*, *Pterocarya* and various pre-Quaternary microfossils. These are clearly derived, as the organic sediment is mixed with sand and gravel at the base, and the channel in which the deposits lie cuts through boulder clay and into the Cromer Forest Bed Series, both rich sources of pollen and spores for these basal sediments. The base of the interglacial in the pollen diagram is taken at the point where there are no longer any pre-Quaternary microfossils.

In the uppermost pollen samples from borehole MuB, between 370 and 378 cm, one of the spectra, MuB 378 cm, belongs to a different zone to the others. These samples were taken from the auger, not from a core, and the disturbed sequence may be due to distortion of the sediments by the auger. The presence of detritus erratics in sand, and the mixture of organic and mineral sediments at the top of core 1 also suggest some natural reworking after the final infilling of the channel.

Ipswichian Interglacial zones and subzones, as described by West (1968), can be clearly recognized in the Mundesley pollen diagrams, although the *Betula* curve is considerably affected by local conditions. The pollen zones have been delimited as follows:

Zone Ip III. MuB 378 cm. *Carpinus–Quercus–Pinus–Corylus* zone

Subzone Ip II*b*. MuA 310–332 cm; MuB 370–399 cm (except MuB 378 cm). *Quercus–Pinus–Corylus* subzone. The lower boundary of the subzone is drawn where *Quercus* first exceeds *Pinus*.

Subzone Ip II*a*. MuA 332–659 cm; MuB 399–540 cm. *Pinus–Betula–Quercus–Ulmus* subzone. In MuA, the lower boundary of the subzone is drawn where a continuous curve for *Quercus* is established.

Subzone Ip I*b*. MuA 659–703 cm. *Betula–Pinus* subzone.

(iii) *Vegetational history*

Zone Ip I. The Ipswichian Pre-temperate zone

Subzone Ip Ib

Betula is the most important tree taxon in the pollen diagram, followed by *Pinus*. *Betula* percentages rise from 25 % of total land pollen (l.p.) to over 70 %, then start to fall again. A large increase in *Betula* percentages in this position in an interglacial pollen diagram is undoubtedly due to local growth of birch. In the lower part of the subzone, Gramineae, Filicales and *Thelypteris palustris* percentages are very high, and swamp plants are represented by *Sparganium*-

type and *Typha latifolia* pollen. These curves fall as the *Betula* curve rises. At the same time, the sediment changes from a fine wood peat to organic mud. A possible explanation for these phenomena is that initially birch carr is growing and wood peat is forming at the site of deposition, while fen and reedswamp communities are very near and contribute to the pollen rain. This is followed by a more widespread succession from wet fen and reedswamp communities to birch carr all over the valley floor.

At the very top of the subzone, *Betula* starts to fall, and Gramineae, Filicales, *Thelypteris palustris*, *Sparganium*-type and *Typha latifolia* percentages all drop to very low levels. At this level, the sediment changes to a grey silt. The local birch carr and reedswamp vegetation has declined with the establishment of fluviatile conditions, and the organic deposits have been flooded.

The regional forest vegetation is dominated by pine and birch. It is, however, difficult to assess the relative importance of the two trees. The high Gramineae levels probably largely represent locally growing grasses, but may also indicate incomplete forest cover as there are also low frequencies of pollen of open habitat plants.

Zone Ip II. The Ipswichian Early-temperate zone

Subzone Ip IIa

In this subzone, the rise of *Quercus* and *Pinus* gives a phase of pine-birch-oak woodland, and a variety of woodland trees and shrubs make their first appearance and become established. *Betula* frequencies are still high initially but fall rapidly with the final decline in the local birch carr, then more gradually as birch also loses its importance in the regional forest. *Ulmus* pollen appears at the beginning of the subzone, rises rapidly to a low peak, then falls to low levels.

The tree pollen: non-tree pollen (a.p.:n.a.p.) ratio is high at the beginning of the subzone, although limited open areas are indicated by the continued presence of *Artemisia* and Chenopodiaceae pollen. The tree pollen values fall slowly at first, then more rapidly, to about 50 % by the end of the subzone. This is primarily caused by an increase in Gramineae and Cyperaceae percentages. In the uppermost samples, the grass and sedge pollen often occurs in clumps, suggesting a local origin for the pollen. At the same time, more herbaceous taxa appear and Compositae percentages increase slightly. The layer of sand at MuA 444 cm, and the following sandy detritus and organic mud, suggest that the channel has finally filled in and herbaceous vegetation has spread. Remains of animals such as *Bos* and *Elephas antiquus* have been found in the Mundesley River Bed deposits, and these large mammals may have contributed to the spread and maintenance of herbaceous vegetation on the valley floor by grazing and trampling.

Hedera pollen occurs throughout this subzone, indicating mild winters, and fairly high average summer temperatures are indicated by the presence of *Viscum* pollen and microspores of *Salvinia natans*. Further indications of summer warmth are the presence of the European pond tortoise *Emys orbicularis* L. (*Emys lutaria* Merr.) and the freshwater mollusc *Belgrandia marginata* Mich. (*Hydrobia marginata* Mich.), recorded from the River Bed in the nineteenth century. Although the exact provenance of these fossils is not known, they are most likely to have come from the subzone Ip II*a* deposits, as these are the most extensive.

Subzone Ip II*a* is very protracted at Mundesley, covering 3.4 m (11 ft) of sediment in borehole MuA, in marked contrast with 30 cm at Selsey (West & Sparks 1960) and 7 cm at Ilford (West, Lambert & Sparks 1964). This may be partly due to the very rapid sedimentation at this site which undoubtedly took place. However, the pine-oak phase is also well-represented at Ipswich and at Beetley, where the sedimentary conditions were different, and it seems likely that the later immigration of the oak into the established pine forests of East Anglia retarded its rise to dominance. The elm, on the other hand, had an earlier and higher maximum in East Anglia than in southern England, probably due to its immigration from the east and growth on rich soils with no competition from oak.

Subzone Ip II b

Oak continues to rise and a mixed oak forest is established. *Corylus* values are very low at first, but rise to high levels in spectra probably representing the later part of the subzone. *Carpinus* appears in MuB and eventually rises to 12 % a.p. (2½ % l.p.). In the upper samples from this subzone in MuB, and in the subsequent zone, *Alnus* percentages rise to relatively high levels, representing a local development of alder fen carr in the river valley (see Phillips 1974).

The a.p.:n.a.p. ratio remains low and the herbaceous vegetation consists mainly of locally growing grasses and sedges. Filicales percentages are high in the earlier samples, and become very high at the top of the organic sediments as ferns spread over the infilled channel.

Zone Ip III. The Ipswichian Late-temperate zone

The earliest part of this zone is represented by one sample from borehole MuB, at 378 cm. The spectrum is very similar to the late subzone Ip II *b* assemblage except that *Carpinus* exceeds *Quercus*, and *Ulmus* has finally disappeared. n.a.p. is high, with a further increase in grass and sedge pollen.

The samples from the earlier part of subzone Ip II *b* come from the top of the organic sediments. Above these, there is sand in borehole MuA, with thin layers and erratics of detritus at the base giving pollen spectra characteristic of late subzone Ip II *b*. In borehole MuB, the lowest part of the overlying sand is mixed with gravel and organic mud, and there is a detritus erratic. These organic sediments give pollen spectra of late subzone Ip II *b* and early zone Ip III. Clearly, aggradation in the river channel had largely ceased early in subzone Ip II *b* and erosion started, although later on in this period conditions were again favourable for some organic sedimentation, either at this locality or further upstream. Ipswichian deposits characteristically end in subzone Ip II *b*, or show a break in subzone Ip II *b* and continue later in the subzone or in zone Ip III (figure 5). No English pollen diagram covers continuously Zones II and III of the Ipswichian Interglacial. It has been suggested (Sparks & West 1963) that there may have been two marine stages in the Ipswichian Interglacial resulting from an interruption in the general rise in sea-level between subzone Ip II *b* and zone Ip III. This fall in sea-level would give an erosion phase in the river valleys, followed by continued aggradation as sea-level rose again, allowing the deposition of organic sediments in the river valleys at the end of subzone Ip II *b* and later.

(*c*) *The sequence of events in the Mundesley basin*

The pollen analyses show the organic deposits to belong to the Ipswichian Interglacial and the channel was probably cut at a late stage in the Wolstonian Glaciation. It is unlikely to have been cut before the Wolstonian and then remained empty until the Ipswichian, or to have been filled in and completely re-excavated. Deposition of the basal gravels, sands and clayey material probably took place in the late Wolstonian. Peat then formed in the valley bottom where birch fen carr was growing in the earliest phase of the interglacial. This phase is fairly short, but subzone II *a* spans a considerable depth of sediment, over 3 m (10 ft) in borehole MuA, so that there must have been rapid silting in the valley, suggesting a heavy silt load in the lower reaches of the river, and a rapidly rising sea-level along a coast not far away. The sediments became much more organic at the top as aggradation slowed down. Periods of erosion resulted in disturbance at the top of the organic sediments.

The organic deposits were then covered with sand and gravel in the latter part of the Ipswichian, or in the Devensian. In borehole MuB, there is a layer of rounded flint pebbles which could be interpreted as beach gravel of the Eemian marine transgression, although there is no palaeobotanical evidence for marine conditions in the underlying organic deposits. The base of the pebble layer is at approximately 8.5 m (30 ft) O.D.

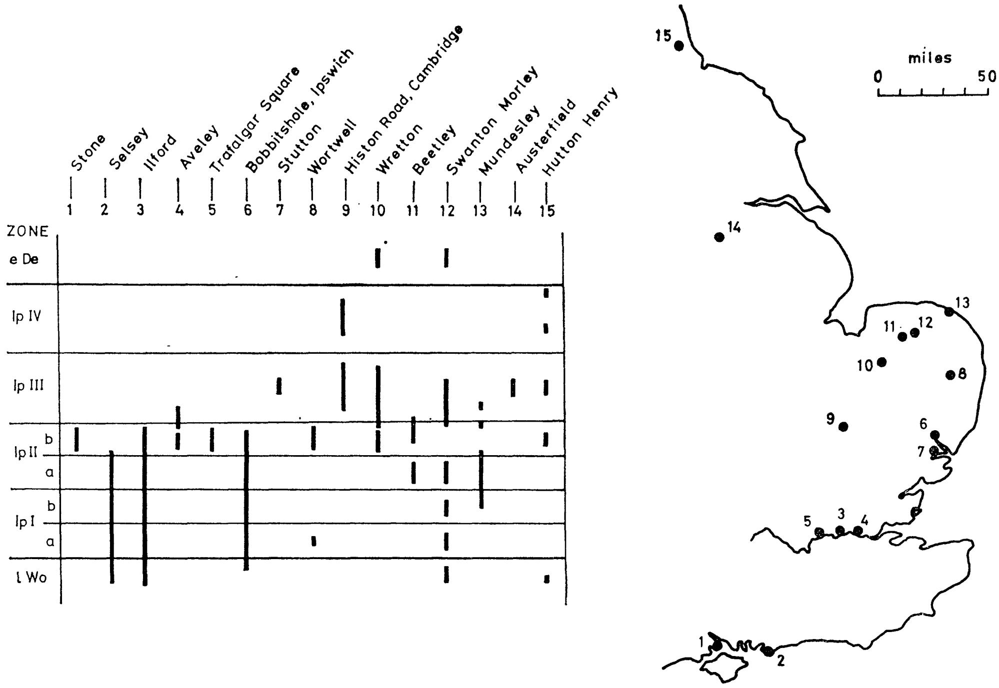

FIGURE 5. Ipswichian Interglacial sites in England, and zones represented.

(*d*) *The stratigraphic importance of the Mundesley River Bed*

The dating of the organic deposits to the Ipswichian Interglacial has various implications for the stratigraphy in the area. The channel cuts through the contorted Third Till (Banham 1968; Contorted Drift of Reid 1882) and the underlying deposits, so that any suggestion of a Devensian age for the Third Till, or for the ice movements producing the contortions can clearly be discounted. There is no further palaeobotanical evidence for the age of the glacial deposits, and the absence of Hoxnian Interglacial deposits along this coast is disappointing. The Valley Gravels of Reid (1882) and Banham (1968) comprise two sets of gravels of different ages, the lower one probably late Wolstonian and the upper one late Ipswichian or younger. These two gravels coalesce at each side of the basin and continue as a single bed for some distance at the top of the cliffs.

3. IPSWICHIAN INTERGLACIAL DEPOSITS IN THE WENSUM VALLEY

(*a*) *The stratigraphy of the deposits*

The central section of the River Wensum flows eastwards across the chalky boulder clay plateau of Norfolk, through an area made distinctive by the extensive spreads of high-level 'cannonshot' gravel, mainly to the north and northwest of East Dereham. The relationship and age of the boulder clay and these high-level gravels are a long-standing problem. Blake (1888) described a series of glacial deposits, comprising Lower Boulder Clay, Glacial Sand and Gravel, and Upper Boulder Clay, overlain by Plateau Gravel on the high ground and Valley Gravel in the Wensum Valley. The chalky boulder clay covering most of the surface comes within the area of the Lowestoft (Anglian) Glaciation of Baden-Powell (1948) and West & Donner (1956), and the 'cannonshot' gravels in the west of the district are tentatively described as outwash gravels of the succeeding Gipping (Wolstonian) Glaciation by West (1961). The chalky boulder clay, or Marly Drift, of north Norfolk is considered by Straw (1965) to be Gipping (Saale: Wolstonian) in age, giving way to a chalky boulder clay of the preceding (Elster: Anglian) glaciation south and east of the Wensum basin (see table 7). All the high-level gravels in the Wensum basin are interpreted as Wolstonian outwash gravels associated with the boulder clay (Straw 1973). Only one chalky boulder clay is recognized in Norfolk by Cox & Nickless (1972) and Bristow & Cox (1973), west and south of the Norwich Brickearth and belonging to the same glaciation, the Saale. This is the equivalent of Baden-Powell's Lowestoft Till. The broad zone of sand and gravel near Norwich, the sand and gravel within the boulder clay and the high-level gravels on the boulder clay plateau are all regarded as outwash deposits intimately associated with the boulder clay.

On the basis of field observations and existing geological records, the following stratigraphy has been recognized in the area.

(i) *Boulder clay*

There appears to be only one chalky boulder clay, variable in character, but continuous with the blue-grey chalky boulder clay to the south and the white or sometimes blue-grey chalky boulder clay to the north. Masses of sand and gravel, frequently very chalky, are contained within it. The sand is usually pale brown, medium and often stratified, with fine and medium subangular flint gravel. The gravel is occasionally very much coarser and includes a variety of erratics. These sand and gravel masses include most of Blake's Glacial Sands and Gravels, and also smaller lenses of gravel described as occurring within the Upper Boulder Clay.

This is in agreement with Woodward and Bennett (in Blake 1888) and Bristow & Cox (1973) who recognize a single chalky boulder clay containing masses of sand and gravel. There is, however, evidence for a period of erosion between the deposition of the boulder clay and its associated sands and gravels, and the deposition of the high-level gravels in the west of the area.

The chalky boulder clay of the Wensum Valley region is a direct continuation of the chalky boulder clay southeast of Norwich, which is overlain by lake deposits of the Hoxnian Interglacial at Barford and so is Anglian in age.

(ii) *The Hungry Hill Gravels*

The sheet of coarse rounded pure flint gravel on the boulder clay plateau between East Dereham and North Elmham is the Plateau Gravel of Blake (1888), who compares it, in type and in age, with the Plateau Gravel, Cannonshot Gravel and Flood Gravel of neighbouring districts. The gravel is composed of rounded and well-rounded, sometimes subangular, flint pebbles and cobbles. Finer subangular flint gravel occurs between the large stones and sometimes occupies more extensive areas. The matrix is a medium to coarse orange sand, sometimes silty. Some of the rounded flints have a 'basketwork' patina. Erratics are virtually absent.

Characteristically, the gravel forms an upper layer, varying from one to several feet in thickness, above a greater depth of coarse orange sand. This may be due to the mode of deposition of the materials, but the stones may have become concentrated at the top as a result of repeated frost action. Other evidence of frost disturbance includes vertical stones, involutions and ice wedge casts.

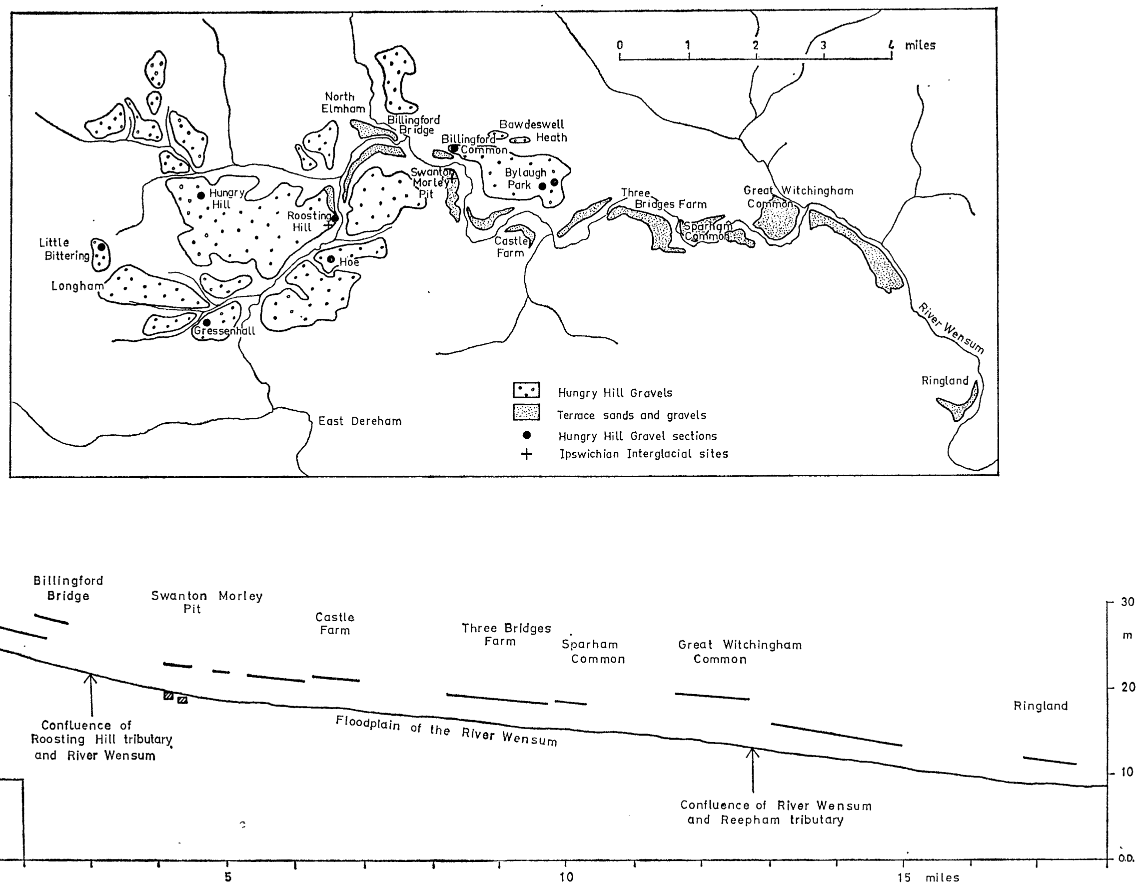

FIGURE 6. The Hungry Hill Gravels, and the low terrace of the River Wensum.

The gravels, whose surface varies from 76 to 24 m (250–80 ft) O.D. with a general slope eastwards, are part of a dissected sheet of outwash resting in non-sequence on the boulder clay, and at Roosting Hill directly on the Chalk. They are here called the Hungry Hill Gravels, and the exposures shown in figure 6 are described in appendix 2.

The Hungry Hill Gravels are interpreted as outwash gravels of the Wolstonian retreat. They may be related to the same phase of outwash represented on the north Norfolk coast by the Holt outwash plain, the Blakeney ridge and the kames and kame terraces of the Glaven Valley. There, the same lithological and positional contrast between the younger outwash gravels, and the older gravels associated with the chalky boulder clay, has been described by Solomon (1932), Baden-Powell & Reid Moir (1942) and West (1961).

(iii) *Organic deposits*

Organic deposits have been found at Roosting Hill, Beetley, where they overlie Hungry Hill Gravels, and at Swanton Morley, where they are interbedded with fluviatile sands and gravels.

(*A*) *Roosting Hill, Beetley*

Two pits (now filled in or flooded) at Roosting Hill (No. 1: NGR TF 987181; No. 2: NGR TF 986179) revealed organic deposits of the Ipswichian Interglacial (pit 1) and a Devensian interstadial (pit 2) lying in depressions in the Hungry Hill Gravels (see appendix 3).

The interglacial beds consist of an upper and a lower mud bed separated by a sandy layer. These deposits lie in a broad, shallow, flat-bottomed channel and thin out at each end of the section. They are overlain by sand, and then clay with involutions at the base. The clay may have been deposited in the Devensian glacial stage, in water held up at a time of permafrost, or in the latter part of the interglacial and into the Devensian due to a constantly rising water table at this site.

The interstadial deposits consist of sandy muds with wood peat near the base. They lie in a small hollow which may have been a product of ground ice mound collapse in the early Devensian, with organic deposits being laid down later in an open pool possibly fed by springs from the Chalk. In other excavations at Roosting Hill, broad hollows at different levels over the gravels contain Devensian mud and peat, and probably had such an origin. After the pool at BD was filled in, solifluction deposits of poorly sorted stony silt covered them to give the relatively smooth slope of the present land surface (figure 7).

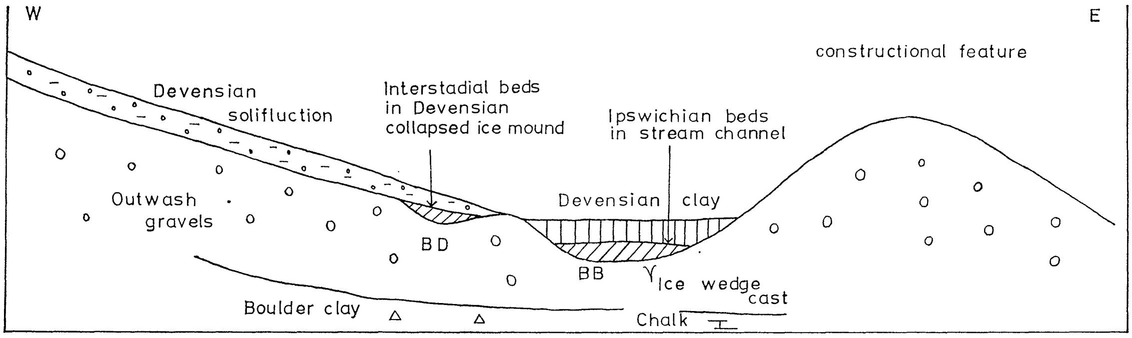

Figure 7. Diagrammatic section across Roosting Hill gravel pit.

(*B*) *Swanton Morley*

The Swanton Morley gravel pit (NGR TG 018191) in fluviatile sands and gravels has yielded mammalian bones and organic sediments in a sequence summarized in figure 8. The organic deposits are shown by pollen analysis to belong to the late Wolstonian, the Ipswichian Interglacial and the early Devensian, and the mammal bones are Ipswichian in age.

The thin bed of cobbles at the base of the river gravels is at a much lower level than the coarse flint gravel at Roosting Hill and is not continuous with the gravel capping the high ground, so it is unlikely to be outwash gravel *in situ*. The presence of late Wolstonian organic deposits in the overlying river gravels indicates that an aggrading river was present in the late Wolstonian, and the cobble bed is most likely to represent the lowest part of the fluviatile series deposited by an overloaded river cutting through the outwash-covered uplands. The fluviatile sands and gravels extend below the modern floodplain and river bed, so the initial interglacial water level must have been lower than it has been since.

The organic muds and silts lie in pockets in the sand and gravel, and presumably represent sedimentation in depressions and abandoned channels in the floodplain of a meandering river.

Continuous aggradation is indicated by organic deposits from late Wolstonian to early Devensian in age, with the exception of Zone Ip IV. The interglacial deposits are at approximately the level of the modern floodplain. Most of the river gravel is above the organic deposits so there must have been an aggrading river here in the Devensian, with a water level a little above the present one.

The gravels form a wide terrace whose surface is at about 21 m (70 ft) O.D. Where the terrace edge is visible there is a drop of several feet to the modern alluvial plain, but in places the edge is overlapped by Flandrian peat.

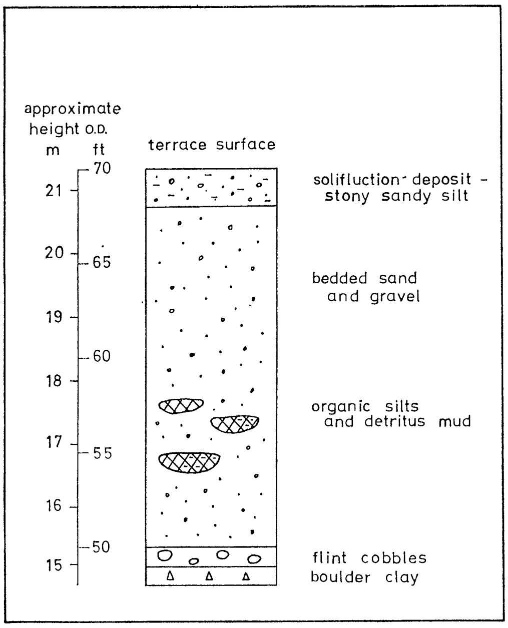

FIGURE 8. Generalized section at Swanton Morley gravel pit.

The low terrace can be traced upstream almost to Roosting Hill, and it has been followed for some distance downstream (figure 6). Mid-terrace height above the floodplain, measured by aneroid barometer, is approximately 3 m (10 ft), varying between 2.1 m (7 ft) and 4 m (13 ft). Two anomalous readings, 5.2 m (17 ft) at Billingford Bridge and 6.1 m (20 ft) at Great Witchingham Common, occur at the confluence of two rivers and the small height difference is not regarded as providing evidence for more than one terrace in the Wensum Valley.

The terrace is largely composed of bedded sand and fine to medium subangular flint gravel. The terrace was cut in the Devensian and at Swanton Morley was covered with a solifluction deposit of unsorted stony silt which thins out towards the river. Other signs of periglacial activity include involutions at Sparham Common and the hummocky surface of the terrace at Mill Street near Swanton Morley pit.

(*b*) *The development of the Wensum River system*

Several boreholes described by Woodland (1970) indicate the existence of deep channels in the chalk surface in this area (figure 9). These are characteristically associated with Anglian glacial deposits and are thought to have been excavated beneath the Anglian ice sheet and filled with drift as the ice withdrew. There are two elements in the Wensum drainage system, one along a

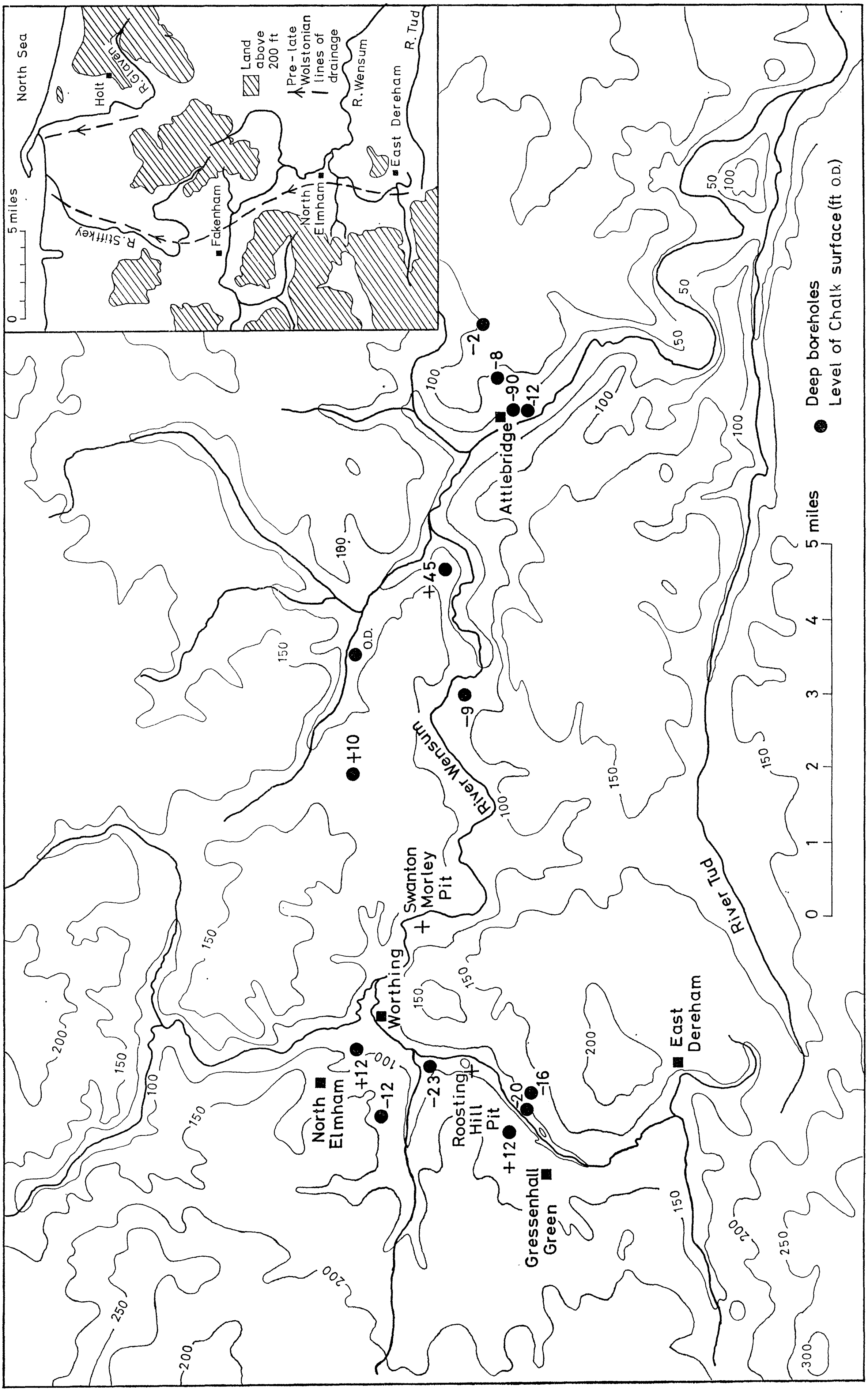

FIGURE 9. The Wensum River system.

south–north line, the other along a west–east line. Both these elements appear to have been controlled to a large extent by the position of the deep channels.

At Roosting Hill there was clearly a phase of valley excavation along a line of deep channels before the deposition of the late Wolstonian Hungry Hill Gravels, as the gravels come down into the valley, where they directly overlie the Chalk. By analogy with the Waveney Valley (Sparks & West 1968) this period of drainage development was probably in the Wolstonian glacial stage. The Roosting Hill valley may have been the upper valley of a northward-flowing river whose lower reaches are represented by the River Stiffkey (figure 9, inset). To the east, the lower Glaven Valley is also a pre-late Wolstonian feature, incised into the boulder clay and containing constructional landforms of the Wolstonian (Gipping) retreat (West 1961).

The main west–east section of the Wensum Valley was excavated in the late Wolstonian after the deposition of the Hungry Hill outwash sheet. In the Swanton Morley section of the valley, the Hungry Hill Gravels cap the high ground and do not come down into the valley as they do at Roosting Hill. The valley is cut through the Hungry Hill Gravels, then the chalky boulder clay, and downstream the river becomes deeply incised into the Chalk. In cutting through the boulder clay, the River Wensum also cut through its included sand and gravel masses so that these are now exposed along the valley sides in the middle Wensum Valley. There is no evidence for a train of outwash gravels following the Wensum Valley as suggested by Straw (1973).

Since the establishment of the main part of the River Wensum, the Roosting Hill tributary appears to have captured the headwaters of another eastward-flowing river, the Tud, and in the upper part of the Wensum system, to the north of this area, the drainage pattern suggests that other diversions may have taken place. These developments have reinforced the Wensum as the principal river of central Norfolk, draining most of the eastern side of the plateau.

(*c*) *Summary*

The geological succession in the Wensum Valley area can now be summarized as follows:

Flandrian	deposition of alluvium and peat reduction of terrace to remnants
Devensian	solifluction formation of organic deposits at Roosting Hill frost disturbance of high- and low-level gravels cutting of low terrace
Ipswichian	continued aggradation of sands and gravels in Wensum Valley formation of organic deposits under fluviatile conditions at Roosting Hill and Swanton Morley
Wolstonian	aggradation of sands and gravels in Wensum Valley and dissection of Hungry Hill Gravel sheet deposition of Hungry Hill Gravel outwash sheet, possibly with constructional features in the valley at Roosting Hill and Gressenhall excavation of Roosting Hill valley
Hoxnian	
Anglian	deposition of chalky boulder clay and associated sands and gravels cutting of deep channels

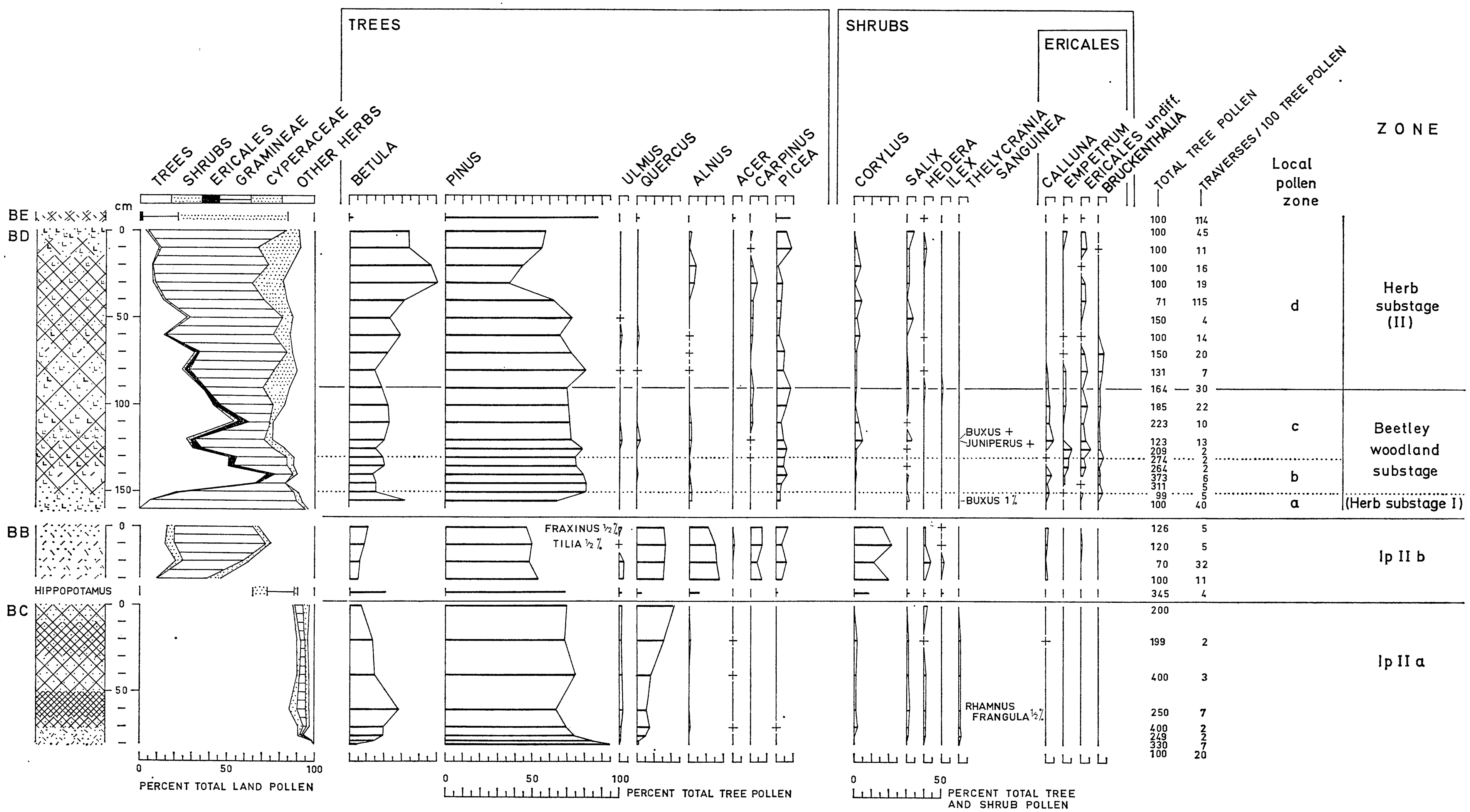

FIGURE 10. Tree and shrub pollen diagram from Roosting Hill, Beetley.

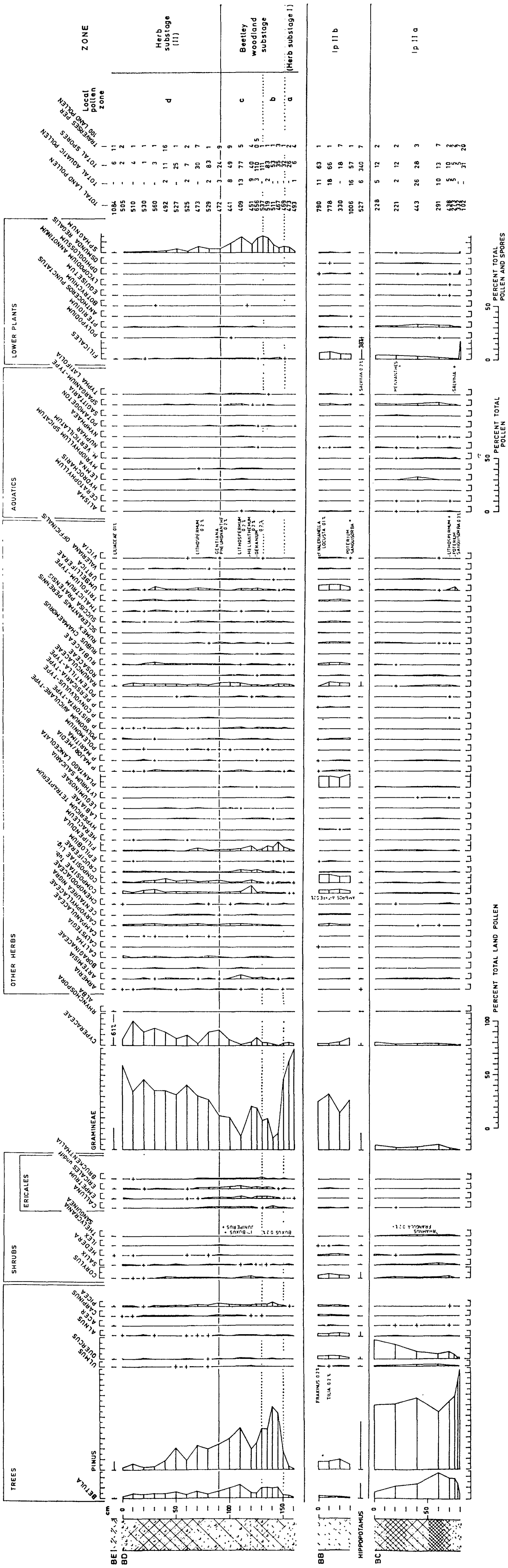

FIGURE 11. Total pollen diagram from Roosting Hill, Beetley.

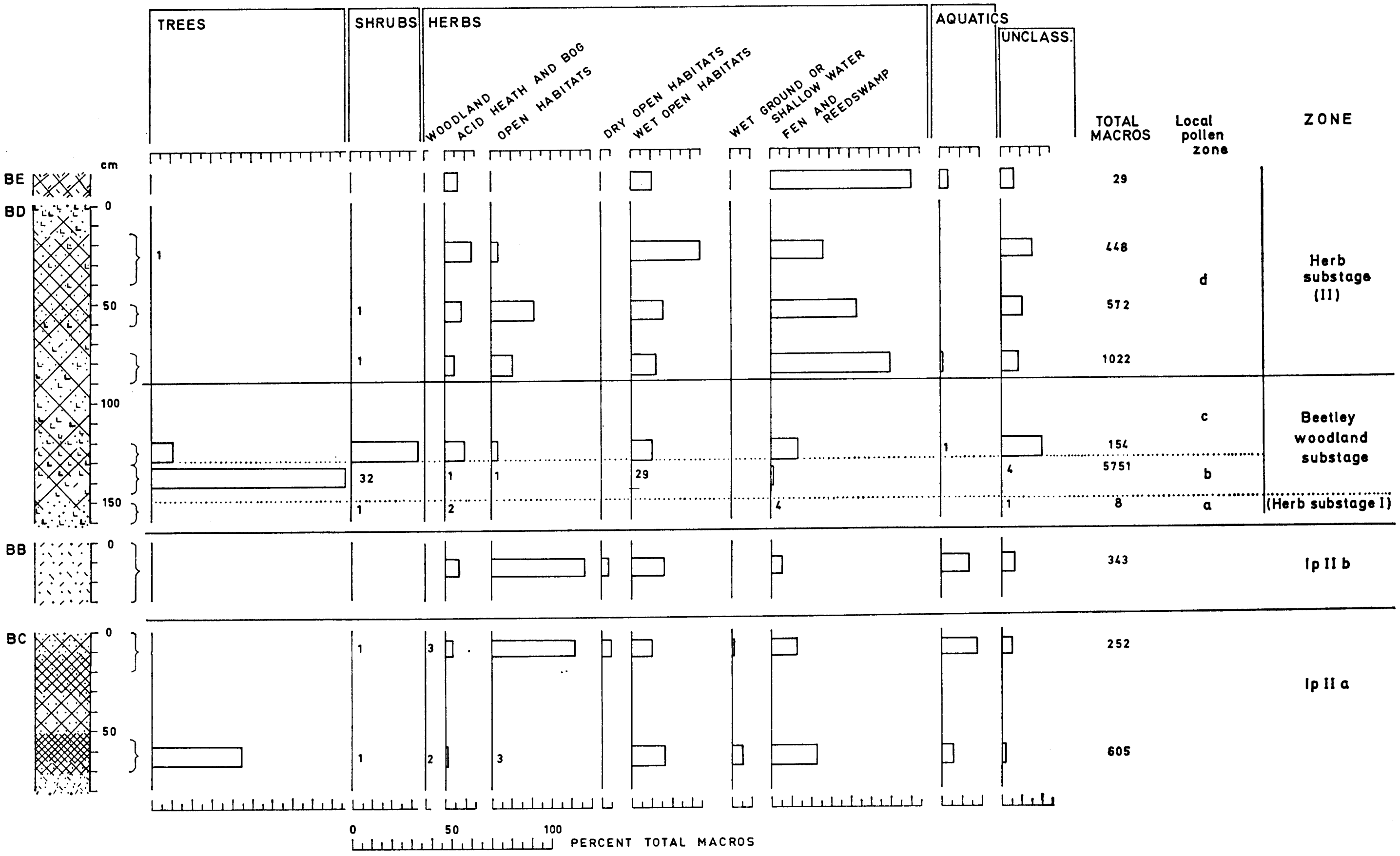

FIGURE 12. Relative frequency of ecological groups in the macroscopic plant remains from Roosting Hill, Beetley.

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(*d*) *The palaeobotany of the deposits at Roosting Hill, Beetley*

Samples from the following were analysed for pollen and plant macrofossils: the lower mud bed in section BC, a *Hippopotamus* bone from section BB, the upper mud bed in section BB, the mud beds in section BD and the moss peat in section BE (figures 10, 11, 12 and table 2). The diagrammatic presentation of the lithology follows Troels-Smith (1955).

(i) *Pollen assemblage zones and the age of the deposits*

The pollen diagrams have been divided into pollen assemblage zones (p.a.z.) which can be correlated with regional pollen zones in the interglacial deposits, and some of which have regional significance in the BD and BE sections.

BE			Cyperaceae–Gramineae p.a.z.
BD	zone *d*	0– 90 cm	Gramineae p.a.z.
	zone *c*	90–130 cm	*Pinus–Betula–Picea*–Ericales–*Sphagnum* p.a.z.
	zone *b*	130–150 cm	*Pinus–Betula–Picea* p.a.z.
	zone *a*	150–160 cm	Gramineae p.a.z.

BD zones *b* and *c* represent a forested period, called here the Beetley woodland substage and tentatively correlated with the Chelford Interstadial.

BB. *Pinus–Quercus–Alnus–Corylus* p.a.z.

This zone is correlated with the later part of subzone II*b* of the Ipswichian Interglacial.

Hippopotamus bone. *Pinus–Betula–Alnus–Quercus–Corylus* spectrum

This spectrum is assigned to the early part of subzone II*b* of the Ipswichian Interglacial. The bone came from the base of the upper mud bed in section BB.

BC. *Pinus–Betula–Quercus–Ulmus* p.a.z.

This zone is correlated with subzone II*a* of the Ipswichian Interglacial.

These Ipswichian Early-temperate pollen assemblages are characterized by the dominance of *Pinus* and *Quercus*, by the low levels of *Ulmus* and by the virtual absence of *Tilia*. The very high *Pinus* values are a local feature of this site, and pine needles are common in the interglacial beds.

(ii) *Vegetational history of the Ipswichian Early-temperate zone*

Subzone Ip II a

This is a period of closed forest with *Pinus*, *Betula* and *Quercus*. Oak becomes more important later in the subzone, as birch declines. *Ulmus* pollen is initially very low, then rises slightly. There are sporadic occurrences of *Alnus*, *Acer* and *Picea* pollen, and *Corylus* and *Hedera* are present throughout. There may be a division into mixed coniferous-deciduous woodland, with *Pteridium*, over the sands and gravels, and deciduous woodland with oak and elm on the better soils over the boulder clay. *Pinus* pollen is greatly overrepresented at the very base of the bed, where pine cones were found.

The a.p.:n.a.p. ratio remains high throughout this subzone, but small areas of scrub and open herbaceous vegetation are indicated by low frequencies of *Thelycrania sanguinea*, Gramineae, *Artemisia*, Chenopodiaceae, *Plantago* spp. and *Poterium sanguisorba*. There are macroscopic remains of *Thelycrania sanguinea* and *Rubus fruticosus* and several open ground herbs.

Near the base of the diagram, high values for Filicales and *Ophioglossum vulgatum* spores are succeeded by a peak in the *Betula* curve, which is accompanied by a low *Salix* peak and the occurrence of *Rhamnus frangula* pollen. Local birch carr has developed, and the macroscopic remains are dominated by cone-scales and fruits of tree birches. Macroscopic remains of many plants of wet open habitats, shallow water, and fen and reedswamp, together with several aquatic species, indicate marsh and reedswamp communities bordering a slow-flowing shallow stream.

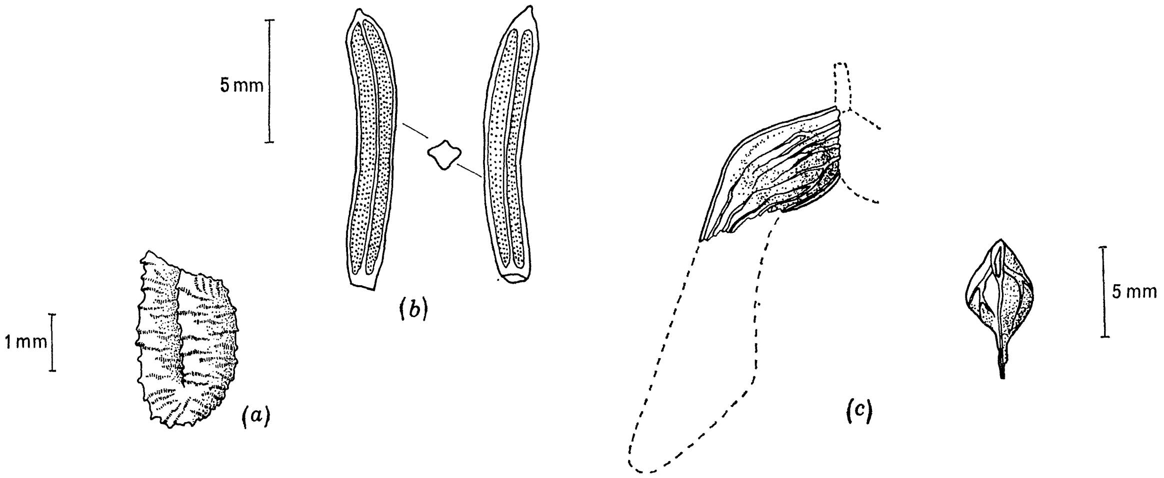


FIGURE 13. Plant macrofossils from Beetley and Swanton Morley. (*a*) *Damasonium alisma* Mill. seed from Beetley C; (*b*) *Picea abies* cf. ssp. *obovata* (Ledeb.) Hultén needle from Beetley D; (*c*) *Acer monspessulanum* L. fruit from Swanton Morley X.

The plant macrofossils from the upper part of the bed, BC 0–20 cm, present an altered picture of the local vegetation. There are no birch remains and the fen and reedswamp communities are considerably reduced, the most abundant species being *Ranunculus sceleratus* and *Urtica dioica*. There is a much greater representation of plants of open habitats, including *Aphanes microcarpa* and *Rumex acetosella*, species that are indicative of poor sandy soils. The fen and carr communities near the site have declined and open weedy vegetation has spread on the sandy and gravelly soils of the floodplain. Aquatics have greater relative importance than before, although the numbers of macrofossils are similar. Some of the taxa in the lower sample are no longer present, but several new species occur, including *Damasonium alisma* (figure 13*a*) which has previously only been found in full-glacial deposits.

Subzone Ip IIb

The sample from the *Hippopotamus* bone yielded a pollen spectrum representing the early part of the mixed oak forest phase. The high *Pinus* and *Betula* values depress the *Quercus* percentage, but *Ulmus*, *Picea* and *Ilex* are present and *Corylus* has expanded. N.a.p. is still low, though Gramineae pollen is higher and fern spores are very abundant, probably from local riverside vegetation.

In the upper mud bed spectra from BB, n.a.p. has risen to high levels. The remaining forest is still dominated by *Pinus*, with *Quercus*, *Betula*, *Carpinus*, *Picea* and *Corylus*. *Ulmus* is present, and also *Ilex* and *Hedera*. The *Carpinus* and *Picea* levels show that these spectra represent the very end of the Early-temperate zone. *Picea* pollen reaches 7 % a.p., and the presence of spruce in the vegetation may be having an adverse effect on the growth of hornbeam (Phillips 1974). *Alnus* pollen percentages are higher, and local alder carr may be forming, although alder may also be growing on areas of impeded drainage on the boulder clay, which comes down into the bottom of the valley in places.

The high levels of n.a.p. are due primarily to increased amounts of Gramineae pollen, though other herbs have also increased considerably. There are several herbs of open habitats, notably *Plantago lanceolata*, and two species, *Scleranthus perennis* and *Valerianella locusta*, are plants of dry sandy ground. Sporadic occurrences of *Calluna*, Ericales and *Sphagnum* indicate the beginnings of an acid heath community.

The macroscopic remains support the pollen diagram. The only well-represented taxa are herbaceous plants of open habitats, and there is a long list of species, including plants of dry sandy ground and wet open habitats. The macrofossils are very similar to those from the top of BC, while in the pollen diagram n.a.p. rises from below 30 % at the top of BC to 75–90 % in BB. The vegetation around the site of deposition is therefore much the same as before, but the open herbaceous vegetation near the river has spread over the valley floor, and the forest in the area has probably become more open as well.

By this stage in the interglacial, the light soils over the gravels on the surrounding slopes would have become very leached, and the woodland growing on these soils may have been similar to that described by Summerhayes, Cole & Williams (1924) on Oxshott Heath and Esher Common. There, a varied open mixed woodland, dominated by *Betula*, *Quercus* and *Pinus*, was growing on a poor acid soil over sands and gravels in an area of low rainfall. The relatively high light intensity in these woods resulted in a well-developed ground vegetation, varying in species composition according to local drainage conditions.

Aggradation in the river valley at this time would have greatly extended the area of open sandy floodplain for herbaceous vegetation to colonize. At the same time, animal grazing and trampling may have helped to maintain and extend the open vegetation on the floodplain and valley sides. Large mammals recorded from Beetley include *Megaceros giganteus*, *Hippopotamus*, *Rhinoceros hemitoechus* and *Elephas antiquus*, although the *Hippopotamus* bone is from an earlier part of the subzone, and the exact provenance of the other bones is unknown. Pollen of *Plantago lanceolata*, a grazing indicator, reaches 12 % l.p. and is present in the macroflora in BB. *P. major/media* pollen is present in all the BB spectra and *P. major* flourishes on bare ground created by animal treading. However, in the spectrum from the *Hippopotamus* bone sample, a.p. is high and there are few open habitat plants, so animal activity may only be a minor factor.

(iii) *The Beetley woodland substage and herb substage(s)*

(1) *Vegetational history.*

The BD and BE organic deposits were formed in a small shallow pool on the surface of the outwash gravels in the valley. This provides an ideal situation for the reconstruction of local plant communities, and the abundance of macroscopic remains in these deposits has allowed a very detailed picture of the local vegetation to be built up.

Zone a BD 150–160 cm Gramineae p.a.z.

In this zone, grass pollen is at very high levels, and there are small amounts of other herbs, mainly Cyperaceae and Ranunculaceae. At 160 cm there is virtually no tree pollen, only a few grains of *Pinus* and *Betula*, but at 155 cm both these taxa start to rise and at 150 cm the continuous curve for *Picea* begins.

		Beetley										Swanton Morley							
		BC		BB	BD						BE								
	type of remains	55–70	0–20	0–30	150–160	130–145	120–130	75–90	50–60	15–40		SF	SC	SH	SG	SD	SX	Hi6	SB
(1) Trees																			
Acer monspessulanum L.	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Alnus glutinosa (L.) Gaertn.	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.
Alnus Mill.	c	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Betula pendula Roth.	cs	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	fr	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B. pubescens Ehrh.	cs	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	fr	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Betula L. (tree sp.)	cs	5	.	.	.	5	.	.	.	.	.	.	.	84	3	1	.	.	.
	fr	252	.	.	.	248	3	.	.	1	.	.	.	385	70	12	.	.	.
Picea abies (L.) Karst. cf. ssp. *obovata* (Ledeb.) Hultén	l	.	.	.	.	4714	7	.	.	.	.	.	.	.	.	.	.	.	.
Pinus sylvestris L.	s	5	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
Pinus subg. *Diploxylon*	l	3	.	.	.	552	1	.	.	.	.	.	.	.	.	.	.	.	.
(2) Shrubs																			
Betula nana L.	fr	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
Bruckenthalia spiculifolia (Salisb.) Reichenb.	s	.	.	.	1	29	53	1	1	.	.	.	.	.	.	.	.	.	.
Erica L.	l	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Rubus fruticosus L. s.l.	a	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sambucus nigra L.	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Thelycrania sanguinea (L.) Fourr.	fst	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
(3) Woodland herbs																			
Ajuga reptans L.	n	.	3	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.
Moehringia trinervia (L.) Clairv.	s	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
(4) Herbs of acid heath and bog																			
Eriophorum vaginatum L.	scl	.	.	.	1	1	2	.	.	.	2	.	.	.	.	.	.	.	.
Juncus acutiflorus Ehrh. ex Hoffm.	s	.	.	.	.	.	2	.	4	1	.	.	.	.	.	.	.	.	.
Juncus articulatus – type	s	7	9	25	1	.	10	50	39	63	.	.	.	.	.	.	.	.	.
J. bulbosus L.	s	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
Acrocladium stramineum (Brid.) Richards & Wallace	l	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.
Dicranum scoparium Hedw.	l	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.
Mnium cf. *cinclidioides* Hubn.	l	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Sphagnum palustre L.	l	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.
Sphagnum sect. *Palustria*	l	.	.	.	.	++	.	.	.	.	.	.	.	.	.	.	.	.	.
S. squarrosum Pers.	l	.	.	.	.	++	+	.	.	.	+	.	.	.	.	.	.	.	.
Sphagnum L.	l	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
(5) Herbs of open habitats																			
Alopecurus L.	car	.	.	.	.	.	2	6	.	.	.	.	.	.	.	.	.	.	.
cf. *Agropyron repens* (L.) Beauv.	car	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.
Anthoxanthum odoratum L.	car	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Chenopodium sect. *Pseudoblitum*	s	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cirsium arvense (L.) Scop.	a	.	.	.	.	.	.	2	1	1	.	.	.	.	.	1	.	.	.
cf. *Hordeum* L. and/or *Agropyron* Gaertn	car	.	.	.	.	.	.	17	.	.	.	.	.	.	.		.	.	.
Juncus bufonius L.	s	1	62	120	.	.	1	22	13	6	.	.	.	.	.	.	.	7	.
Leontodon autumnalis L.	a	.	2	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

		Beetley										Swanton Morley							
		BC		BB		BD					BE								
	type of remains	55–70	0–20	0–30	150–160	130–145	120–130	75–90	50–60	15–40		SF	SC	SH	SG	SD	SX	Hi6	SB
cf. *Poa* L.	car	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Poa L. spp. and/or *Alopecurus* L. spp.	car	.	.	.	.	1	.	.	13	3	.	.	.	.	.	.	.	.	.
Plantago cf. *lanceolata* L.	cap	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polygonum cf. *nodosum* Pers.	n	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.
Ranunculus acris L. or *R. bulbosus* L.	a	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	1	.	.
R. repens L.	a	2	20	23	.	.	.	4	1	.	.	.	.	.	.	1	.	1	.
R. subg. *Ranunculus*	a	.	.	.	.	.	.	.	.	.	.	.	.	.	1	7	.	2	.
Sagina cf. *procumbens* L.	s	.	3	6	.	.	2	54	63	6	.	.	.	.	.	.	.	.	.
Stellaria media (L.) Vill.	s	.	1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
(6) Herbs of dry open habitats																			
Aphanes microcarpa (Boiss. & Rent.) Tothm.	a	.	10	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rumex acetosella L.	n	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scleranthus L.	cal	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
(7) Herbs of wet open habitats																			
Carex cf. *pulicaris* L.	n	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
Juncus conglomeratus L.	s	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.
Juncus effusus L. and/or *J. conglomeratus* L.	s	90	16	41	.	.	13	61	37	85	.	.	.	.	.	.	.	7	.
Juncus inflexus L.	s	9	4	1	.	.	3	57	53	60	.	.	.	.	.	.	.	3	.
Montia fontana L.	s	.	1	3	.	27	.	5	.	.	3	.	.	.	.	.	.	1	.
Ranunculus flammula L.	a	.	1	2	.	.	.	6	5	10	.	.	.	.	.	.	.	.	.
R. sardous Crantz.	a	.	4	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rorippa islandica (Oeder.) Borbas	s	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
cf. *R. sylvestris* (L.) Bess. or *R. amphibia* (L.) Bess.	s	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.
(8) Herbs of wet ground or shallow water																			
Alisma plantago-aquatica L.	s	34	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rumex maritimus L.	n	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
(9) Fen and reedswamp herbs																			
Berula erecta (Huds.) Coville	fr, s	29	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.
Carex panicea L.	u+n	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Carex L. spp.	n	29	2	10	4	84	22	612	233	119	21	.	1	65	20	128	.	16	53
Cladium mariscus (L.) Pohl	n	.	1	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.
Epilobium hirsutum L. or *E. parviflorum* Schreb.	s	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eupatorium cannabinum L.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.
Hydrocotyle vulgaris L.	s	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypericum tetrapterum Fr.	s	12	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	3	.
Lycopus europaeus L.	n	16	1	.	.	.	.	.	.	.	.	.	.	.	1	8	.	.	.
Mentha aquatica L.	n	32	6	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Menyanthes trifoliata L.	s	.	1	.	.	.	.	.	.	.	.	.	.	.	.	11	.	.	.
Ranunculus lingua L.	a	2	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.
R. sceleratus L.	a	3	9	3	.	.	.	6	7	.	.	.	.	.	1	4	.	.	.
Rorippa microphylla (Boenn.) Hyland	s	11	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Urtica dioica L.	a	4	9	4	.	.	.	.	4	.	.	4	405	.	1	7	.	.	88
(10) Aquatics																			
Callitriche stagnalis Scop. or *C. intermedia* Hoffm.	s	.	2	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

		Beetley										Swanton Morley							
		BC		BB	BD						BE								
	type of remains	55–70	0–20	0–30	150–160	130–145	120–130	75–90	50–60	15–40		SF	SC	SH	SG	SD	SX	Hi6	SB
Ceratophyllum demersum L.	fr	4	.	.	.	.	.	.	.	.	.	.	.	.	4	17	5	1	.
Damasonium alisma Mill.	s	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Elatine hexandra (Lapierre) DC.	s	.	12	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Elatine L.	s	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Hippuris vulgaris L.	fst	.	.	.	.	.	.	.	.	.	.	1	.	.	.	2	.	.	.
Hydrocharis morsus-ranae L.	s	3	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
Lemna trisulca L.	s	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Naias marina L.	s	1	1	.	.	.	.	.	.	.	.	.	.	.	2	13	.	.	.
N. minor All.	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.
Nuphar lutea (L.) Sm.	s	1	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.
Nymphaea alba L.	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Potamogeton cf. *natans* L.	fst	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
P. nodosus Poir.	fst	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. obtusifolius Mert. & Koch/*perfoliatus* **L.**	fst	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.
P. pectinatus L.	fst	.	7	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. cf. *praelongus* Wulf.	fst	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potamogeton L. spp.	fst	1	2	1	.	.	.	1	.	.	.	.	.	.	1	9	.	.	2
Ranunculus subg. *Batrachium* (DC.) A. Gray	a	6	15	20	.	.	.	8	.	.	.	.	.	.	7	2	3	4	.
Scirpus lacustris L.	n	2	.	1	.	.	.	.	.	.	.	.	.	.	.	28	.	.	.
Sparganium erectum L.	fst	8	1	.	.	.	.	.	.	.	.	.	.	.	1	8	.	1	.
Typha L.	s	8	1	1	.	.	1	.	.	.	.	.	1	6	15	.	.	2	.
Zannichellia palustris L.	a	1	2	.	.	.	.	.	.	.	.	.	.	.	.	2	.	2	.
Salvinia natans (L.) All.	m	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Characeae	o	+	+	.	.	.	+	.	.	.	.	.	+	++	+	++	+	+	+
(11) Unclassified																			
Caryophyllaceae	s	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Cerastium L. sp.	s	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cruciferae	s	.	1	.	1	1	.	.	.	1	.	.	.	.	.	.	.	.	.
Gramineae	car	.	.	.	.	.	.	2	.	2	2	.	.	1	1	.	.	.	.
Juncus L. spp.	s	1	3	4	.	1	31	86	50	38	.	.	.	.	1	.	.	2	.
Polygonum L.	n	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	3	1
Potentilla L. spp.	a	2	1	7	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Ranunculus L. spp.	a	.	2	8	.	.	.	.	14	32	.	.	.	.	.	.	.	.	.
Rumex L. sp.	n	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Umbelliferae	fr	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Valeriana L.	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Viola odorata L. or *V. hirta* L.	s	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dryopteris-type	sp	+	+	+	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.
Mosses	l	+	+	+	+	++	+	+	+	.	++	.	.	.	.	.	.	.	.
Charcoal		.	.	.	++	+	+	.	.	.	.	.	.	.	.	.	.	.	.
	Total macros	605	252	343	8	5751	154	1022	572	447	28	5	407	541	132	389	16	65	147

Abbreviations: a, achene; c, cone; cal, calyx; cap, capsule; car, caryopsis; cs, cone scale; fr, fruit; fst, fruitstone; l, leaf; m, megaspore; n, nutlet; o, oospore; s. seed; scl, sclerenchyma spindle; sp, sporangium; u, utricle; + present; ++ abundant.

There are several possible explanations for the dominance of grass pollen at the base of the diagram. The abundance of charcoal fragments at 160 cm suggests temporary clearance by fire although birch, usually the first tree to recolonize areas of burnt-out woodland, does not have a peak here. Alternatively, the site may have been overgrown by a gramineous plant such as *Phragmites*, but no macros of *Phragmites* were found. Plant macrofossils were very scarce at this level and they do not greatly clarify the picture, although the presence of *Eriophorum vaginatum*, *Juncus articulatus*-type and *Sphagnum* indicate rather wet acid soil conditions.

The change from the grass-dominated vegetation of this zone to the coniferous forest of the subsequent zone may be a regional one, reflecting a change from severe to less severe climatic conditions, although if the zone *a* assemblage is a full-glacial one, it is surprisingly poor in taxa and pollen of open habitat herbs is very sparse.

Zone b BD 130–150 cm *Pinus–Betula–Picea* p.a.z.

Tree pollen rapidly reaches a peak of 73 % and is dominated by *Pinus*, with *Betula* and *Picea*. Such high levels of *Pinus* must indicate regional coniferous woodland. Pollen of *Calluna*, *Empetrum*, Ericales, *Bruckenthalia* and *Rubus chamaemorus* appears in this zone and *Sphagnum* increases, indicating the development of acid heath and bog communities. Gramineae pollen falls but there is an increase in the frequency and variety of other herbaceous taxa.

The macroscopic remains are dominated by needles of *Picea abies*. *Picea* pollen has a maximum of only 4 % l.p. (6 % a.p.) in this zone, but spruce is clearly present in the vegetation. Needles of *Pinus* are abundant but not nearly so numerous as *Picea* needles, the reverse of the situation in the pollen spectra. There are also many fruits and cone scales of tree birches. It is difficult to assess the relative importance of these genera in the regional forest, but is it probable that spruce has much more relative importance than the pollen levels would suggest. Shrub taxa represented by macrofossils are *Betula nana*, *Erica* sp., and *Bruckenthalia spiculifolia*. *Eriophorum vaginatum* is present, and there are abundant remains of *Sphagnum* species and other mosses.

The sediment in this zone is much more organic than in the basal 10 cm and must have accumulated in a shallow pool bordered by swampy ground. The pollen and macro assemblages include many herbaceous taxa, which would have belonged mainly to this wet ground and swamp vegetation near the pool and to open herbaceous vegetation on sand and gravel in the river valley.

Behind the pool, on the gently rising ground and up onto the plateau, woodland of spruce, pine and birch grew over a layer of moss peat covering the sandy soil. *Dicranum scoparium* grows in pine woods in Britain and is one of the characteristic species of the moss stratum of the spruce forests in northern European Russia (Sukachev 1928). *Sphagnum palustre* is intolerant of deep shade, but grows in more open pine woods. The forest would have had an undergrowth of dwarf birch and ericaceous shrubs, and where the woodland opened out, these shrubs would have become more abundant and formed an acid heath community with *Sphagnum* and *Rubus chamaemorus*.

The pollen assemblage of this zone is very similar to the interstadial assemblage at Chelford (Simpson & West 1958), and the vegetation type represented at Beetley may similarly be compared with the conifer-birch forests of Fennoscandia. The presence of *Picea* as an important member of the coniferous forest indicates a continental climate on the basis of its modern distribution, although the present western limit of *Picea* may not be climatically determined (Iversen 1944), and it has been suggested by several authors that the modern spruce may be poorer in biotypes than the fossil genus.

Zone c BD 90–130 cm *Pinus*–*Betula*–*Picea*–Ericales–*Sphagnum* p.a.z.

A reduction in tree pollen takes place in this zone, mainly due to a fall in *Pinus*. Increased levels of ericaceous shrubs, Gramineae, Cyperaceae, Compositae and *Artemisia* indicate a spread of acid heath and open herbaceous vegetation at the expense of the forest.

The continuation of acid conditions around the pool is indicated by *Succisa pratensis* and *Gentiana pneumonanthe*. The marsh gentian is local to the area today in wet acid places. A variety of open water taxa occurs in this zone, some of which indicate fairly base rich water, for instance *Hydrocharis* and *Myriophyllum spicatum*. Spring water from the Chalk may counteract the acidity of the water draining through the peat and sand and gravel.

The relative proportions of the plant macrofossils change drastically in this zone. Remains of tree taxa are very sparse, while shrubs have increased, with large numbers of *Bruckenthalia spiculifolia* seeds. Moss remains are less abundant, but wet acid conditions are indicated by *Eriophorum vaginatum*, *Juncus acutiflorus* and *J. articulatus*-type.

At 120 cm, the sediment becomes much more inorganic. Towards the edge of the pool, in section BE, there is a layer of gravel just above this level. The water level has risen in the pool and there is an influx of mineral material from the surrounding area. There is a marked increase in the number of pollen taxa in this zone, mostly thermophilous trees and shrubs, open habitat herbs and aquatics. The increase in thermophilous taxa is most marked at the flooding level at 120 cm, and reworking from interglacial deposits is the most likely origin for the pollen of thermophilous trees and shubs in these sediments. The increase in open habitat herbs does not take place at the flooding horizon, and probably indicates a true expansion of open habitats. Aquatic pollen increases in variety and frequency, probably representing an increase in open water and shallow water vegetation following the rise in water level.

Zone d BD 0–90 cm Gramineae p.a.z.

Tree pollen falls to very low levels, especially *Pinus*. Ericales and *Sphagnum* decline and virtually disappear. There is a great increase in grass pollen, and Cyperaceae levels also rise. Even if there were a large local area of open ground, a shallow pool in this situation would receive much greater quantities of pine and birch pollen if those trees were forming regional forest vegetation. The change to open herbaceous vegetation must therefore be a widespread one reflecting a deterioration in climatic conditions.

In the lower part of the zone, there may still be some woodland in the area, probably dominated by birch. The low levels of pine and spruce pollen suggest that coniferous forest is not present in the area but is not a great distance away. The heath vegetation of the previous zone lingers on for a time but the regional vegetation is dominated by grasses. In the uppermost part of the zone, a.p. falls very low. The coniferous forest must have retreated far away with the continued deterioration in climate, and only a few birches survive.

The herbaceous flora is similar to the previous zone, but several of the taxa that occur principally in this zone are plants of calcareous grassland, including *Centaurea nigra*, *Vicia*, *Polemonium* and *Plantago major/media*, suggesting that fresh calcareous soils are being formed over the chalky boulder clay under the influence of a severe winter climate. The macrofossils are dominated by *Carex* and *Juncus*, and there are several grasses and other herbs of open habitats. In the pollen assemblage, grasses are much more important than sedges, while the reverse is true in the macrofossil assemblage. Furthermore, the macroscopic grass remains belong to open grassland taxa rather than to marsh or swamp taxa. The Cyperaceae pollen must come from local sedge swamp, while the Gramineae pollen comes from the regional grass-dominated vegetation.

At the beginning of the zone, the sediments still have a high mineral content, then at 70 cm there is a change to detritus with large fragments of herbaceous debris. The pool has become shallower with the build-up of inorganic deposits, and organic material is starting to accumulate. There is finer detritus above this until at the very top there is a fresh influx of inorganic material.

BE Cyperaceae–Gramineae p.a.z.

This pollen spectrum is dominated by Cyperaceae. Gramineae pollen is quite important and there are low frequencies of other herbs, including some taxa characteristic of open habitats. *Pinus*, Ericales, *Empetrum* and *Sphagnum* are present but low.

The high level of Cyperaceae pollen is clearly related to the development of a local sedge-moss community. The macros are nearly all *Carex* nutlets, and moss remains include leaves and shoots of *Dicranum scoparium*, *Sphagnum palustre*, *S. squarrosum*, and *Mnium cinclidioides* (= *Pseudobryum cinclidioides*) which has also been recorded from the interstadial deposit at Chelford (Dickson 1973). *Eriophorum vaginatum* is another acid bog species present here, and there is pollen of *Rhynchospora alba*, a plant of wet acid peaty soils.

The sedge-moss peat formed at the edge of the pool, and the sediment changes in BE are about 10 cm above the equivalent changes in BD, so the BE peat is contemporaneous with the detritus mud at BD 50–60 cm. This is in the middle of zone *d*, the high Gramineae p.a.z. The high level of Cyperaceae relative to Gramineae in the BE pollen spectrum is due to pollen from the very local sedge vegetation masking the regional pollen rain, and the macrofossils were also derived almost entirely from the growing vegetation over the peat. The deposits of BD 50–60 cm formed in open water and so received pollen and macroscopic remains from the open grassland vegetation on the hillside as well as from the sedge and wet ground communities around the pool.

(2) *Problems of correlation*

The dating of the Beetley woodland substage presents several difficulties. In the upper part of the diagram, there is clearly a regional change from coniferous forest to open vegetation. However, the change from open vegetation to forest at the base of the diagram may be regional, representing a complete oscillation, or it may be a local effect, in which case only the end of a forested period is seen here. Assuming the latter to be the case, the forested period could be part of an interstadial in the Devensian or it could be at the end of the Ipswichian Interglacial. The regional pollen zones for each of these cases are shown in table 3.

TABLE 3. ALTERNATIVE REGIONAL POLLEN ZONES FOR BD AND BE

	end of Interglacial	end of interstadial	complete interstadial
BE and BD *d*	early Devensian	herb substage	herb substage II
BD *c*		woodland substage	woodland substage
——	Ipswichian	(interstadial)	(interstadial)
BD *b*			——————
——	zone IV		
BD *a*			herb substage I

The BD pollen diagram compares well with diagrams showing the end of the Eemian at Amersfoort and Moershoofd in the Netherlands (Zagwijn 1960) and at Brørup Hotel Bog, Herning and Hollerup in Denmark (Andersen 1961, 1965). At Beetley, there is some increase in ericaceous heath vegetation at the end of the forested period, but this does not develop to the extent that it does in the Netherlands at the beginning of the early Weichselian, and instead the declining forest is replaced by grassland. However, the rise in Ericales on the Continent is not always very marked, for instance at Herning and Hollerup. At Wretton in Norfolk, the beginning of the early Devensian is represented by high n.a.p. spectra with insignificant Ericales levels (West *et al.* 1974). Conditions in the early Devensian in Britain may have been more like the cold open conditions in Denmark, and the low Ericales at Beetley should not preclude an Ipswichian/Early Devensian correlation.

If the Beetley woodland substage is regarded as an interstadial in the Devensian, then it can be compared with the interstadial at Chelford (Simpson & West 1958) and with the Chelford woodland substage at Wretton. The Beetley pollen assemblage is very similar indeed to the Chelford assemblage, and there are similarities in the macrofossil lists which may be significant, for instance the occurrence of the moss *Pseudobryum* (*Mnium*) *cinclidioides* (Dickson 1973), and the very abundant remains of *Picea abies*.

Ericales levels are low at Beetley and at Chelford, in contrast with the Brørup and Odderade Interstadial on the Continent and with the Chelford woodland substage at Wretton. The development of ericaceous heath vegetation at different sites may be greatly affected by local conditions of water level and soil as well as by regional climate, and it could be misleading to attach too much importance to the Ericales curve in correlating interstadial diagrams. Nevertheless, while it may be a purely local feature, it may be significant that taxa other than *Calluna* make up most of the Ericales curve at Beetley, although *Calluna* is usually the most important taxon.

The BD diagram probably represents all or part of a woodland substage in the Devensian, followed by a period of open herbaceous vegetation. This woodland substage may be correlated with the interstadial at Chelford, but it is not possible to come to a more definite conclusion at this stage. New excavations at Beetley have revealed extensive organic deposits, which preliminary investigations have shown to represent several different vegetational phases in the Devensian. These may throw more light on the correlation of the Beetley woodland substage.

(iv) *Notes on identifications*

Bruckenthalia spiculifolia (Salisb.) Reichenb.

(1) *Pollen*

In most of the BD spectra, an ericaceous monad pollen type was found which matched fossil grains previously identified as *Erica* cf. *terminalis*. '*Erica* cf. *terminalis*' has been recorded from interstadial (possibly Chelford) beds at Four Ashes (identified by Miss R. Andrew), from Hoxnian Interglacial deposits at Marks Tey (Turner 1970) and from Cromerian deposits at Corton (identified by Miss R. Andrew). As a result of recent work by Miss R. Andrew and Dr C. Turner, this pollen type is now identified as *Bruckenthalia*. Fossil grains from Beetley and modern *Bruckenthalia* pollen are shown in figures 15 and 17 (plate 1). Similar grains have been recorded by Menke (1970) from interstadial deposits in the early Weichselian of Schleswig-Holstein, and also from Middle and Lower Pleistocene deposits. These are recorded as '*Blaeria*-type' and are compared with modern *Blaeria* and *Bruckenthalia* grains. In his photographs, the fossil grains more closely match *Bruckenthalia*, which has pronounced endocracks not seen in *Blaeria*. Andersen (1973) records ericaceous monads, probably of *Bruckenthalia*, from Brørup Interstadial deposits in Denmark.

The fossil grains from Beetley are tricolporate, with well-defined pores, and furrows bordered by broad costae. The furrows are long, giving a small polar area. The endexine is relatively thick and has distinct cracks which are especially strong in the polar area and down the sides of the costae. The surface sculpturing is scabrate-verrucate. The grains are more or less spherical, but vary from oblate to prolate.

The grains are very similar to *Erica terminalis*, but the latter have a much more pronounced pattern of endocracks and are larger than modern *Bruckenthalia* and the fossil grains (figure 16, plate 1). For the figures given in table 4, the polar length (*P*) and equatorial diameter (*E*) of 10 grains in each sample were measured. The measurements of modern *E. terminalis* grains from Corsica and Spain are from Oldfield (1959), and the third sample was of fresh material from the Cambridge Botanic Garden. The modern *Bruckenthalia* was fresh material from Kew Gardens. The fossil samples are from Beetley (BD 135 cm) and from Marks Tey (BB 505 cm).

TABLE 4. MEASUREMENTS OF *BRUCKENTHALIA* AND *ERICA TERMINALIS* POLLEN

	P		*E*		*P*		*E*
Bruckenthalia (modern)				*Erica terminalis* (modern)			
Kew Gardens	18 μm (17–19 μm)	×	18.5 μm (17–20 μm)	Corsica	27 μm (25–30 μm)	×	24 μm (21–27 μm)
Bruckenthalia (fossil)				Spain	25 μm (21–29 μm)	×	27μm (25–31 μm)
Beetley	18 μm (17–20 μm)	×	19 μm (17–20 μm)	Cambridge	26 μm (23–29 μm)	×	27 μm (24–30 μm)
Marks Tey	20 μm (16–23 μm)	×	19 μm (16–22 μm)				

There is some variation in the fossil pollen and a proportion of the grains are thinner walled with little pattern and often straight or even concave walls in polar view (figures 15*e–f*, plate 1). Similar grains were observed by Menke, who originally identified them as 'Rhamnaceae-type' due to their resemblance to *Frangula*, and Andersen also originally referred *Bruckenthalia* grains to *Frangula alnus*.

(2) *Seeds*

Ericaceous seeds were abundant in the BD deposits. They measure *ca.* 0.3 mm × 0.5 mm and vary in shape from flattened and asymmetrical to ovoid (figures 14*a–c*, plate 1). The epidermal cells are long and narrow, up to 10 times as long as broad, and with thick wavy walls, heavily pitted. The seeds matched fossil seeds from Gort, supplied by Professor W. A. Watts, and referred by Jessen, Andersen & Farrington (1959) to an extinct taxon, *Erica scoparia* var. *macrosperma*. These seeds have now been found to match seeds of *Bruckenthalia spiculifolia* (figures 14*d–f*, plate 1).

The original identification of the seeds from Gort as a variety of *Erica scoparia* was made on the basis of the occurrence of the seeds in flowers matching *E. scoparia*, and the elongated, though thin-walled, cells of *E. scoparia* seeds from Algeciras. However, only small unripe seeds were found in complete flowers and the ripe seeds were found separately or associated with incomplete flowers.

The seeds from Gort occurred in Gortian (Hoxnian) Interglacial deposits and similar seeds have been found in Gortian Interglacial deposits at Kilbeg (Watts 1959) and Baggotstown

(Watts 1964), and in deposits assigned to the Hoxnian Interglacial in the Shetlands (Birks & Ransom 1969).

Bruckenthalia spiculifolia is a characteristic dwarf shrub of high mountain communities in the Balkan Peninsula (Turrill 1929). It grows in acid *Sphagnum* bogs with *Vaccinium* and *Eriophorum*, and in moorland vegetation on better drained land, occupying a similar habitat to *Calluna* on northwest European moors. It also occurs in heath vegetation in openings in *Abies*- and *Picea*-dominated forests. The fossil assemblages in which *Bruckenthalia* has been found are compatible with its modern communities, and it has occurred in northwest Europe all through the Pleistocene although it is now restricted to the Balkan area.

Picea abies (L.) Karst cf. ssp. *obovata* (Ledeb.) Hultén

Several thousand conifer needle fragments and complete needles, identified as *Picea abies*, were recovered from BD 130–145 cm (figure 13*b*). The needles are 7–14 mm long and about 1.1 mm wide. They are square or rhombic in cross section though they are sometimes slightly flattened laterally. (This flattening is found in living material and occurs during growth.) The needles have acute tips, sometimes with a definite point, and a blunt base. There is a band of stomata on all four faces of the needle, and each band consists, on average, of 4–5 rows of stomata on each ventral face and 3–4 rows on each dorsal face.

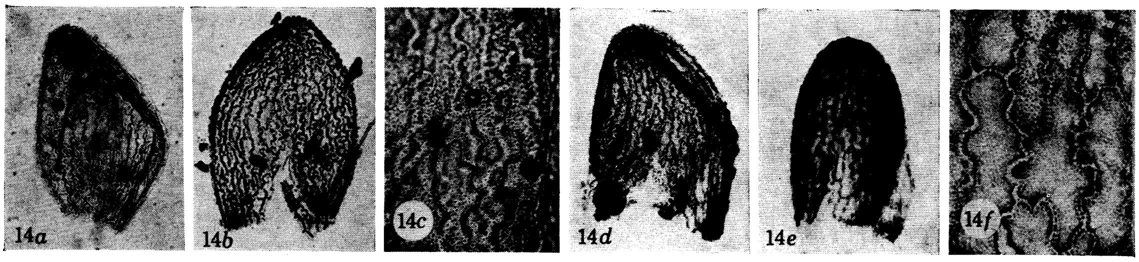
In Flora Europaea, *Picea abies* (L.) Karst. has two subspecies, ssp. *abies* and ssp. *obovata* (Ledeb.) Hultén, which were formerly recognized as two separate species, *P. excelsa* (Lam.) Link., the Norway spruce, and *P. obovata* Ledeb., the Siberian spruce. The basis of classification of these taxa is principally cone-scale shape, and also the more variable cone shape and size, and pubescence of the shoots. *P. abies* ssp. *obovata* is a distinctive form in contrast to ssp. *abies* which is highly variable, and it has a large distribution area in northeast Europe (except Scandinavia) and Northern Asia.

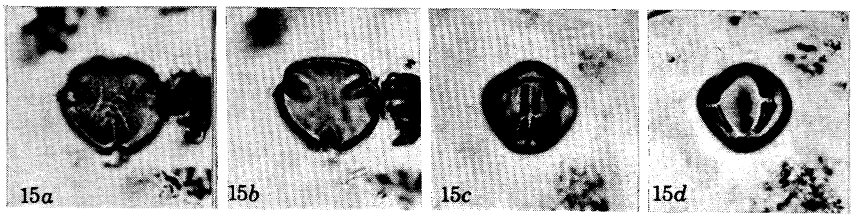
TABLE 5. MEASUREMENTS OF NEEDLES OF *PICEA ABIES*

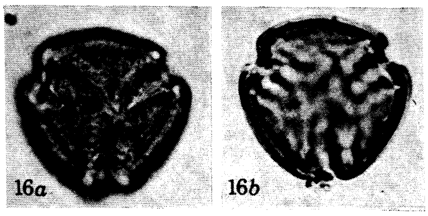
	stomatal rows	needle width/mm	needle length/mm
P. abies ssp. *abies*			
Upsala, Sweden	3:2 (3:2–2:1)	0.7 (0.5–0.8)	10 (8–13)
Suffolk (cultiv.)	2:2 (3:2–2:1)	0.9 (0.8–1.1)	11 (9–13)
P. abies ssp. *obovata*			
Russia	4:3 (7:5–2:1)	1.2 (0.8–1.4)	13 (11–16)
Altai Mountains	4:3 (7:5–2:1)	1.0 (0.8–1.6)	12 (7–15)
Finnish Lapland	4:3 (5:4–3:3)	1.2 (0.9–1.6)	11 (8–14)
Beetley (fossil)	4:3 (8:4–2:1)	1.0 (0.6–1.9)	10 (7–14)

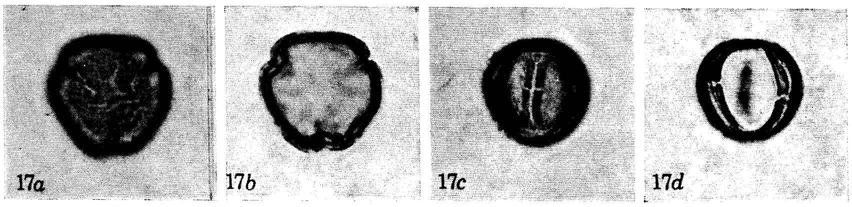
(Stomatal row number is not always proportional to needle width.)

There are some differences in needle morphology between the two subspecies. *P. abies* ssp. *obovata* needles are more robust than those of *P. abies* ssp. *abies*, they are rarely very flattened, and in a population of needles the average number of stomatal rows on each of the four faces is higher, with some needles having very high numbers. In table 5, the stomatal row numbers are the number of rows on one ventral face to the number of rows on one dorsal face. 20 needles in each reference sample were examined, and 500 fossil needles. The material from Finnish Lapland was provided by the Herbarium of the British Museum (Natural History). There is some overlap between the two subspecies in the ranges of the various measurements, but it is possible









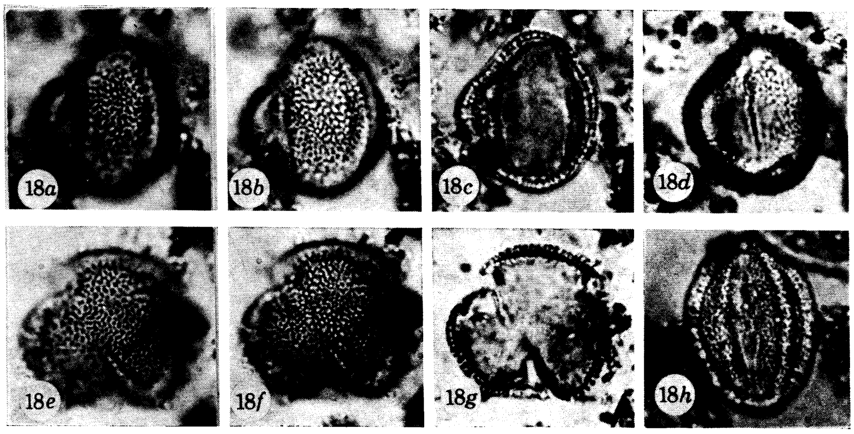


Figure 14. (*a–c*) *Bruckenthalia spiculifolia* seeds from Beetley D. (*d–f*) *Bruckenthalia spiculifolia* seeds, modern. Magnification of figures *a*, *b*, *d* and *e*, × 50; figures *c* and *f*, × 150.

Figure 15 (*a–f*). *Bruckenthalia* pollen from Beetley D.

Figure 16 (*a–b*). *Erica terminalis* pollen, modern.

Figure 17 (*a–d*). *Bruckenthalia* pollen, modern.

Figure 18 (*a–h*). Type X pollen from Barford (I.G.S. ref. nos: *a–d*, MPK 850; *e–g*, MPK 849; *h*, MPK 851). (Magnification of figures 15–18, × 750.)

to distinguish them when populations of needles are used. As this identification has been made on a statistical basis, the needles from BD have been referred to *Picea abies* cf. ssp. *obovata*.

Fossil cones of *P. abies* ssp. *obovata* (= *P. obovata*) have been found in abundance in Eemian deposits in Poland (Środoń 1950, 1967). These localities are to the west of the main area of distribution of *P. abies* ssp. *obovata* today, although it has scattered outposts in Central and Western Europe (Środoń 1950). The tentative identification of this subspecies at Beetley is of interest in that it indicates an extension of its range in the Upper Pleistocene much farther westwards.

(*e*) *The palaeobotany of the deposits at Swanton Morley*

The samples for pollen analysis were obtained from blocks of organic material and bones of large mammals that were dredged up during gravel working (figures 19 and 20). In the absence of information regarding the exact provenance of the organic material and the bones, their order of arrangement in the pollen diagram has been based on the tree pollen spectra and the a.p.:n.a.p. ratio, following the general pattern of interglacial vegetation development described by Turner & West (1968).

Local overrepresentation of certain taxa in some spectra could be determined by the presence of macroscopic remains, and these have been identified from most of the blocks and from one animal bone (table 2 and figure 21).

The bones of large mammals were identified by Mr B. MacWilliams of the Castle Museum, Norwich. They include remains of *Bos primigenius*, *Hippopotamus*, *Elephas antiquus* and *Rhinoceros*. The sample numbers from the *Bos* and *Hippopotamus* bones are as follows: *Hippopotamus*, 1, left tibia; 2, 3, right tibia; 4, left femur; 5, right femur; 6, sacrum; *Bos*, 7, 8, right humerus; 9, right tibia. A sample from the *Elephas* tooth was analysed, but the *Rhinoceros* bone yielded no material.

(i) *Age of the deposits*

The pollen assemblages are considered to belong to the Ipswichian Interglacial for the following reasons: the dominance of *Pinus* in the early part of the interglacial; the low *Ulmus* maximum, before the expansion of *Quercus*; the *Carpinus*-dominated Late-temperate zone; the absence of *Abies* and *Tilia*; the absence in the late-glacial of *Hippophaë*, which is characteristically present in the late Anglian.

(ii) *Pollen zones*

The pollen assemblages have been assigned to Ipswichian Interglacial zones and subzones as follows:

Zone e De. SB. *Betula*–high n.a.p. zone.
Zone Ip III. *Bos* and *Hippopotamus*. *Carpinus–Pinus–Quercus–Corylus* zone, with high *Alnus*. The spectra have been arranged so that *Carpinus* increases upwards relative to *Quercus*. This is purely for convenience, as the spectra are very similar, and the *Hippopotamus* bones may have belonged to one individual (B. MacWilliams, personal communication).
Subzone Ip II*b*. SX and *Elephas*. *Quercus–Pinus–Corylus* subzone, with high *Alnus*.
Subzone Ip II*a*. SD and SA. *Pinus–Quercus–Betula–Ulmus* subzone.
Subzone Ip I*b*. SG and SH. *Pinus–Betula* subzone. The high levels of *Betula* in SH are clearly a local effect.
Subzone Ip I*a*. SC. *Betula–Pinus* subzone.
Zone l Wo. SE and SF. *Betula*–high n.a.p. zone.

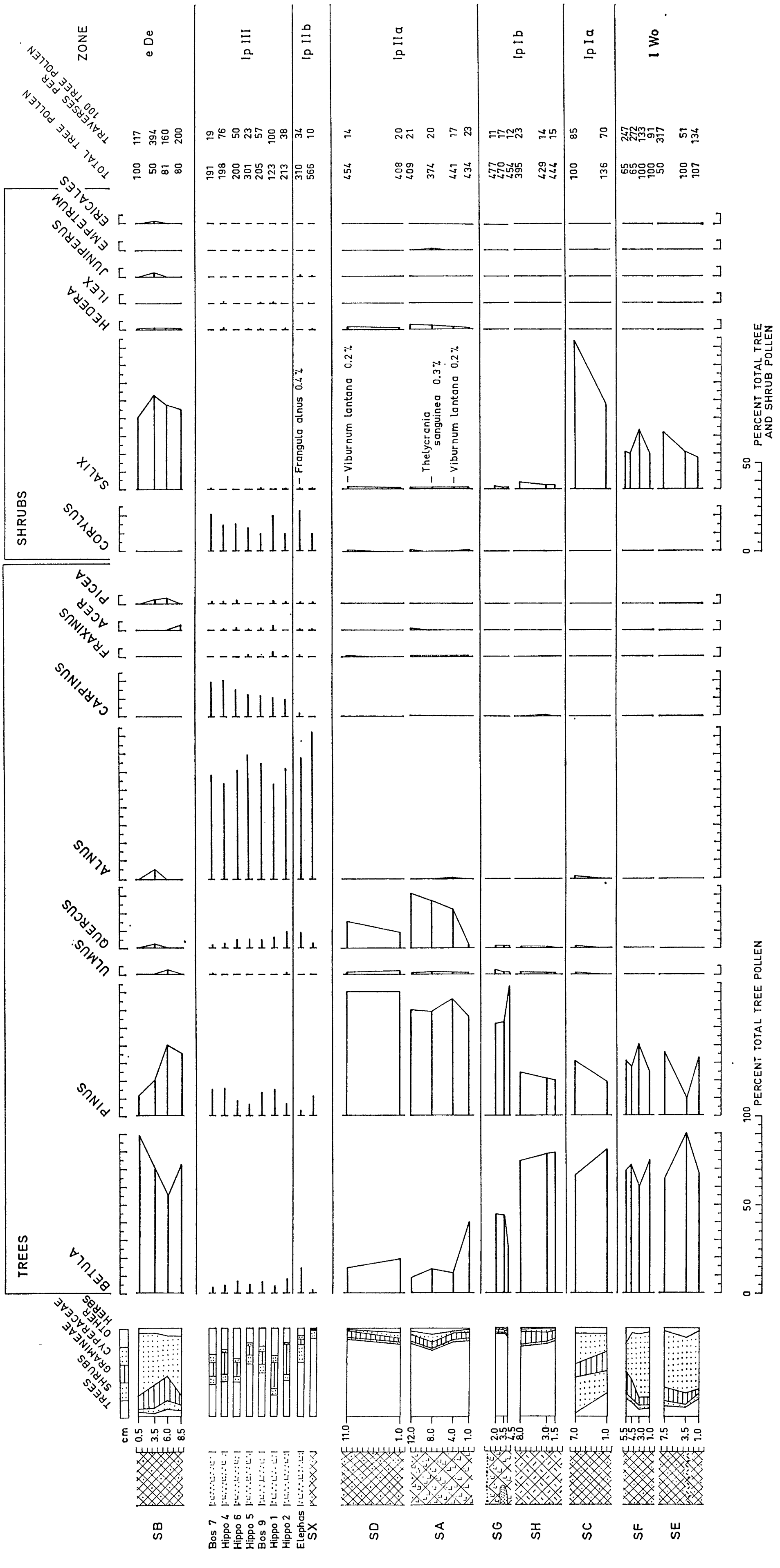


Figure 19. Tree and shrub pollen diagram from Swanton Morley.

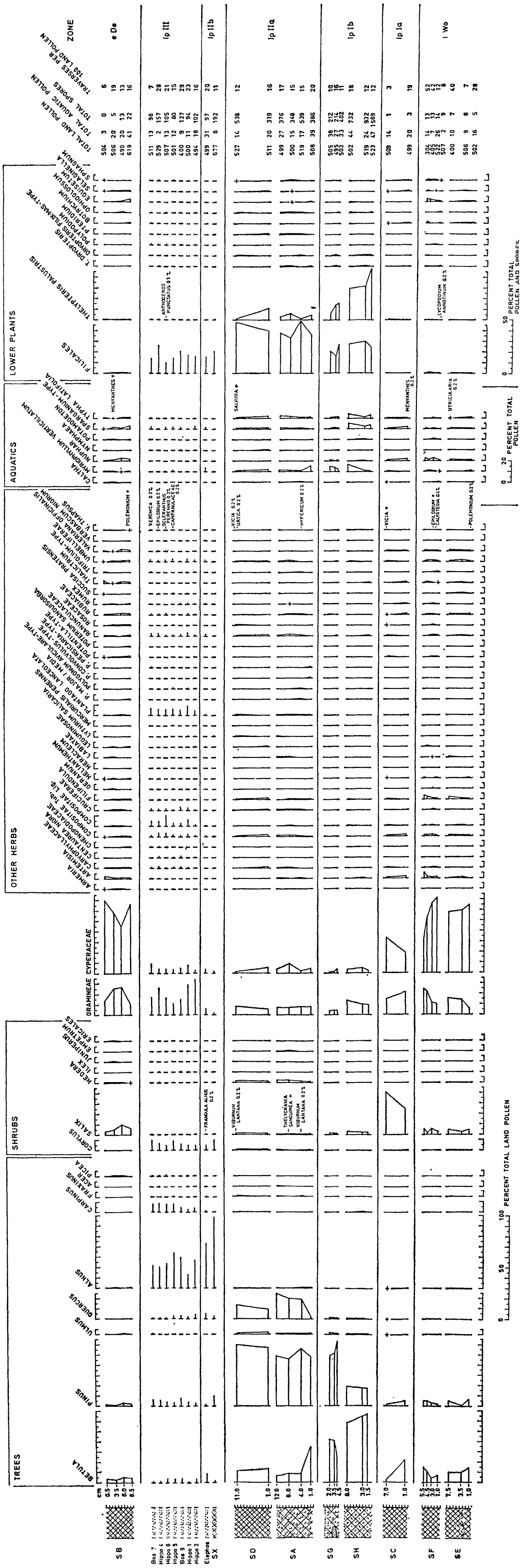


FIGURE 20. Total pollen diagram from Swanton Morley.

(iii) *Vegetational history*

The pollen assemblages at Swanton Morley have been greatly influenced by local conditions. The organic deposits were laid down in pools, cut-offs and shallow channels, and the sediments range from silty sand to detritus mud. Soil conditions on the extensive floodplain would have been varied, and in zones II*b* and III the possible effects of large mammals on the vegetation and soils have to be taken into account.

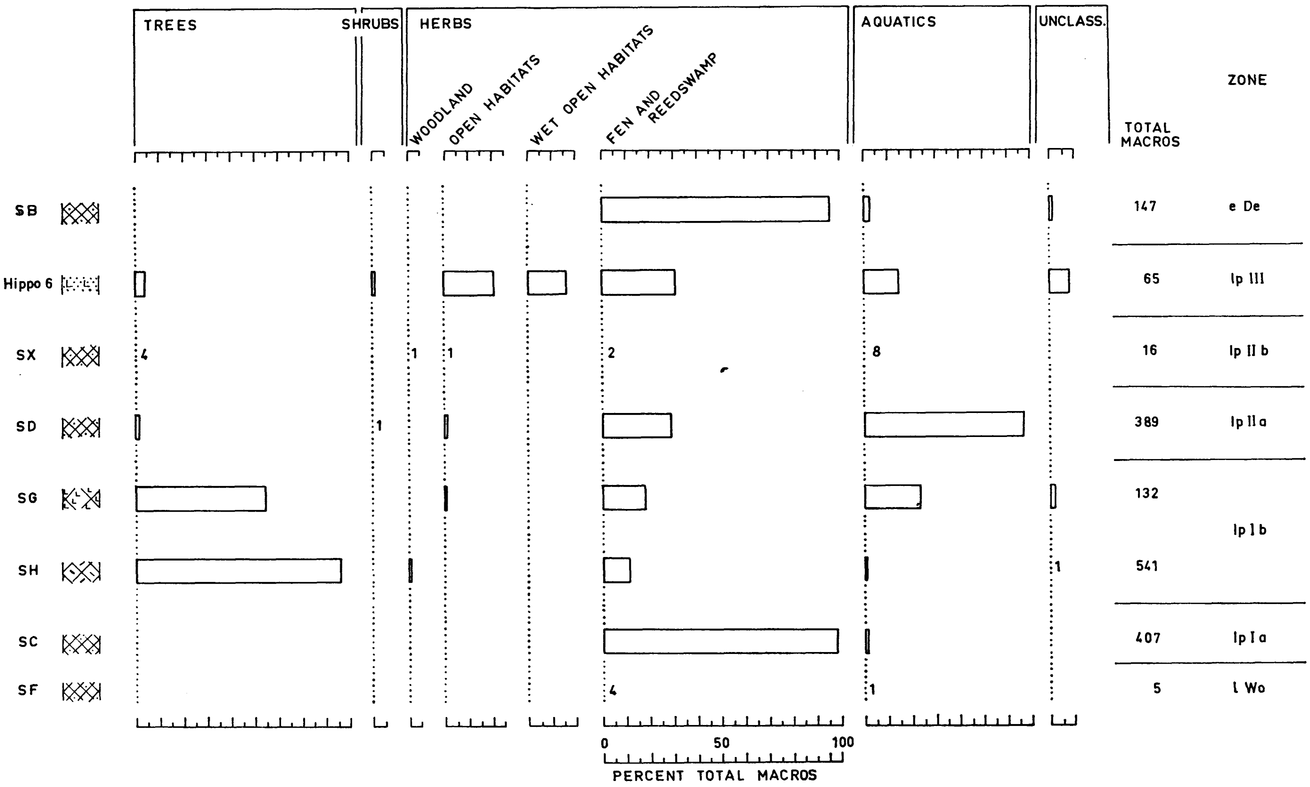


FIGURE 21. Relative frequency of ecological groups in the macroscopic plant remains from Swanton Morley.

Zone l Wo The late Wolstonian

The low a.p. : n.a.p. ratio and the presence of *Betula* indicate open herbaceous vegetation, possibly with scattered birch trees. *Pinus* pollen is very low and was probably introduced by long-distance transport. *Salix* pollen is also present, and there may be shrub willows in damper places.

Cyperaceae and Gramineae form the bulk of the herb pollen, but many other herbaceous taxa are present. These can be assigned to several communities, both near the site of deposition and on the higher ground away from the river. On the latter area, fresh unleached soils over the chalky boulder clay are indicated, in various stages of colonization and stabilization. Plants of open ground include *Plantago major/media*, Chenopodiaceae, *Epilobium* and the fern *Botrychium*, and *Polemonium* and *Filipendula* might come from a closed grassland, perhaps in damper hollows. Cyperaceae pollen makes up over 50 % l.p. through most of the zone. Much of this is likely to be of local origin, although there are no macroscopic remains of Cyperaceae and sedges may also be important in the regional vegetation.

Marsh and shallow water plants represented by pollen include *Typha latifolia*, *Sparganium*, *Caltha*, *Succisa pratensis* and *Calystegia*, and there are nutlets of *Urtica dioica*. Open water plants are represented by pollen of *Myriophyllum verticillatum*, *Potamogeton*, *Nuphar* and *Utricularia*, and by a fruitstone of *Hippuris vulgaris*. These taxa grow in relatively eutrophic water, so run-off from the chalky boulder clay, both locally and in the upper Wensum Valley, must have counteracted any acidity caused by water flow through sands and gravels in the area.

The late Wolstonian pollen assemblage at Swanton Morley is very similar to those at Ipswich, Ilford and Selsey, although there is no *Juniperus* at Swanton Morley. At all these sites, true arctic or sub-arctic taxa are lacking, and the presence of *Typha latifolia* suggests some degree of summer warmth (Iversen 1954).

Zone Ip I The Ipswichian Pre-temperate zone

Subzone Ip Ia

In this subzone a.p. increases though not a great deal. *Betula* is still the main tree pollen taxon but there is a slight rise in *Pinus* and pine is probably present now in the regional vegetation. In one sample, pollen of the thermophilous trees *Ulmus*, *Quercus* and *Acer* is recorded, although *Acer* pollen does not reappear until subzone Ip II*a*. There is a considerable reduction in Cyperaceae pollen in this zone, and the pollen of open ground and grassland herbs is reduced in variety and frequency with the increase in birch forest.

Salix pollen has high values in these spectra, reaching 40% l.p. This is likely to be a local effect, reflecting the formation of *Salix* fen carr in the river valley. At the same time, there is a decrease in the pollen of aquatics and marsh plants. The macroscopic remains indicate that conditions in the immediate vicinity of the site of deposition are much the same as in the preceding zone.

Subzone Ip Ib

Herbaceous pollen falls very low in this subzone and remains low until the latter part of the interglacial. In the SG spectra, *Betula* falls and is exceeded by *Pinus*, and *Ulmus* and *Quercus* pollen is present. Forest cover is almost complete and grass and sedge pollen is low. The rest of the herb pollen comes from plants likely to be growing on the floodplain, such as *Filipendula*, Ranunculaceae and Umbelliferae.

Fruits of tree birches in the macroscopic remains from SG indicate local birch fen carr. This points to some overrepresentation of *Betula* in the SG pollen spectra. The spores of Filicales and *Thelypteris palustris* come from ferns probably growing in the carr community. Fen and reed-swamp herbs, and plants of shallow and open water, are represented by macrofossils of several taxa.

The pollen spectra and macroscopic remains from SH are dominated by *Betula*, and there are abundant fern spores and sporangia, while open water aquatics are absent. The sediment of SH is a felted peat with compressed twigs and was probably formed in a shallow pool very near the area of fen carr.

Zone Ip II The Ipswichian Early-temperate zone

Subzone Ip IIa

Pinus remains dominant in this subzone, but *Quercus* is much higher and *Betula* declines. *Ulmus* pollen remains low and after this subzone only occurs sporadically. *Hedera* is present throughout. *Fraxinus*, *Acer*, *Thelycrania sanguinea* and *Viburnum lantana* pollen occurs infrequently, indicating some fairly open woodland or scrub on calcareous soils in the area. *Betula* and *Thelycrania sanguinea* are also present macroscopically in SD.

There is some grass and sedge pollen but herb pollen is generally low and probably comes from the field layer of the woodland. A few occurrences of *Artemisia*, Chenopodiaceae, *Plantago lanceolata* and *P. major/media* pollen indicate small areas of open ground. Filicales spores are abundant and presumably come from locally growing ferns, as there are many fern sporangia present in the sediment.

Aquatics are poorly represented in the pollen diagram, but are varied and abundant in the macrofossil flora of SD. Fen, marsh and reedswamp plants are also well represented in the macros. The aquatics and the marsh and reedswamp herbs indicate deposition of the SD sediment in eutrophic and fairly shallow water at the edge of a slow-flowing branch of the river, bordered by marsh and reedswamp vegetation. Mr B. W. Sparks has identified Mollusca from sample SD (see appendix 4), and his conclusions on the environment of deposition compare closely with those drawn from the plant remains. SD was a sandy calcareous organic mud, with lenses of shelly sand, and SA was a calcareous silt, muddy in places and shelly near the top.

The water plants *Naias minor*, *Salvinia natans* and *Hydrocharis morsus-ranae* indicate considerable summer warmth in this subzone. Among the terrestrial plants, *Thelycrania sanguinea* also indicates warm summers, while *Hedera* and the reedswamp plant *Cladium mariscus* cannot tolerate very cold winters.

Subzone Ip IIb

The phase of maximum development of the mixed oak forest, with dominant *Quercus* and high *Corylus*, is absent from this diagram. The very end of the phase is represented by spectra from SX, a small block of calcareous sandy silt, and from a sample of silty sand from a tooth of *Elephas antiquus*.

A.p. is still high in these spectra and a striking feature is the very high level of *Alnus* which constitutes up to 83 % a.p. Alder is probably forming a local carr community in the river valley, and macros are present in SX. Excluding *Alnus*, the main trees are *Pinus*, *Betula* and *Quercus*. *Carpinus*, *Fraxinus*, *Acer* and *Picea* are also present. Besides the alder remains, trees are represented macroscopically by a fruit of the Mediterranean species *Acer monspessulanum* (figure 13*c*).

Corylus is an important shrub and reaches 23 % of the total tree and shrub pollen. This is low for subzone Ip II*b*, where hazel is usually very abundant, but this may be because only the very end of the subzone is represented, and a fall in *Corylus* often takes place here. *Hedera* is virtually absent from these spectra, but *Ilex* appears for the first time.

Macroscopic remains in SX are not abundant, but include the aquatics *Ceratophyllum demersum*, *Ranunculus* subg. *Batrachium* and Characeae, which indicate deposition of the sediment in slow-moving base-rich water.

Zone Ip III The Ipswichian Late-temperate zone

Alnus still dominates the a.p. and is again represented macroscopically. Other than *Alnus*, the main tree taxa are *Carpinus*, *Pinus*, *Quercus* and *Betula*. *Picea* and *Acer* are present in most of the samples, and *Fraxinus* and *Ulmus* occur sporadically. *Corylus* is still the most important shrub, though at fairly low levels, and *Hedera* and *Ilex* occur infrequently. The regional woodland is dominated by *Carpinus*, probably forming hornbeam-oak woods on calcareous soils over the chalky boulder clay. *Pinus* pollen is quite high and may come from pine–oak–birch woods growing on sands and gravels on the uplands.

At Wretton, both pollen and fruits of *Carpinus* are abundant in zone Ip III, while *Alnus* is very low in the pollen diagram and absent from the macrofossil lists. *Carpinus* was considered to be growing both in the upland forest and in a wetter floodplain community (Sparks & West 1970). In zone Ip III at Swanton Morley, *Alnus* plays a much more important part in the local vegetation and *Carpinus* is probably absent from local communities in the river valley.

The a.p.:n.a.p. ratio is greatly reduced in this zone, primarily due to an increase in grasses, herbs of open habitats and other herbs. *Plantago lanceolata*, a herb characteristically associated with grazing, constitutes up to 10% l.p. Other herbs of open habitats occurring here are *Artemisia*, Chenopodiaceae, *Centaurea nigra*, *Helianthemum*, *Plantago major/media*, *Poterium sanguisorba*, *Scleranthus perennis* and *Verbascum thapsus*. In the macroscopic remains too, there is a greater proportion of open habitat herbs than in previous zones, suggesting disturbed open vegetation on the floodplain. Possible causes of the spread of herbaceous vegetation in this zone, and the part played by large mammals, are discussed in Phillips (1974).

Zone e De The early Devensian

The a.p.:n.a.p. ratio drops very low, with a return to open conditions similar to those of the late Wolstonian. There is no evidence for vegetational conditions at Swanton Morley in the period between the hornbeam zone and the early-glacial.

Betula is the main tree in this zone, although it must be very sparse in the vegetation. *Pinus* pollen is low and has probably been transported from much further away. *Juniperus*, *Picea* and Ericales pollen is present in very low frequencies, as well as thermophilous tree and shrub pollen probably reworked from older deposits. The assemblage can be compared with the Early Weichselian assemblage of zone W2b at Brørup Hotel Bog in Denmark (Andersen 1961).

The herbaceous pollen is dominated by Cyperaceae, followed by Gramineae. Nutlets of *Carex* are plentiful in SB, suggesting that the Cyperaceae pollen belongs to a local rather than to a regional sedge community. Grasses are probably more important in the regional herbaceous vegetation. *Artemisia*, *Thalictrum* and *Selaginella* are characteristic of early- and late-glacial pollen assemblages, and open conditions in this zone are indicated especially by *Armeria*, *Artemisia* and *Helianthemum*, and other open habitat herbs occurring sporadically. Pollen and seeds of several aquatics are present, and pollen of *Succisa pratensis* and Cyperaceae, and macros of *Carex* and *Urtica dioica* probably come from a marshy floodplain community in the immediate vicinity of the pool.

4. Hoxnian Interglacial deposits

Organic deposits of the Hoxnian Interglacial have been described in the Nar Valley in west Norfolk, where the interglacial beds overlie a boulder clay correlated with the Lowestoft Till (Stevens 1959). Two Hoxnian lake deposits are now known in central Norfolk, both lying above deep troughs in the Chalk. The deposit at Barford, seven miles west of Norwich, lies in the valley of the River Tiffey, a tributary of the River Yare. The deposit at Dunston, south of Norwich, lies in the valley of the River Tas which joins the River Yare just outside Norwich (figure 22).

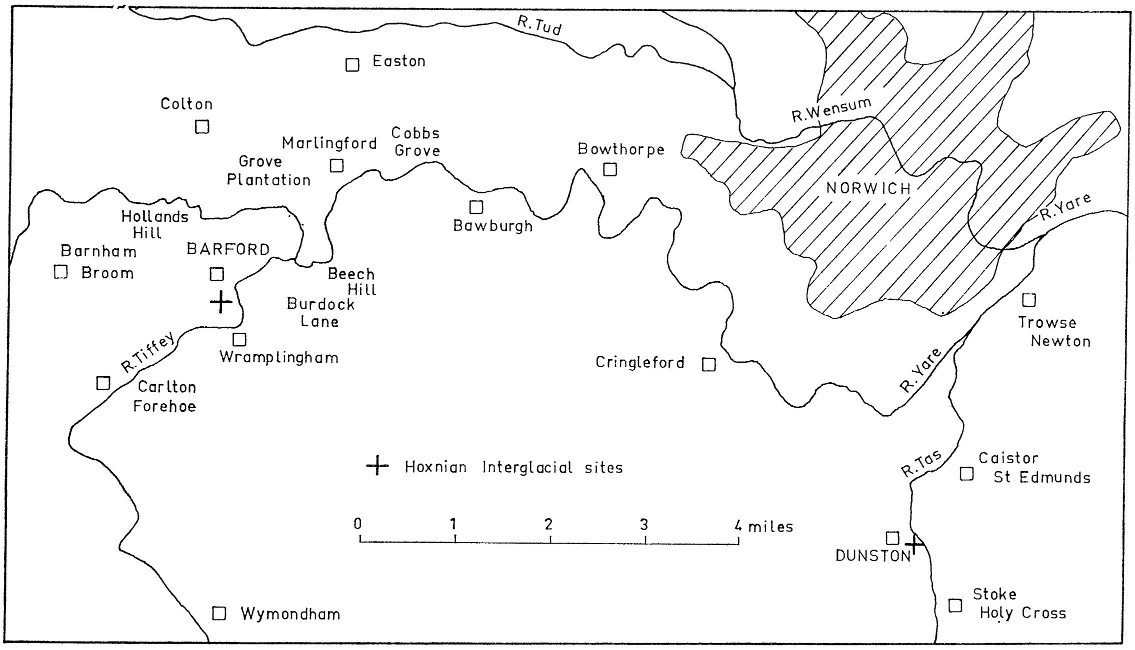


Figure 22. Location of Hoxnian Interglacial sites in central Norfolk.

The Chalk is the bedrock of the area, and its general surface level is between 21 m (70 ft) and 9 m (30 ft) O.D., sloping down eastwards. There are limited outcrops of Norwich Crag and Norwich Brickearth, but the main superficial deposit is a blue-grey chalky boulder clay. This reaches a considerable thickness where it occupies deep channels in the Chalk which often extend well below O.D. The later deposits comprise the Hoxnian Interglacial lake deposits over deep channels, clayey sand deposits, coarse glacial outwash gravels capping the high ground, fluviatile sands and gravels in the valleys and modern alluvium.

(a) *The stratigraphy of the deposits at Barford*

The Institute of Geological Sciences borehole at Barford (NGR: TG 111069) revealed 2 m (6 ft 5 in) of light brown clayey sand over nearly 9 m (30 ft) of organic clay mud which overlies more than 30.5 m (100 ft) of chalky boulder clay (figures 23 and 24; appendix 5).

Augering into the steep sides of a pond just west of the borehole revealed clay-mud in the side nearest the borehole, and a little further round, chalky boulder clay. Brown clayey sand with chalk fragments, similar to that at the top of the borehole, was exposed at the base of the back wall of the pond. The land rises quite steeply from the borehole to the back of the pond, and proceeding up the slope, the auger penetrated 1.2 m (4 ft) of clayey sand behind the pond, and 1.2 m (4 ft) of clayey sand with chalk fragments over chalky boulder clay higher up the slope. Beyond this, a few feet of soil cover chalky boulder clay. The augerings are shown in figures 23 and 24, together with several sections in field drainage ditches, 1.2–1.5 m (4–5 ft) deep, which are described below.

1. Gravel.
2. Chalky boulder clay.
3. Chalky boulder clay.
4. Chalky boulder clay 1m (3 ft) over chalk.
5. Chalk.
6. Chalky boulder clay.
7. Buff clayey sand.
8. Buff clayey sand 1.2 m (4 ft) over chalky boulder clay.

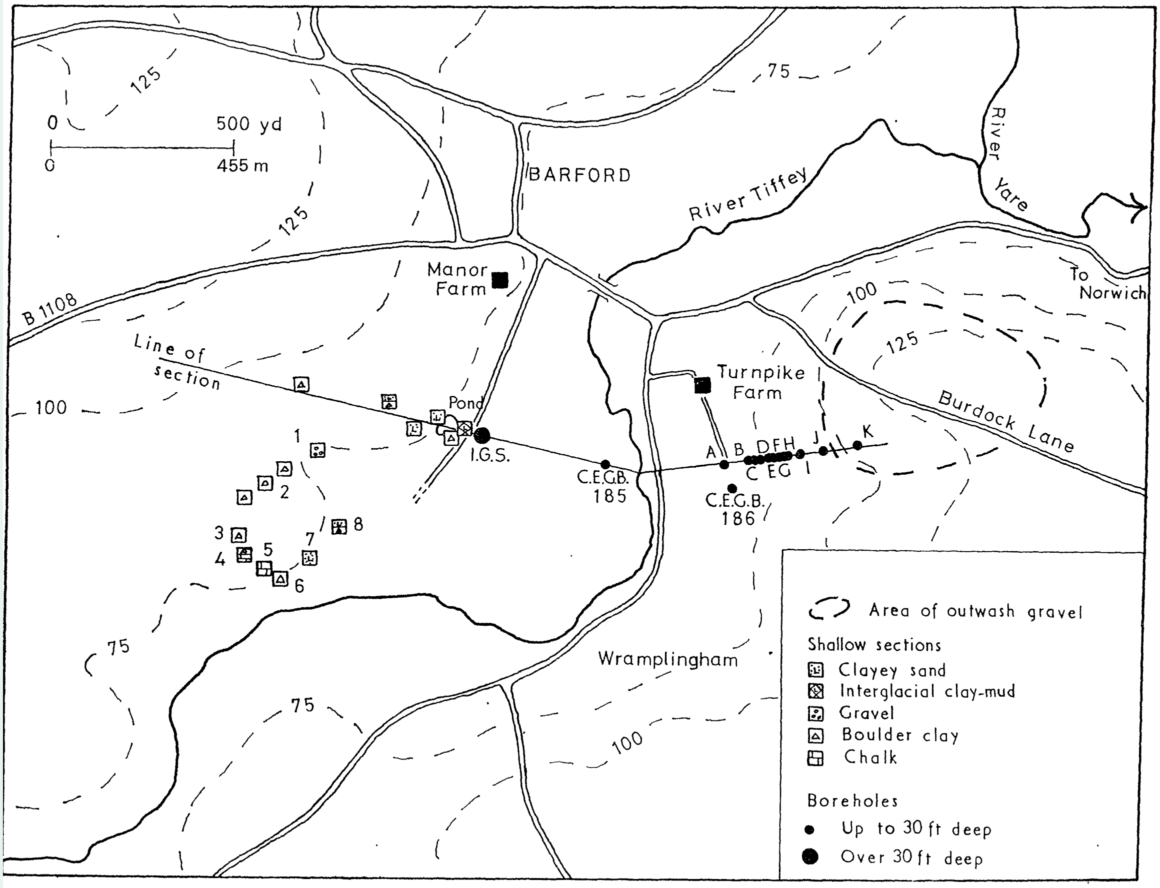


FIGURE 23. Location of boreholes and sections at Barford.

Between the I.G.S. borehole and the river, C.E.G.B. borehole 185 (NGR: TG 114068) showed 3.8 m (12 ft 6 in) of grey-brown sandy gravel over 5.3 m (17 ft 6 in) of grey-brown silty sand with flint and chalk up to medium gravel size and stratified in places with grey silt. The top of the borehole is at 19.2 m (63 ft) O.D.

On the other side of the valley, at Turnpike Farm, a line of holes, up to 9.1 m (30 ft) deep, was drilled down the hillside by means of a power-driven auger. The logs are given in appendix 5.

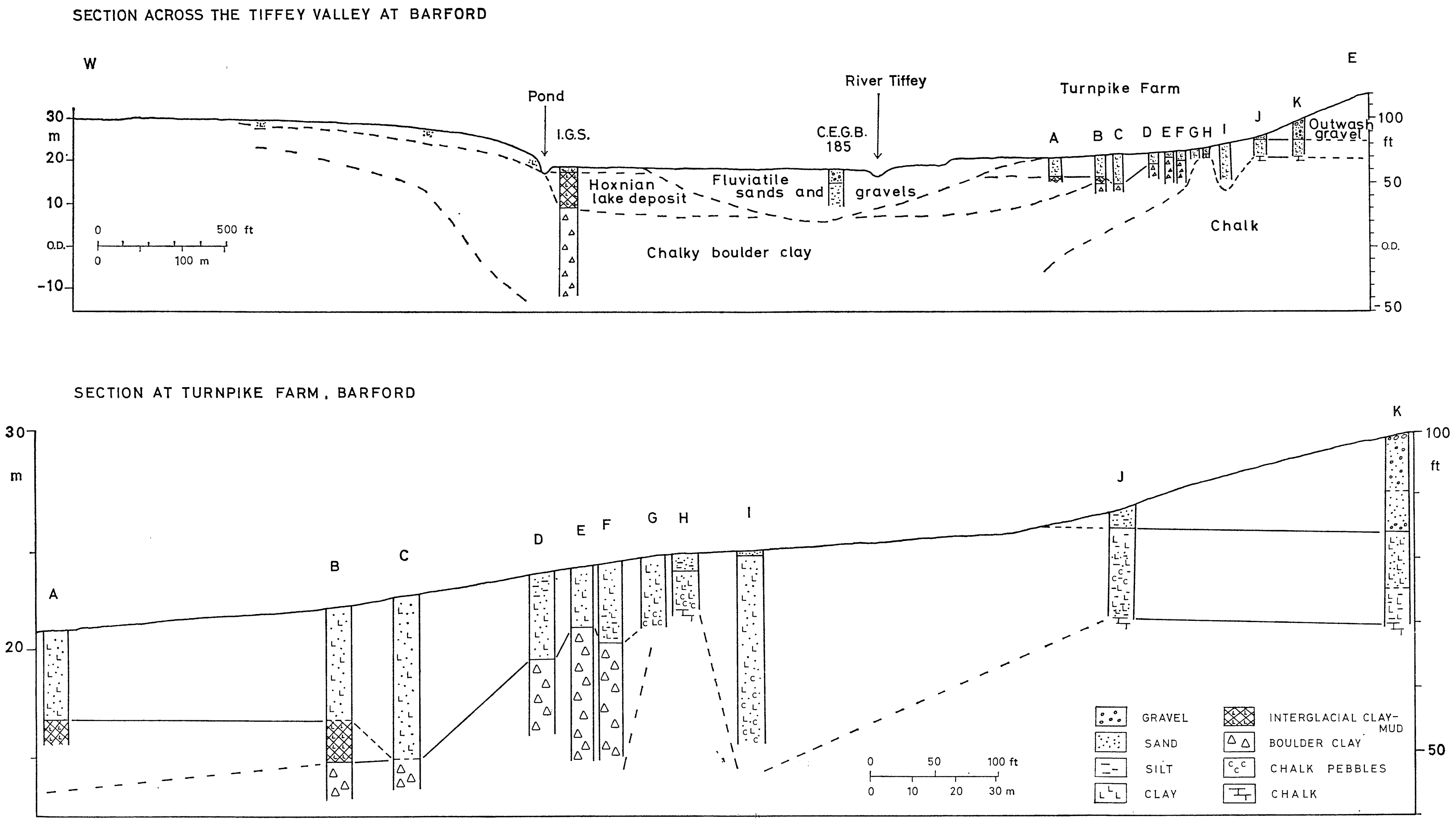


FIGURE 24. Sections at Barford.

(i) *Boulder clay*

The interglacial lake deposits overlie boulder clay which reaches a depth of at least −11.3 m (−37 ft) O.D. The boulder clay was not bottomed in the I.G.S. borehole, although the general level of the chalk surface is about 21–15 m (70–50 ft) O.D. The lake deposits and boulder clay presumably occupy a deep channel in the Chalk. Another borehole record indicating the existence of a deep channel at Barford is given by Woodland (1970). On the hillside in the village, at NGR: TG 114077, 60.1 m (197 ft) of clay with chalk overlay the Chalk, which was reached at −34.7 m (−114 ft) O.D. The existence of deep channels is not generally apparent in the present surface topography although parts of the Tas, Tiffey and Yare Valleys above Norwich show some relationship to the position of deep channels.

At Barford, a later river valley has been excavated over the trough containing interglacial deposits and boulder clay, and the organic sediments have been largely eroded away, remaining as patches on each side of the valley. Interglacial deposits in this situation are not always removed by later river erosion, and Hoxnian lake sediments are much more extensively preserved at Marks Tey where a small valley lies obliquely across the position of the trough (Turner 1970).

The boulder clay which fills the deep trough and covers much of the surface in this area is a dark to light blue-grey or grey chalky clay with pebbles and sometimes larger fragments of chalk, and also containing flint and quartzite, and other rocks in smaller quantities. It is in the area of the Lowestoft (Anglian) Glaciation of Baden-Powell (1948) and West & Donner (1956), and confirmation of its Anglian age is given by the presence of Hoxnian Interglacial deposits directly overlying it at Barford.

The chalky boulder clay contains pockets of sand or sand and gravel which have frequently become exposed on hillsides by subsequent erosion. These sand and gravel masses are usually chalky and may also contain quartz, quartzite and other rock types besides flint. They are usually clearly associated with the boulder clay, for example at Barnham Broom and Colton (Blake 1888). Near Barford, Beech Hill (NGR: TG 130074) is a long gravel ridge along the side of the Yare Valley. This might be a later constructional feature, but was probably a gravel mass within the boulder clay, exposed by the incision of the River Yare through the boulder clay and left as an upstanding feature through its resistance to erosion. This may also be the origin of the gravel ridge of Hollands Hill (NGR: TG 096084).

(ii) *Organic deposits*

Organic clay-mud of the Hoxnian Interglacial overlies the boulder clay on each side of the valley (figure 24). The deposit is about 9 m (30 ft) deep in the I.G.S. borehole, and shallower on the other side of the valley. The former extent of the deposit in other directions is not known.

Pollen analysis of a sample from the base of the organic deposits in the I.G.S. borehole gave a characteristic late Anglian pollen spectrum (figure 26). The pollen in the next two or three feet of sediment was poorly preserved and included pollen and spores probably derived from the boulder clay. The main period of lacustrine deposition began in subzone Ho II*c* and a continuous sequence from subzone Ho II*c* to subzone Ho III*b* was obtained. Pollen analyses of samples of clay-mud from boreholes A and B at Turnpike Farm on the other side of the valley indicate subzone Ho III*a* (table 6). These sediments are at the same general level as the upper part of the clay-mud in the I.G.S. borehole, although the top of the deposit in A and B is slightly lower and younger sediments may have been eroded away later in the interglacial.

(iii) *Solifluction deposits*

The boulder clay and the Chalk are covered by a sheet of buff or yellow-brown soft sandy clay or clayey sand, with small flints and chalk fragments. Variations in the colour and chalk content of this material reflect the type of underlying deposit. The material becomes paler, with abundant chalk fragments, near the Chalk, and it becomes grey over the boulder clay or the interglacial clay-mud. It overlies the Chalk in Turnpike Farm boreholes K, J and H, and probably I and G. It covers the boulder clay in F, E, D and C, and in some shallow sections on the other side of the valley, and it covers the interglacial clay-mud in B, A, C.E.G.B. borehole 186 and the I.G.S. borehole.

Mechanical analyses of three samples of the clayey sand were carried out. One sample was taken from the back of the pond level with the clayey sand at the top of the I.G.S. borehole. The other two samples came from Turnpike Farm, at 4.3 m (14 ft) from the surface in borehole I, and at 5.5 m (18 ft), below the coarse sand and gravel, in borehole K. The curves indicate a relatively poor degree of sorting and a coarseness which are compatible with an interpretation of the deposit as solifluction material. The curve for sample I is bimodal and it has been suggested that wind-blown silt may have been added to the solifluction deposit during a cold dry period with an open land surface (H. Davies, personal communication).

(iv) *High-level gravels*

In places, patches of coarse flint gravel cap the high ground. The gravel consists of rounded and subangular flint cobbles and pebbles with some small subangular flints in a matrix of coarse orange sand. It contains some erratics of sandstone and quartzite, and differs in this respect from the virtually pure flint Hungry Hill Gravels, although the gravels are otherwise similar. The gravel differs lithologically from the chalky boulder clay sands and gravels which normally contain much chalk and also larger quantities of more varied erratics. Little work has been done on the erratics in the gravels of this area, and a detailed survey would be of great value for distinguishing the different deposits.

The gravel in the Turnpike Farm section overlies the solifluction deposit over the Chalk towards the top of the slope. The coarse orange sand and fine subangular flint gravel in borehole K, reaching a depth of 15 ft (4.6 m) below the surface, is the typical matrix of the high-level gravels in this area, and of the Hungry Hill Gravels. In the fields around K and on the other side of Burdock Lane, the ground is covered with rounded and subangular flint pebbles and cobbles, with some subangular sandstone erratics. At the very top of boreholes H, I and J, there is a thin layer of orange or brown slightly silty coarse sand very similar to the outwash gravel matrix. In J, this is clearly part of the gravel sheet. In H and I, lower down the slope, it might represent a continuation of the gravel sheet *in situ*, but has probably been washed down at a later date.

Other remnants of the gravel sheet can be seen in pits at Grove Plantation near Colton and at Cobb's Grove near Marlingford. At Grove Plantation (NGR: TG 120092; 46 m (150 ft) O.D.) a section 3–6 m (10–20 ft) high shows coarse rounded and subangular flint gravel in the upper metre or so, giving way to coarse orange sand. A sandstone erratic was found here. At Cobb's Grove (NGR: TG 138093; 34 m (110 ft) O.D.) 1.2 m (4 ft) of coarse rounded and subangular flint gravel overlie 0.6 m (2 ft) of yellow sand, and an I.G.S. borehole near this pit (number TG10 NW 14) showed 4.9 m (16 ft) of flint gravel and sand over chalky boulder clay (Nickless 1973).

At Turnpike Farm, the gravels overlie a sheet of solifluction material which covers the Chalk, the boulder clay, and the lake deposits of the Hoxnian Interglacial. The gravels therefore post-date the Hoxnian Interglacial deposits and are interpreted here as outwash gravels of the Wolstonian retreat.

The geological situation in the Nar Valley may be similar in some respects to that at Barford. Stevens (1959) described a thin layer of unsorted yellow sand with flints and chalk fragments covering the Lowestoft Till and the Nar Valley Clay. This was correlated with the Gipping Till on stone orientation measurements, and it was described as passing laterally into 'cannonshot' outwash gravel at the Blackborough End gravel pit. Baden-Powell & West (1960) described 'cannonshot' gravel overlying contorted interglacial freshwater beds at this locality. Recent observations at the Blackborough End gravel pit showed no sections which could confirm that 'cannonshot' gravel directly overlies the interglacial deposits, but there is an unsorted sandy gravel over the interglacial beds which is probably a solifluction deposit. Further up the slope, coarse 'cannonshot' gravel appears where there is a rise in the land surface; it may overlie the solifluction material.

(v) *Terrace sands and gravels*

The deposition of the outwash gravels was followed by a period of erosion when the modern valley system of the Yare and Tiffey was established. The Hoxnian Interglacial lake deposits were cut into, leaving remnants on each side of the modern valley. The outwash gravels were reduced to small patches capping the high ground, while lenses of gravel in the boulder clay were exposed along the sides of the Yare Valley as the new river cut down. At Barford, the hillside to the west of the river was planed off, leaving the Chalk, the boulder clay and its gravel, and solifluction material all outcropping on a smooth gently sloping surface (figure 23).

Thick deposits of well-sorted fluviatile sands and gravels subsequently aggraded in the new river valleys. Nowhere has the solifluction material been shown to cover the river sands and gravels, and in the vicinity of C.E.G.B. borehole 186, a thin layer of yellow sand and angular flint gravel which could be river sand and gravel overlies the solifluction deposit. The aggradation might have taken place at the end of the Wolstonian, during the Ipswichian Interglacial, or in the Devensian.

There are remnants of a terrace at 1.5–3 m (5–10 ft) above the modern floodplain along the Tiffey and Yare Valleys, probably cut in the Devensian, and the terrace has been disturbed by frost action. The terrace sands and gravels at Barford differ from those of the Wensum Valley in containing a certain amount of silt, and fragments of chalk. This may be because the River Tiffey drained an area of chalk and boulder clay with relatively little sand and gravel in contrast with the Wensum whose upper reaches are in an area of extensive sand and gravel deposits. Like the Swanton Morley deposits, however, there is some evidence for coarse flint gravel at the base of the river gravels at Barford, as rounded flint cobbles are often dredged up from the river where the bed is being artificially deepened.

Frost activity at Barford is shown by vertical stones in the gravel exposed in the river banks, and by the hummocky uneven surface of the lower land, over both terrace deposits and solifluction deposits. In the Wensum Valley, the terrace surface is usually smooth and even, and this difference may be related to the higher silt and clay content of the various deposits at Barford.

The ground is most disturbed over the clayey solifluction material at the back of the terrace on the left bank and higher up at A on the right bank. The terrace is also dissected by small streams on the left bank. The present river channel is cut in and floored by the terrace gravels. The floodplain is cut in gravel which has only a thin veneer of alluvium or peat although this does become thicker in places.

(*b*) *The stratigraphy of the deposits at Dunston Common*

The Institute of Geological Sciences borehole at Dunston Common (NGR: TG 227026), which lies at 9.6 m (31 ft) O.D., penetrated 0.9 m (3 ft) of soil, then 4.0 m (13 ft) of sandy gravel and 13.4 m (44 ft) of silty clay (see Nickless 1971). These deposits are described below.

(i) *Organic deposits*

The general situation of the interglacial deposits at Dunston is very similar to their situation at Barford, although the organic beds are much deeper at Dunston. They were not bottomed in the borehole, which extended down to −8.8 m (−29 ft) O.D. The Chalk surface in this area is at about 15–9 m (50–30 ft) O.D., sloping down eastwards, so the deposits must lie in a deep channel in the Chalk. There is much evidence from boreholes in this area for deep troughs cut in the Chalk and containing boulder clay and glacial sand and gravel (Funnell 1958; Woodland 1970; Nickless 1971).

The interglacial beds in the deep channel at Dunston represent the latter part of the Hoxnian Interglacial, extending from subzone Ho III*b* into zone Ho IV (figure 27). In the upper 4.9 m (16 ft) of the lake clays, the pollen is poorly preserved and there is a large component of pre-Quaternary microfossils and of pollen taxa characteristic of the lower part of the interglacial deposit. Pollen analysis of chalky boulder clay from Barford, which appears to be continuous with the boulder clay in this area, showed a similar pre-Quaternary microfossil assemblage to that in the Dunston lake deposits, so erosion of the boulder clay land surface must have been taking place at this time. The main Hoxnian marine transgression is at the end of zone Ho III, and there is no sign of any marine influence here, either in the pollen taxa or in the presence of Foraminifera or marine molluscs, so the deposits must have formed at a time of marine regression in a lake with a throughflow of water and an artificially high water level. It is probable that the lake at Barford had completely filled in by this time, and the uppermost deposits were eroded away.

(ii) *Terrace gravels*

The interglacial lake deposits are overlain by a sandy gravel with traces of clay. The grave rises up from the modern floodplain forming a low terrace crossed by a small stream. There is little indication of the age of this gravel other than that it is post-Hoxnian, but the terrace lies in the modern valley and extends upstream, and downstream into the Yare Valley. It is reasonable to assume that the modern Tas Valley was cut at the same time as the modern Tiffey Valley, at the end of the Wolstonian Glaciation, and that the gravel represents aggradation of the late Wolstonian, or the Ipswichian and Devensian, with cutting of the terrace probably taking place in the Devensian.

(*c*) *Summary*

Cox & Nickless (1972) have put forward a chronology for the Middle and Upper Pleistocene of this area, which is summarized below.

Flandrian	formation of present floodplain
Devensian	dissection of terrace gravels deposition of terrace gravels erosion period; modern valley system established by joining up of lakes along line of deep channels
Ipswichian/Hoxnian	deposition of lake clays
Wolstonian	slumping of boulder clay into deep channels, and formation of lakes deposition of chalky boulder clay, and of outwash sands and gravels near Norwich; deposition of high-level coarse gravels ('torrent gravels') in final phase of decay of ice cutting of deep channels

This scheme presents two major difficulties. First, it requires the fusing of two interglacial periods, the Ipswichian and the Hoxnian, and second, it involves the correlation of pre-Hoxnian deposits with the Wolstonian Glaciation. However, field observations in the Barford area suggest a different succession, as follows

Flandrian	deposition of alluvium and peat
Devensian Ipswichian	frost disturbance of sands and gravels cutting of low terrace aggradation of sands and gravels in modern river valleys
Wolstonian	erosion period; cutting of modern valleys and dissection of high-level outwash gravels deposition of high-level outwash gravels solifluction
Hoxnian	erosion period; general erosion of land surface deposition of clay-mud in lakes formation of lakes over boulder clay in deep channels
Anglian	deposition of chalky boulder clay and its associated sands and gravels; cutting of deep channels

(*d*) *Geological comparison with Ipswichian Interglacial deposits in Norfolk*

The interglacial deposits in the Wensum Valley are in a quite different geological situation to the deposits in the Tiffey and Tas Valleys. This difference can be illustrated by reference to the interglacial sites at Swanton Morley and Barford (figure 25).

At Swanton Morley, interglacial organic muds and silts are intimately associated with the terrace sands and gravels. The organic deposits lie within a fluviatile aggradation series, laid down in the modern Wensum Valley. At Barford, interglacial lake deposits lie in a hollow in the boulder clay which occupies a deep trough in the Chalk. The lake muds have been cut into by the River Tiffey whose valley was excavated over the old deep channel at this point. The later terrace sands and gravels lie in the modern valley, unrelated to the interglacial beds.

The Ipswichian Interglacial deposits at Swanton Morley and Beetley are stratigraphically above the high-level outwash gravels, while at Barford Hoxnian Interglacial deposits are stratigraphically below these gravels, showing that the two interglacials are separated by a glacial phase.

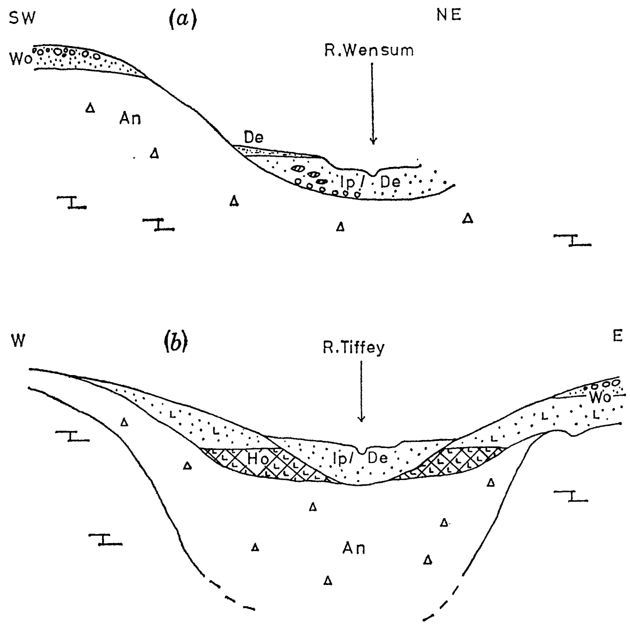


Figure 25. Diagrammatic sections of the deposits at (*a*) Swanton Morley and (*b*) Barford. De, Devensian; Ip, Ipswichian; Wo, Wolstonian; Ho, Hoxnian; An, Anglian.

(*e*) *The palaeobotany of the deposits at Barford*

Pollen analyses were carried out on the organic clay mud from the I.G.S. borehole at Barford (figure 26; appendix 6), and on two samples of clay mud from boreholes A and B at Turnpike Farm (table 6).

(i) *Age of the deposits*

The pollen diagram shows a vegetation sequence that is considered to belong to the Hoxnian Interglacial for the following reasons: the high level of *Hippophaë* in the late-glacial, which is characteristic of the late Anglian substage; the varied mixed oak forest with *Alnus*, *Quercus*, *Taxus*, *Ulmus* and *Tilia*; the presence of Type X; the presence of *Vitis* and *Pterocarya*; the establishment of a *Picea* curve before the rise of *Carpinus*; the strong development of *Abies* in the late-temperate zone.

(ii) *Pollen zones*

The pollen diagram can be zoned according to the zonation system for East Anglian Hoxnian diagrams proposed by Turner (1970). Zones and subzones have been distinguished as follows:

Subzone Ho III*b*. *Abies–Alnus* subzone. 198–292 cm (6.5–9.5 ft). The lower boundary is drawn where there is a sharp rise in the *Abies* curve.

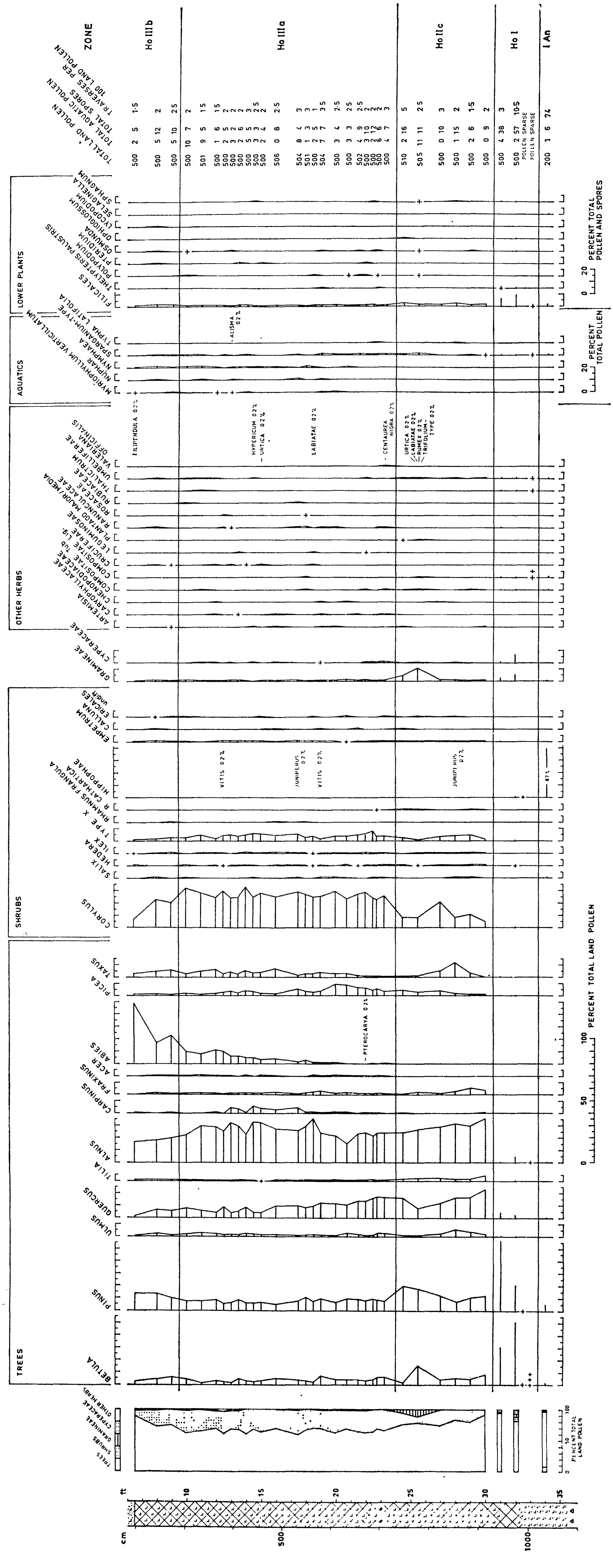


FIGURE 26. Pollen diagram from the Barford borehole.

Subzone Ho III*a*. *Alnus–Corylus–Quercus–Picea–Carpinus* subzone. 292–731 cm (9.5–24 ft).

The lower boundary is drawn where a continuous curve for *Carpinus* is established.

Subzone Ho II*c*. *Alnus–Quercus–Pinus–Corylus–Taxus–Ulmus* subzone. 731–929 cm (24–30.5 ft).

Zone Ho I. *Betula–Pinus*–Gramineae zone. 929–1020 cm (30.5–33.5 ft).

Zone l An. *Hippophaë* zone. 1032 cm (34 ft).

The two spectra from the Turnpike Farm deposits fall in subzone Ho III*a*, with *Alnus*, *Corylus*, *Quercus*, *Picea* and *Carpinus*, and low *Ulmus*, *Tilia* and *Abies*.

TABLE 6. POLLEN SPECTRA FROM TURNPIKE FARM, BARFORD

	A	B		A	B		A	B
	% land pollen			% land pollen			% land pollen	
Betula	2	6	*Corylus*	31	19	*Artemisia*	½	—
Pinus	6½	16	*Salix*	½	1	Cruciferae	½	—
Ulmus	1	3	*Hedera*	—	½	Rubiaceae	—	½
Quercus	9	10	*Ilex*	½	1	Umbelliferae	—	½
Tilia	½	1	*Rhamnus frangula*	—	½		% total pollen	
Alnus	32	27	Type X	4	2	*Nymphaea*	½	½
Carpinus	1	1	*Hippophaë*	½	½	*Sparganium*-type	½	½
Fraxinus	2½	1	*Empetrum*	—	½		% pollen and spores	
Acer	½	½				Filicales	½	1
Abies	½	½	Gramineae	1	1	*Sphagnum*	—	½
Picea	4	2	Cyperaceae	1	½			
Taxus	2	4					Total land pollen	
Pterocarya	½	—					500	500

(iii) *Vegetational history*

The late Anglian. Zone l An

In one spectrum from grey silty clay at the very bottom of the organic deposits, high levels of *Hippophaë* pollen indicate *Hippophaë* scrub, probably growing on fresh calcareous soils over the Chalk and chalky boulder clay of the hillsides. Very low frequencies of *Betula*, Gramineae and Compositae pollen indicate some open grassland with scattered birches, while the *Salix* pollen and fern spores may have come from a fen community in the damper parts of the boulder clay-floored depression. *Selaginella* is present, and this is characteristic of late- and early-glacial pollen spectra.

Single grains of *Quercus* and *Alnus* are probably reworked, and the small amount of *Pinus* pollen is likely to have been brought in by long-distance wind transport.

The Hoxnian Pre-temperate zone. Zone Ho I

During most of this period, there was little deposition in the hollow. In the two lowest pollen spectra, pollen was very sparse but at 1005 cm (33 ft) a few grains of *Betula*, with Compositae and single grains of other herbs, may indicate the earliest part of zone Ho I when birch spread over the landscape and shaded out *Hippophaë*.

At 975 cm (32 ft) the spectrum is dominated by *Betula* and *Pinus*, with *Alnus* and *Quercus* and single grains of other thermophilous trees, probably representing the immigration of these taxa into the region. *Corylus*, *Hedera* and Type X are represented among the shrubs, *Hippophaë* is still present and *Juniperus* occurs. The spectrum at 944 cm (31 ft) is very similar, but *Pinus* is higher than *Betula*, *Taxus* appears and *Hippophaë* has finally gone. In both these spectra, the high

Betula values, with the presence of *Alnus* and the abundance of fern spores, suggest the development of a local fen carr community, and birch and alder fruits and fern sporangia are present in these samples.

The Hoxnian Early-temperate zone

Subzone Ho IIc.

In the lower part of this subzone the pollen assemblage indicates a mixed oak forest rich in deciduous taxa, and with a coniferous element comprising *Pinus*, *Taxus* and *Picea*. *Hedera*, *Ilex* and *Rhamnus cathartica* are present among the shrubs, and the unidentified pollen taxon Type X reaches 5 % l.p. N.a.p. is very low. *Empetrum* is present at low levels and there are occasional records of *Sphagnum*, indicating the beginning of a wet heath community. There are no open water plants in this subzone, but *Sparganium*, *Typha*, ferns and Umbelliferae are present and these plants probably grew in swamp communities at the edge of the newly-formed lake.

In the upper spectra, a sharp rise in grass pollen and the appearance of new herbaceous taxa indicates a sudden opening out of the woodland vegetation. After this there is a more gradual recovery of the trees. A high n.a.p. phase at the end of subzone Ho II*c* has been found at Hoxne in Suffolk (West 1956) and at Marks Tey in Essex (Turner 1970), so it is evidently a widespread phenomenon in East Anglia.

After the high n.a.p. phase, *Corylus*, *Quercus*, *Ulmus* and Type X all recover quite rapidly, although *Quercus* and *Ulmus* are rather lower than before. *Taxus* recovers more slowly in zone Ho III, and never regains the high levels of subzone Ho II*c*. *Pinus* and *Betula* rise in the high n.a.p. phase, the fall to lower levels than before. Not all the tree curves are upset, however, and *Alnus*, *Tilia* and *Picea* are hardly affected.

Turner (1970) has compared in detail the vegetational changes during this phase at Hoxne and Marks Tey. The common features at those sites are also seen at Barford, namely the increase in grasses, the depression of *Corylus*, the drastic and long-lasting fall in *Taxus*, the increase in *Pinus* and *Betula* during the phase, and the increase in *Quercus* after the *Taxus* decline, although this is not marked at Barford. There are differences between all three sites in the precise order of events, but these are unlikely to have any great significance.

The possible causes of this temporary deforestation were discussed by Turner, and although a firm conclusion was not reached, fire was considered to be the best of the available explanations. The evidence from Barford provides little new information, but the absence of charcoal from the deposits at Barford, together with the lack of effect on *Picea*, a fire-sensitive tree, argues against the occurrence of a large-scale forest fire.

The Hoxnian Late-temperate zone

Subzone Ho IIIa

In the early part of the subzone, the mixed oak forest taxa still dominate, although deciduous trees are less important than before, and *Picea* has risen to around 10 % l.p. All these taxa decline as the subzone progresses, but *Taxus* slowly recovers after the high n.a.p. phase, and *Alnus* and Type X remain at the high levels of subzone Ho II*c*, while *Corylus* expands further. *Hedera* and *Ilex* persist all through the subzone.

The most important feature of this subzone is the immigration and expansion of *Carpinus* and *Abies*. *Carpinus* reaches a maximum of 6 % l.p. in the middle of the subzone, then declines, but

Abies increases steadily. *Acer* also appears for the first time and is almost constantly present, at low levels, in this subzone.

Two other new taxa, *Vitis* and *Pterocarya*, add to the variety of the forest. Both taxa are found, as pollen and macrofossils, in deposits of the latter part of the Holsteinian Interglacial on the Continent, and they were recorded for the first time in British Hoxnian deposits at Marks Tey, in subzone Ho III *b* (Turner 1970).

Herbaceous vegetation remains sparse, but there is some increase in acid heath vegetation with *Empetrum*, *Calluna*, Ericales and sporadic occurrences of *Sphagnum*, indicating deterioration in soil conditions.

Several water plants appear in this subzone, and the lake level probably rose rapidly at this time, in response to the general rise in water level as the interglacial sea level reached its maximum relative height in zone Ho III. This is seen as a marine transgression and the deposition of marine sediments at Clacton (Pike & Godwin 1953) and in the Nar Valley (Stevens 1959).

Subzone Ho III b

A marked change takes place in this subzone, with the rapid rise of *Abies* to dominance. At the same time, most of the deciduous trees and shrubs are greatly reduced, although *Alnus* shares the dominance of the regional forest with *Abies*, occupying wetter areas. The expansion of *Abies* in the latter part of the Hoxnian (Holsteinian) Interglacial is a characteristic feature of the vegetation succession of this interglacial all over Europe, and the fir then extended far north and west of its present distribution.

Hedera almost disappears, but the persistence of *Ilex*, *Taxus* and *Tilia* indicates that this period is not markedly colder, in spite of the importance of conifers. Herbaceous vegetation is still very sparse, and the heathland element is still present but has not spread.

(iv) *Note on Type X*

Type X is an unidentified tricolpate reticulate pollen type that has been recorded from almost all British Hoxnian deposits, but has not been found in other interglacials. The grain appears in zone Ho II, reaches its maximum in subzone Ho II *c* or Ho III *a*, usually between 5 and 10 % l.p., and then tails off through subzone Ho III *b*, following the behaviour of the thermophilous mixed oak forest genera. Type X has been recorded at the following sites

England	range	maximum
Hoxne (West unpub., in Turner 1970)	Ho II *b*–Ho II *c*	9 % a.p. (Ho II *c*)
Marks Tey (Turner 1970)	Ho II *b*–Ho III *b*	5 % l.p. (Ho III *a*)
Clacton (Turner & Kerney 1971)	Ho II *b*	1 % l.p.
Hatfield (Sparks *et al.* 1969)	Ho II–Ho III *a*	1 % l.p.
Peterborough (Phillips unpub.)	Ho II *c*	10 % l.p.
Barford	Ho II *c*–Ho III *b*	8 % l.p. (Ho III *a*)
Dunston	Ho III *b*	2 % l.p.
Ireland		
Kilbeg and Gort (Watts 1959)	Ho III	
Baggotstown (Watts 1964)	Ho III	6 % a.p.

The percentages of a.p. and l.p. are comparable as they refer to forested zones.

Specimens of Type X from Barford are shown in figure 18, plate 1. The samples were treated with NaOH, HCl, HF and acetolysis, and were mounted in glycerine jelly. The grains are circular in polar view and oval subprolate in equatorial view. Measurements of 50 grains gave a size range of 26–34 µm polar length × 17–26 µm equatorial diameter, with most grains measuring *ca.* 29 µm × 25 µm. The very small diameters are usually due to contraction of the grains, and uncontracted grains are almost as broad as long.

The grains have three clearly delimited long furrows which taper to pointed ends towards the poles and leave only a small polar area. The furrows broaden out near the equator, where they have a pronounced equatorial constriction, and the furrow edges form arcs at the equator. These morphological features are frequently lost in this grain and often the furrows appear as simple long grooves.

The grains are tectate and suprareticulate with distinct simple columellae, and the reticulum is a uniform size all over the grain. There are 4–6 columellae round each lumen, and the columellae are about 0.4 µm in diameter and the lumina about 0.7 µm.

The identity of Type X is still obscure. Watts (1959) suggested that its frequency of occurrence at the Irish sites indicated a tree or shrub rather than a herb origin for the grain. Turner (1970) considered it to belong to a forest shrub because of its occurrence during the temperate zones of the interglacial and its relatively slight response to the high n.a.p. phase of subzone Ho II*c*. Oldfield (1968) recorded 'Type X' grains in Hoxnian deposits at Marbella in South-west France. He found that the best match was with *Phillyrea*, and so he included them in 'Oleaceae types'. His 'Type X' grains differ from the Type X in British deposits in that they have short rather open furrows with no equatorial constriction. They much more closely resemble *Phillyrea* than do the British Type X grains. However, the behaviour and general morphology of the Marbella 'Type X' suggests a probable relationship with the British Type X.

(*f*) *The palaeobotany of the deposits at Dunston Common*

(i) *Age of the deposits and zonation of the pollen diagram*

Pollen analyses were carried out on the organic lake clays from the I.G.S. borehole at Dunston Common (figure 27).

The pollen diagram shows the latter part of an interglacial, which is considered to be the Hoxnian Interglacial because of the dominance of *Abies* and *Alnus* before the change to boreal forest, and because of the presence of Type X.

The diagram can be divided into two regional pollen zones according to Turner (1970), and the upper zone consists of three distinct local pollen assemblage zones. The zones have been distinguished as follows

Zone Ho IV *Pinus–Betula* zone. 579–1173 cm (19–38.5 ft).
  Local zone 3. *Alnus–Abies–Pinus–Empetrum* p.a.z. 579–868 cm (19–28.5 ft).
  Local zone 2. *Alnus–Abies–Pinus* p.a.z. 868–929 cm (28.5–31 ft).
  Local zone 1. *Pinus–Betula*–Gramineae p.a.z. 929–1173 cm (31–38.5 ft).
Subzone Ho III*b*. *Abies–Alnus* zone. 1173–1798 cm (38.8–59 ft).

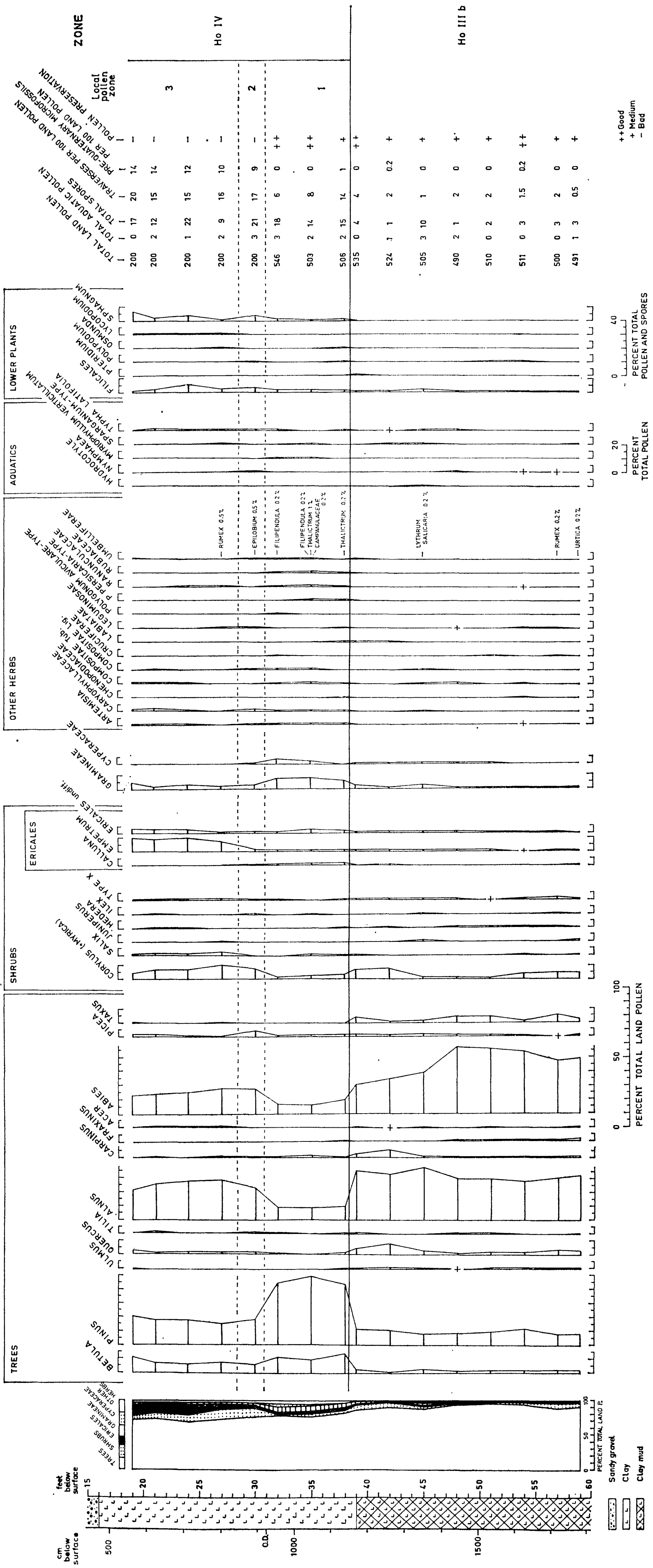


FIGURE 27. Pollen diagram from the Dunston borehole.

(ii) *Vegetational history*

The Hoxnian Late-temperate zone

Subzone Ho IIIb

The forest vegetation is dominated by *Abies* and *Alnus*, with *Pinus* and *Taxus*. Broad-leaved thermophilous trees and shrubs are unimportant, and their decline was recorded at Barford in the earlier part of this subzone. Very little open herbaceous vegetation is indicated, although the grass curve starts to rise at the end of the subzone. There are few other herb taxa. A heath element is present, consisting of small amounts of *Empetrum* and Ericales, with isolated *Calluna* tetrads. Frequencies are no higher than in the earlier part of the interglacial at Barford, and heath vegetation is still very restricted.

At the end of the subzone, *Quercus*, *Carpinus* and *Corylus* make a brief recovery then fall again, and it is likely that this pollen has been reworked from earlier deposits of the interglacial. Directly above this level, a sediment change to more inorganic deposits probably represents a rise in water level after a standstill phase when some erosion took place.

The Hoxnian Post-temperate zone. Zone Ho IV

Local zone 1

In this zone *Abies* and *Alnus* fall sharply, giving way to *Pinus* as the dominant tree taxon. *Betula* increases, while thermophilous taxa virtually disappear. These changes are very abrupt and may be exaggerated to some extent by the change in sedimentary conditions.

At the same time as pine rises to dominate the forest, open herbaceous vegetation spreads, with an increase primarily in grasses. Other herbs are more abundant, and new taxa include plants of open ground. The small heath element remains, and there is a slight increase in *Sphagnum*. These vegetation changes indicate deterioration of the soil, but may also be a result of colder climatic conditions.

Local zone 2

In this spectrum, *Abies*, *Alnus* and *Corylus* suddenly increase again, and *Pinus*, *Betula* and Gramineae fall, so that the assemblage resembles that of subzone Ho III*b*. Filicales and *Sphagnum* are unaffected and continue their increase from zone 1. In the uppermost organic deposits at Dunston, between 579 cm (19 ft) and 929 cm (31 ft), the pollen is poorly preserved, it is relatively sparse, and there is a sizeable component of pre-Quaternary microfossils. Erosion of the land surface is evidently taking place, so there is an influx of pollen into the lake from several sources. The pre-Quaternary microfossils match those in the boulder clay of the region and must be derived from it. Pollen taxa found in the earlier interglacial deposits, principally *Alnus*, *Abies* and *Corylus*, are probably coming into the lake through soil wash and from eroding interglacial deposits in another part of the basin. The remaining tree pollen is entering the lake by wind transport and represents the regional vegetation, which is pine forest with birch as in zone 1.

Local zone 3

The influx of pre-Quaternary microfossils and of reworked interglacial pollen continues in this zone. There are also new features, principally a marked increase for the first time in

Empetrum and Ericales, and also an increase in *Salix*. These changes can be seen more clearly in the corrected pollen diagram (figure 28) in which the percentages have been recalculated with the reworked types reduced to their levels in zone 1.

Empetrum heath, with Ericales, *Lycopodium* and *Sphagnum* has spread, indicating heavily leached and podsolized soils. Pine-dominated woodland is still extensive, with birch relatively more important now, though the forest has retreated to some extent with the spread of heath and the persistance of grassland.

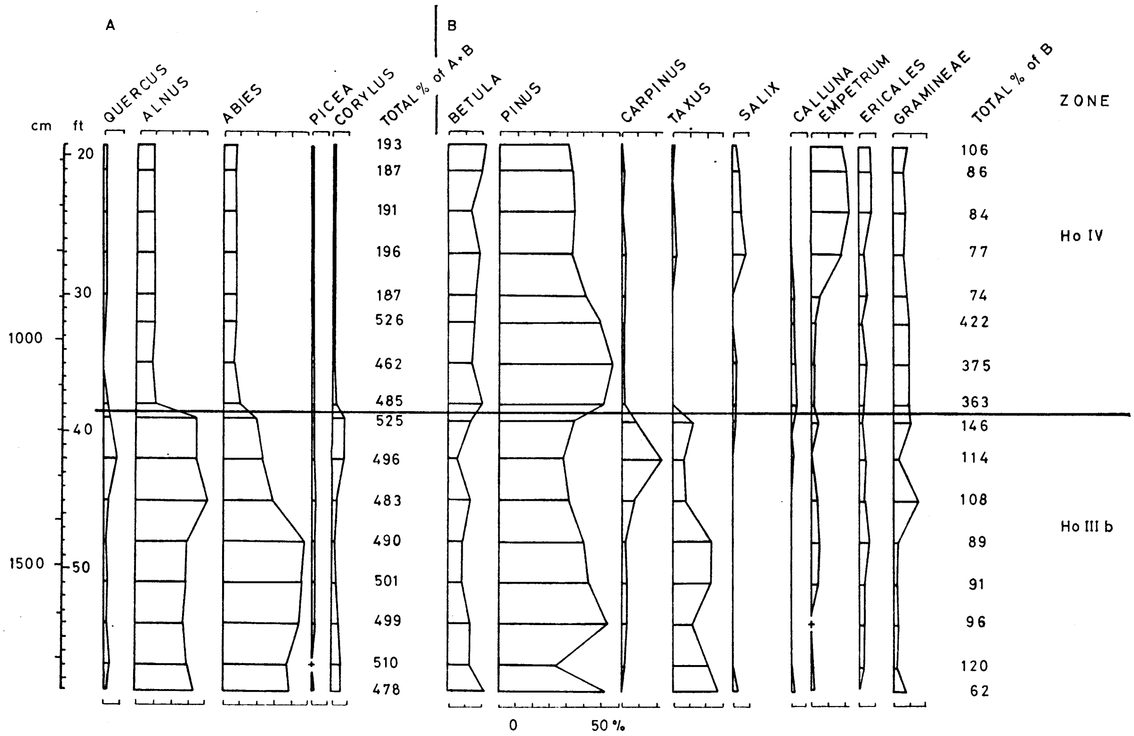


FIGURE 28. Corrected pollen diagram for Dunston Common. Group A taxa are those which increase in zones 2 and 3 after a marked fall in zone 1. These are given as percentages of major taxa (A+B) totals up to 9.75 m (32 ft); above 9.75 m, the percentages are left the same as at 9.75 m. Group B taxa are given as percentages of total pollen of those taxa.

The rise in the *Salix* curve may be due to local development of willow carr on the damp ground near the lake. *Myrica* may also be present on wet rather acid soils. Much of the *Abies* and *Alnus* pollen is reworked in these spectra, and probably all of the *Corylus* pollen. However, part of the *Corylus* curve should be attributed to *Myrica* in this zone. It was difficult to distinguish *Corylus* and *Myrica* with certainty here, but *Myrica* is undoubtedly present. *Myrica* forms a low curve in the Late- and Post-temperate zones at Gort in Ireland (Jessen *et al.* 1959), and its presence was thought to be due to the formation of acid humus under conifers in a humid climate.

(*g*) *Palaeobotanical comparison with other Hoxnian Interglacial sites*

The vegetational history of the Hoxnian Interglacial in England is most fully documented in East Anglia, from the sites at Hoxne (West 1956) in Suffolk, Marks Tey (Turner 1970) and Clacton (Pike & Godwin 1953) in Essex, and the Nar Valley (Stevens 1959) in west Norfolk. The diagrams from Barford and Dunston in central Norfolk conform closely with the Hoxnian vegetation sequence already known. The other important English site is at Nechells near Birmingham (Kelly 1964) where most of the interglacial is covered, and Hoxnian deposits have also been described from Hatfield in Hertfordshire (Sparks, West, Williams & Ransom 1969).

The late-glacial at Barford has the characteristic high *Hippophaë* levels seen at other Hoxnian sites. The very high levels at Barford show that the early part of the late-glacial is represented here, as it is at Hoxne and Nechells, and the deposits are very close to the underlying boulder clay.

In subzone Ho II*c*, and to some extent in zone Ho III, *Pinus* is rather higher than at Hoxne or Marks Tey. There are very high pine levels in zone Ho I at Barford, although these totals may include derived material. High pine values in the Hoxnian are also seen in the Nar Valley, where the estuarine and marine nature of the sediments may be partly responsible for over-representation of conifer pollen, but where nearby outcrops of Cretaceous sandstone were thought to have favoured conifers rather than deciduous trees. At Barford, pine pollen might have been blown in from pine woods on the Anglian outwash sands and gravels, and the Crag sands and gravels around Norwich.

Picea also has a more substantial curve than at Marks Tey or Hoxne, and it is even higher at Nechells and in the Nar Valley. At Barford, the Nar Valley and Nechells, the *Carpinus* curve is reduced in consequence, and this reciprocal relation is probably a competition effect. The relative abundance of *Picea* seems to be a feature of the Middle and Upper Pleistocene in Norfolk, and this may reflect its direction of immigration, or suitability of habitat and climatic conditions in this part of the country.

The high n.a.p. phase of subzone Ho II*c* has now been found in Norfolk as well as Suffolk and Essex, but the causes for this temporary decline of the forest vegetation in East Anglia are still obscure.

The post-temperate zone of the Hoxnian is known in England only at Marks Tey and Dunston. The significant feature of both sites is the expansion of *Empetrum* heath, indicating considerable oceanicity of climate at this time in East Anglia. In detail, the vegetation sequence in the early part of zone Ho IV has some differences at the two sites. At Marks Tey, the rise of *Empetrum* occurs at the very beginning of the zone, at the same time as the rise of *Pinus*. At Dunston, the pine rise is accompanied instead by an expansion of grassland, and the increase in *Empetrum* and Ericales is delayed. The situation is complicated by the fact that a sediment change occurs at the zone Ho III/IV boundary at both sites, apparently due to a temporary but marked fall in lake level at Marks Tey and perhaps to a standstill phase at Dunston, followed by renewed deposition as the lake levels rose again. It is probable, then, that the vegetational developments at the beginning of zone IV are not fully covered at either site, although the picture may be more complete at Dunston.

5. Conclusions

(*a*) *Interglacial vegetational history in Norfolk*

The interglacial sites described here present no difficulties in palaeobotanical dating and can be easily assigned to the Ipswichian or Hoxnian Interglacial. The flora and vegetation succession of the two stages are quite distinct, and the pollen taxon Type X appears to be absolutely characteristic of British Hoxnian deposits. The two interglacial stages must be separated by a period of glacial climate in East Anglia, as an early-glacial assemblage follows the Hoxnian

Interglacial succession at Marks Tey (Turner 1970), and a late-glacial assemblage precedes the Ipswichian Interglacial succession at Ipswich (West 1957) and at Swanton Morley.

Certain differences between Hoxnian and Ipswichian pollen diagrams can be attributed to differences in depositional environment. Most British Ipswichian deposits are fluviatile in origin, often situated in terrace sands and gravels which aggraded during the interglacial. Hoxnian deposits are typically lacustrine, laid down in lakes which formed in kettle-holes or in depressions over deep troughs after the retreat of the Anglian ice sheet. While Hoxnian diagrams therefore give a general picture of the regional vegetation, Ipswichian diagrams tend also to show features and changes which are related to changes in conditions of aggradation and erosion in the river valleys. There are also features due to exceptional soil conditions, for instance at Beetley where large areas of poor soils over outwash gravels resulted in the dominance of conifers and in the presence of an unusual herbaceous flora. Nevertheless, these local effects do not obscure the characteristic pattern of vegetational development in the Ipswichian. As more Ipswichian Interglacial deposits are investigated, the characteristic flora and vegetational history of the Ipswichian is confirmed and its similarity with the Eemian Interglacial is reinforced.

Table 7. Geological history of the Middle and Upper Pleistocene in Central Norfolk

			Phillips (1973)	
stage	Straw (1973)	Bristow & Cox (1973)	Wensum Valley	Tiffey and Yare Valleys
Devensian (Weichselian)	periglacial activity	solifluction aggradation of terrace gravels	solifluction; frost disturbance of gravels ground ice mounds low terrace cut aggradation continues	frost heaving of terrace low terrace cut aggradation continues
Ipswichian (Eemian)	erosion	formation of Eemian and Hoxnian Interglacial deposits	aggradation of sand and gravel, and formation of organic deposits, in river valleys	aggradation of sand and gravel in river valleys
Wolstonian (Gipping; Saale)	two outwash phases in Wensum Basin; Marly Drift deposited in North Norfolk and Wensum Basin	high-level torrent gravels deposited in final outwash phase; chalky boulder clay and outwash sand and gravel deposited; deep channels cut	aggradation in modern valleys begins establishment of modern river system and dissection of outwash gravel sheet	
			deposition of Hungry Hill Gravels erosion	deposition of high-level, outwash gravels solifluction
Hoxnian	erosion	—	—	erosion organic deposition in lakes over drift-filled deep channels
Anglian (Lowestoft; Elster)	chalky boulder clay deposited south and east of Wensum Basin	—	chalky boulder clay deposited deep channels cut	chalky boulder clay deposited deep channels cut

(*b*) *Pleistocene geological history in central Norfolk*

On the basis of the geological and palaeobotanical evidence presented in this paper, an outline of the geological history of the Middle and Upper Pleistocene in central Norfolk can now be put forward. This sequence of events, with the conclusions reached by other authors, is shown in table 7.

This work was carried out at the Sub-department of Quaternary Research, University of Cambridge. I was supported by a N.E.R.C. Research Studentship and by a grant from the Brooks Fund.

I am most grateful to Dr R. G. West who supervised the research and gave constant encouragement and advice. I should also like to thank Miss R. Andrew for much help with pollen identification and for carrying out the pollen analyses from sections BB and BC at Beetley. The macro identifications for these sections were made by Miss M. Ransom. Slides from Marks Tey were kindly made available by Dr C. Turner.

Assistance in the field has been freely given by members of the Cambridge Sub-department and of the School of Environmental Sciences, University of East Anglia. I have always been allowed access to private land, and Mr Ainger of the Swanton Morley gravel pit, Mr and Mrs Harold of Turnpike Farm, Barford, and the proprietors of the Ship Hotel, Mundesley, have been particularly helpful.

Mr R. Markham and Mr B. MacWilliams of the Castle Museum, Norwich, originally reported the organic beds and mammalian remains at Beetley and Swanton Morley, and have given valuable assistance during the investigation of these sites. The samples from the Barford and Dunston Common boreholes were provided by the Institute of Geological Sciences Palaeontology Department, and I have had useful discussions with Dr F. C. Cox and Mr E. F. P. Nickless of the I.G.S. The logs of C.E.G.B. boreholes 185 and 186 in the Barford area are reproduced by courtesy of the Central Electricity Generating Board.

APPENDIX 1. SECTIONS OF THE MUNDESLEY RIVER BED

In his description of the cliff section, Prestwich (1861) recorded the following beds within the Mundesley basin:

1.5–3.0 m (5–10 ft)	subangular flint gravel
6.0–7.5 m (20–25 ft)	upper sandy beds black peaty beds brown peaty beds
0.6–1.2 m (2–4 ft)	subangular flint gravel

Reid (1882) described the Mundesley River Bed deposits as follows:

0.9 m (3 ft)	soil
2.4 m (8 ft)	gravel and sand (coalesces with the lower gravel at the edge of the basin)
9.1 m (30 ft)	peaty and sandy loam, full of fossils seam of peat at base, full of willow leaves

1.2 m (4 ft)	clayey gravel
	gravel (bottom not seen)

The 1970 boreholes showed essentially the same sequence

MuA	0.8 m ($2\frac{1}{2}$ ft)	soil
	2.1 m (7 ft)	flint gravel and sand
	4.0 m (13 ft)	organic deposits
	0.5 m (2 ft)	clayey gravel and sand
		gravel
MuB	1.1 m ($3\frac{1}{2}$ ft)	soil
	2.6 m (9 ft)	flint gravel and sand
	2.1 m (7 ft)	organic deposits
	0.7 m ($2\frac{1}{2}$ ft)	clayey gravel and sand
		gravel

Appendix 2. Exposures of Hungry Hill Gravels

Hungry Hill, East Bilney

Abandoned pit. Height: 53 m (175 ft) O.D. NGR: TF 958186

0–0.9 m (0–3 ft)	coarse well-rounded, rounded and sub-angular flint gravel with finer sub-angular flint gravel and coarse orange sand. Some of the larger flints have vertical long axes. No erratics
0.9–2.1 m + (3–7 ft +)	coarse orange sand.

Bittering

Working pit. Height: 58 m (190 ft) O.D. NGR: TF 934173

0–0.6 m (0–2 ft)	coarse orange sand and fine gravel
0.6–1.9 m (2–6 ft)	coarse rounded flint gravel in coarse orange sand matrix
1.9–3.4 m + (6–11 ft +)	orange sand and fine gravel

Roosting Hill, Beetley

Working pit. Height: 29 m (97 ft) O.D. NGR: TF 987181

Coarse rounded flint gravel and yellow sand, from 1.2 m (4 ft) to more than 6.1 m (20 ft) in thickness, lie in the valley of a tributary of the River Wensum. The gravel mainly overlies boulder clay but in several places rests directly on the Chalk. Organic deposits of the Ipswichian Interglacial and a Devensian interstadial overlie the gravel, and there is evidence for frost disturbance of the gravel below the interglacial deposits and again in the Devensian.

This gravel area is shown as Valley Gravel on the Old Series drift map as it lies in a valley, but it is Plateau Gravel in type, and there is no boulder clay exposed west of the river between the Plateau Gravel and the 'Valley Gravel' as shown on the map. The gravel is continuous with that on the adjacent hillside, and is part of the same gravel spread as the gravel at Hungry Hill 3 km (2 mile) to the west.

The height of the gravel surface in the valley varies between 24 m (80 ft) and 27 m (90 ft) O.D. Beneath the later deposits, the surface of the gravel is very uneven and may have risen to 30 m (100 ft) O.D. where a closed 30 m (100 ft) contour on the Ordinance Survey map indicates the former existence of a knoll. This has been removed during working by the gravel company, but was probably made of the same gravel, and may have been a constructional feature, which would indicate that ice was present in a pre-existing valley.

Hoe

Abandoned pit. Height: 38 m (125 ft) O.D. NGR: TF 989171

0–0.3 m (0–1 ft)	coarse orange sand with small flints.
0.3–1.0 m (1–3 ft)	coarse rounded flint gravel in orange sand matrix
1.0–4.6 m + (3–15 ft +)	coarse orange sand with small angular flints

Near the top of some sections at Hoe, there are beds of fine sand and medium subangular flint gravel which show frost disturbance, with involutions and vertical stones.

Billingford Common

Small abandoned pit. Height: 30 m (100 ft) O.D. NGR: TF 017197

0–2.1 m (0–7 ft)	Coarse rounded flint gravel with fine and medium subangular flint gravel and coarse orange sand

The gravel becomes more extensive east of Billingford Common, and in Bylaugh Park it is recorded by Blake as overlying dark grey boulder clay.

On Bawdeswell Heath, a small area just north of Bylaugh Park, varying depths of very coarse flint gravel rest unconformably on Glacial Sand. The areas in which the outwash gravel overlies Glacial Sand and Gravel appear to be very limited and there is no evidence for the extensive occurrence of Glacial Sand and Gravel beneath the Plateau Gravel that the Old Series drift map indicates.

Two other sections in Blake may be mentioned here:

Longham

Large gravel pit. Height 62 m (203 ft) O.D. NGR: TF 929163

0–3.4 m (0–11 ft)	coarse flint gravel. Flints rounded and worn, and mostly 10–15 cm (4–6 in) across, with some up to 30 cm (1 ft). Closely packed in a matrix of red clay and sand. No erratics. The gravel overlies boulder clay, which forms the floor of the pit

Gressenhall

Old gravel pit near church. Height 48 m (160 ft) O.D. NGR: TF 958156

0–4.6 m (0–15 ft)	coarse flint gravel. Stones mostly well-rounded, 5–20 cm (2–8 in) across, sometimes larger. In places, some fine subangular gravel. Many stones with longer axis on end, particularly in the upper part of the section

In the valley at Gressenhall, about 5 km (3 mile) upstream from Roosting Hill, the Old Series Drift map shows 'Valley Gravel' at the sides of the valley and forming isolated patches on the valley floor. On the Ordnance Survey map, there are several closed 30 m (100 ft) contours in the valley in this area. The southernmost isolated patch of gravel is above the main 30 m (100 ft) contour, but in the field this too can be seen to rise up from the general level to give an area of higher ground with an uneven surface. Bearing in mind that the gravel at Roosting Hill is wrongly shown as Valley Gravel, and that the terrace sands and gravels described in §3 (*a*) have only been found downstream from Roosting Hill, it seems probable that the areas of 'Valley Gravel' at Gressenhall are in fact mounds of Plateau Gravel, again possibly constructional features left by decaying ice in the valley.

APPENDIX 3. ORGANIC DEPOSITS AT ROOSTING HILL, BEETLEY

The following sections (figure 1) showing organic deposits of the Ipswichian Interglacial (pit 1) and of a Devensian interstadial (pit 2) have been recorded at Roosting Hill, Beetley.

Pit 1

BA Height: *ca.* 29 m (97 ft) O.D.

270–285 cm	grey-green sandy clay
285–300 cm	as above but sandier and with angular and rounded flints
300–320 cm	as above but more stony

Then about 2 m of rusty coarse rounded flint gravel and yellow sand.

BB

2.5 m of grey-blue clay, stratified with pale sand, and weathered brown at top; involutions at base, then

0–120 cm	pale sand, not much stratified
120–128 cm	transition
128–163 cm	brown sandy mud, with black angular flints near the base; the upper mud bed; pollen samples are numbered from 0 to 30 cm (130–160 cm)
163–173 cm	pale stony sand with black and grey flints; less stony to the south
173–223 cm	brown sandy mud with flints
223–270 cm	grey-brown slightly sandy detritus mud with wood and bones in basal 20 cm; the lower mud bed

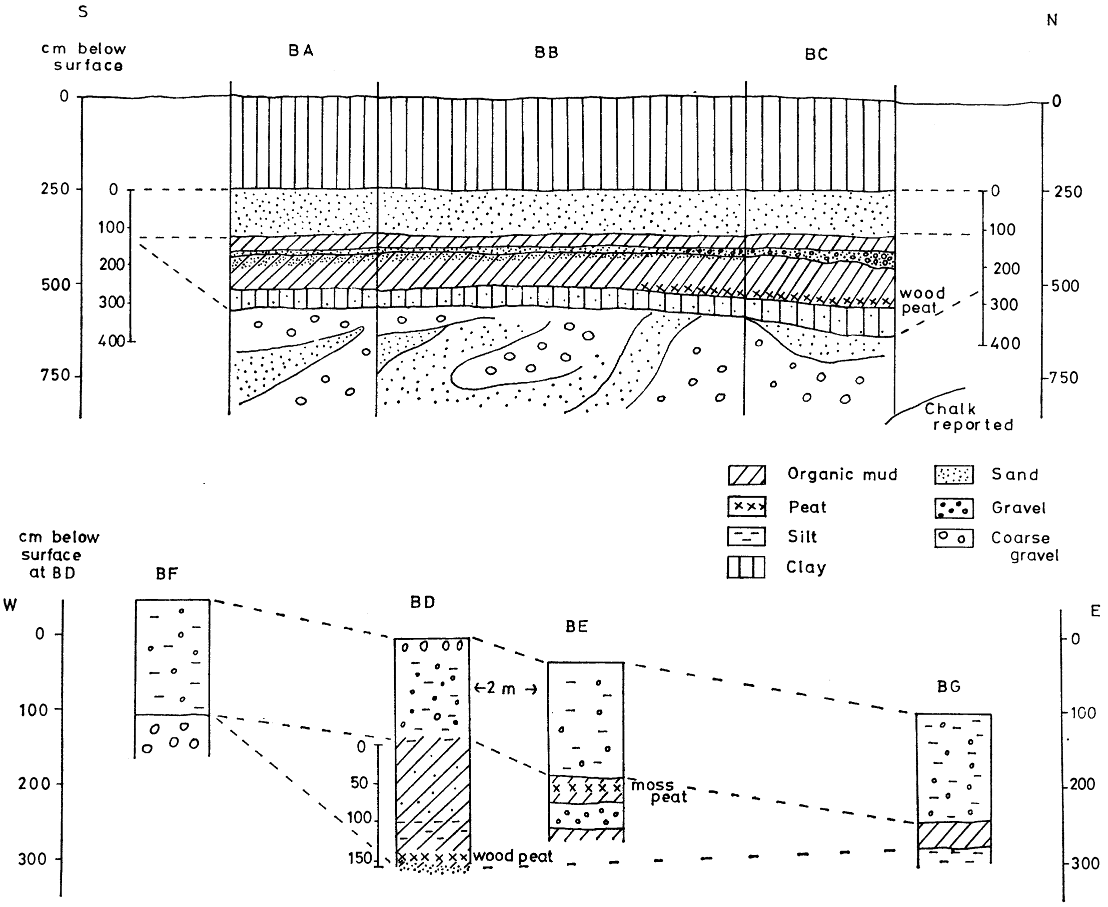


FIGURE 1. Sections at Roosting Hill, Beetley. The sections are not to scale horizontally.

In a later excavation at BB, an ice wedge cast was observed in the gravels below the interglacial deposits. This indicates a period of frozen ground at the end of the preceding glaciation, after the deposition of the gravels and before the deposition of the interglacial beds.

BC

In this section the sand between the mud beds had an irregular wavy base and cut into the lower mud bed which was, however, thicker than at BB, reaching 80 cm, with wood peat in the basal 5 cm. Pollen samples from this bed are numbered from 0 to 80 cm.

Pit 2

BF

1.5 m of grey stony silt overlying coarse rounded flint gravel.

BD Height: *ca.* 29 m (97 ft) O.D.

1.5 m of grey-blue stony silt, with upright stones at the top, and redder at the very top; gradual transition through laminations to mud below, then:

0–100 cm	light brown stiff sandy mud
100–125 cm	irregular paler silty mud; top 10 cm level with gravel in section BE
125–135 cm	light brown coarser stiff mud
135–150 cm	brown wood peat with *Betula* wood and *Pinus* needles
150–160 cm	darker brown-black mud with laminations to white sand

BE

1.5 m of grey-blue stony silt, then	
0–7 cm	sandy mud
7–20 cm	moss-sedge peat
20–35 cm	sandy mud
35–70 cm	pale stony gravel; base level with BD 110 cm mud

BG

1.5 m of blue stony silt, then	
0–30 cm	mud
30–50 cm	green silt

Appendix 4. The non-marine Mollusca from Swanton Morley sample D

By B. W. Sparks

The following Mollusca were recovered from washing a large amount of this material. Land species are prefixed 'L'.

Table 1. The non-marine mollusca from Swanton Morley, sample D

Valvata cristata	673	L *Vertigo antivertigo*	31
V. piscinalis	173	L *V. moulinsiana*	12
Belgrandia marginata	409	L *V. angustior*	2
Bithynia tentaculata	865	L *Pupilla muscorum*	1
B. inflata	1	L *Vallonia costata*	1
L *Carychium minimum*	62	L *V. pulchella*	9
Lymnaea truncatula	3	L *V. enniensis*	20
L. palustris	41	L *Clausilia bidentata*	1
L. peregra	60	L *Arianta* or *Cepaea* apices	2
L. glutinosa	10	L *Punctum pygmaeum*	2
Planorbis carinatus	12	L *Euconulus fulvus*	7
P. planorbis	5	L *Zonitoides nitidus*	13
P. (*Planorbis*) spp.	37	L *Agriolimax* cf. *agrestis*	16
P. vorticulus	73	L *A.* cf. *reticulatus*	31
P. vortex	6	*Sphaerium corneum*	17
P. laevis	22	*Pisidium amnicum*	13
P. crista	80	*P. casertanum*	19
Segmentina complanata	29	*P. obtusale*	19
Acroloxus lacustris	55	*P. milium*	37
L *Succinea* sp. (*putris* or *pfeifferi*)	83	*P. subtruncatum*	35
L *Cochlicopa lubrica*	9	*P. henslowanum*	28
		P. nitidum	122
		total	3146

From its richness and the presence of certain southern species, notably *Belgrandia marginata*, *Planorbis vorticulus* and *Vallonia enniensis*, this is an interglacial fauna, while its attribution to the Ipswichian Interglacial is suggested by the large numbers of *B. marginata* and *P. vorticulus*, and the presence of *V. enniensis* and the occurrence of *Planorbis laevis*. Thus, it has characteristics similar to those of other British Ipswichian deposits.

The local environment suggested is of a marshy area cut by a slow-moving stream rich in plant life and with a muddy bottom and perhaps also local lime-rich springs either in the marsh or in the bed of the stream. The evidence supporting these conclusions is as follows

(*a*) The dominance of the stream is suggested by the fact that 91.4 % of the total specimens are freshwater species. If these are analysed into the four ecological groups that have been used elsewhere (see, for example, Sparks & West 1959) the frequencies in those groups are

group 1 (slum species) 1.5 %
group 2 (catholic species) 15.0 %
group 3 (species characteristic of clear water in plant-rich small drainage channels) 44.5 %
group 4 (moving water species normally found in larger water bodies) 38.0 %

Thus the slow-moving stream rich in plant life is suggested.

(*b*) The muddy bottom is suggested both by the nature of the sediment and by the frequency of *Acroloxus lacustris*.

(*c*) The occasional springs are suggested by the high frequency of *B. marginata* and the development of *Chara* marl at certain horizons. That these two are associated is shown quite clearly by the encrustation of the shells of a proportion of the specimens of *B. marginata*, but of no other species, with tufaceous calcium carbonate.

(*d*) The adjacent marsh is demonstrated by the fact that 98.4 % of the land snails present are either obligatory hygrophiles or often found in such conditions. The virtual absence of both dry land species and 'woodland' species is also consistent with a slow-moving plant-rich stream. Larger and faster streams usually pick up from hillside creep deposits and redeposit in their alluvia Mollusca of these types.

The analysis is very much like that of the Bobbitshole subzone Ip II*b* deposits (Jessen & Milthers zone *f*) of core 4T (Sparks 1957). The comparison is shown in figure 1. This figure only includes species which exceed 0.1 % of the total specimens in at least one deposit of the three compared. It also lumps the species of *Succinea* and *Agriolimax* because of the difficulty of specific identification.

The two deposits are very similar. The major peaks are in the same species, although the proportion of *Belgrandia marginata* and *Bithynia tentaculata* is somewhat different in the two. Further, many of the minor peaks affect the same species while the great number of species in common is shown by the fact that both histograms have only four blanks each.

Yet Swanton Morley D is subzone Ip II*a* (Jessen & Milthers zone *e*) and not subzone Ip II*b* like Bobbitshole core 4T. Bobbitshole core 8B shows a subzone Ip II*a* spectrum from that deposit and it is apparent that this is a more restricted fauna with sharper peaks, though some of these affect the same species, and with 18 blanks in the histogram. At this level there are only 0.3 % land Mollusca (cf. 9.6 % at Swanton Morley and 14.4 % at the other Bobbitshole level). Obviously the freshwater fauna was less diversified and the rich riverside marsh not well developed. In fact Bobbitshole core 8B is best regarded as an earlier stage in the development of the ecosystem. Once again, just as with other Pleistocene mollusc faunas, this fauna is to some extent a facies fauna which developed earlier at Swanton Morley than at Bobbitshole. Perhaps the explanation of this is the fact that Swanton Morley is in a main valley, that of the River Wensum, while Bobbitshole lies in the small valley of the Belstead Brook.

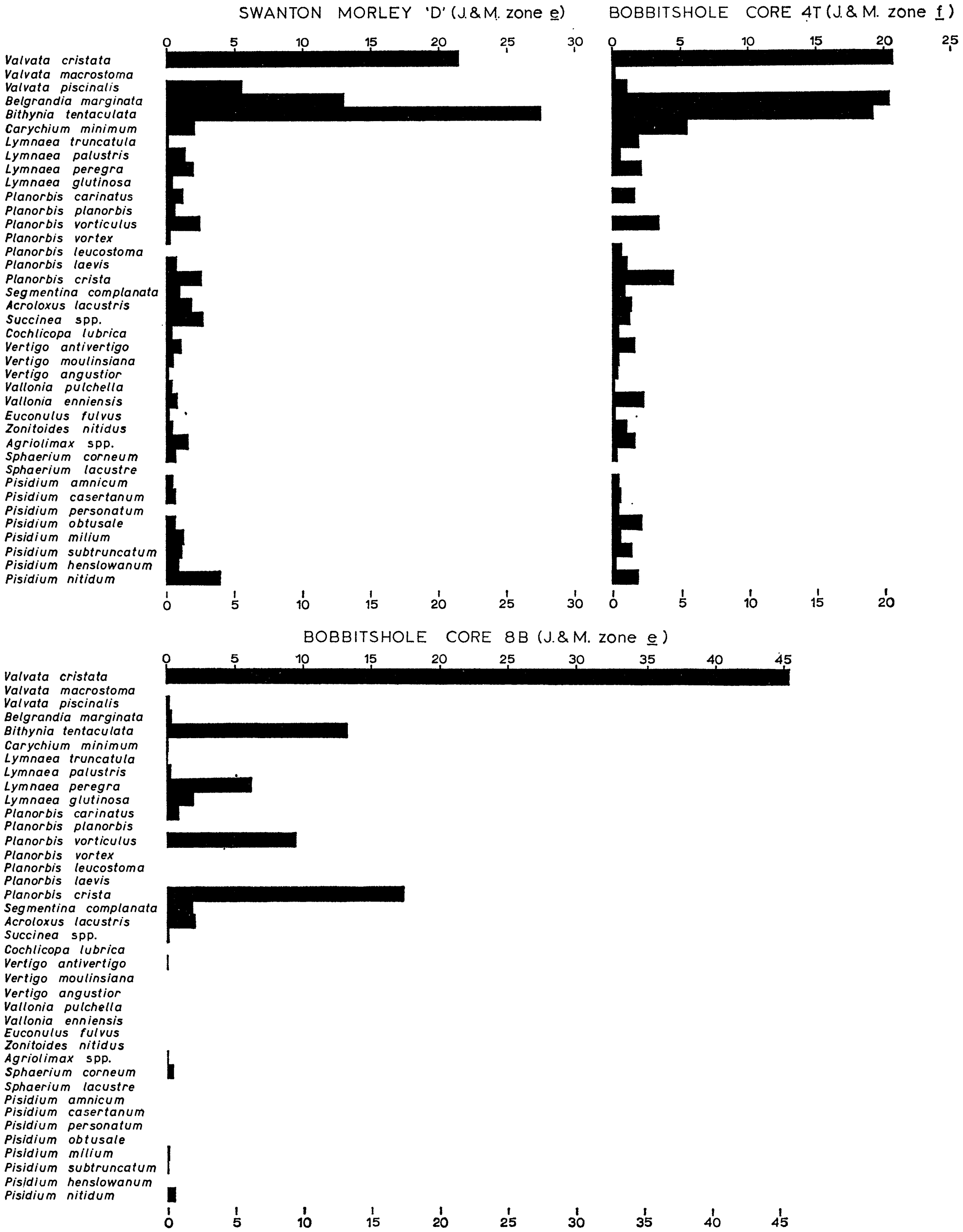


FIGURE 1. Comparison of non-marine Mollusca in Swanton Morley D, Bobbitshole core 4T and Bobbitshole core 8B.

Notes on identification

There were the usual difficulties of separating broken and immature specimens of *Lymnaea* and the recorded numbers must be considered approximate.

For the histogram the *Planorbis* (*Planorbis*) spp. have been allocated to *planorbis* and *carinatus* in proportion to the numbers of these species identified.

Most of the *Succinea* are so small and broken that they cannot be identified any more accurately than indicated.

The separation of the *Agriolimax* species is really a separation of shell shapes as illustrated in Sparks (1957, plate 4*h* and *i*).

APPENDIX 5. SECTIONS AT BARFORD

Barford borehole. Height: 19.5 m (64 ft) O.D.

0–198 cm (0–6.5 ft)	light brown clayey sand, with a little chalk
198–412 cm (6.5–13.5 ft)	grey-brown clay-mud with a few shell fragments
412–426 cm (13.5–14.0 ft)	as above but more shelly
426–534 cm (14.0–17.5 ft)	as above but less shelly
534–670 cm (17.5–22.0 ft)	as above but more shelly
670–692 cm (22.0–22.75 ft)	as above but less shelly
692–707 cm (22.75–23.25 ft)	hard angular lumps of clay-mud
707–875 cm (23.25–29.0 ft)	grey-brown clay-mud with a few shell fragments
875–914 cm (29.0–30.0 ft)	as above but hard and dry
914–944 cm (30.0–31.0 ft)	as above but not hard and dry
944–975 cm (31.0–32.0 ft)	as above but darker, more organic and more shelly
975–990 cm (32.0–32.5 ft)	as above but less organic and shelly
990–1090 cm (32.5–35.8 ft)	1 m core taken by clay cutter; base at 0 cm

40–100 cm	grey silty clay
28–40 cm	as above, with a few shells
20–28 cm	as above, with small chalk pebbles
15–20 cm	grey silty clay
0–15 cm	dark grey chalky boulder clay

The borehole continued in chalky boulder clay to a depth of 30.8 m (101 ft), where it was terminated, still in boulder clay, at −11.3 m (−37 ft) O.D. (Cox & Nickless 1972). The chalky boulder clay contained a seam of coarse sand and gravel between 22.3 and 22.8 m (64 and 65 ft) and was interbedded with gravel between 22.8 and 25.3 m (65 and 72 ft).

A. Height: 21 m (69 ft) O.D.

0–4.3 m (0–14 ft)	yellow-brown clayey sand with small flints. More clayey towards the base
4.3–5.5 m (14–18 ft)	brown clay-mud, passing into grey clay-mud near the base

Just south of A, C.E.G.B. borehole 186, also at 21 m (69 ft) O.D., showed the lake deposit to be at least 5.2 m (17 ft) thick, and a large hole that had been excavated at this point penetrated the underlying boulder clay and showed that the clayey sand over the lake deposit was overlain by a thin cover of yellow sand and angular flint gravel.

B. Height: 22.1 m (72 ft 6 in) O.D.

0–5.2 m (0–17 ft)	pale yellow-brown clayey sand with small flints
5.2–5.5 m (17–18 ft)	transition to grey clay-mud
5.5–7.3 m (18–24 ft)	grey clay-mud
7.3–9.1 m (24–30 ft)	grey-blue boulder clay with chalk fragments and pebbles

C. Height: 22.6 m (74 ft) O.D.

0–4.6 m (0–15 ft)	pale brownish-yellow clayey sand with small flints
4.6–7.6 m (15–25 ft)	as above but paler
7.6–9.1 m (25–30 ft)	light grey boulder clay with chalk fragments and pebbles

D. Height: 23.6 m (77 ft 6 in) O.D.

0–0.6 m (0–2 ft)	pale brown silty sand with small flints
0.6–0.9 m (2–3 ft)	yellow silty sand
0.9–4.0 m (3–13 ft)	pale buff clayey silty sand with many small chalk fragments
4.0–7.6 m (13–25 ft)	blue-grey boulder clay with chalk fragments and pebbles, becoming much paler near the base

E. Height: 23.9 m (78 ft 6 in) O.D.

0–0.9 m (0–3 ft)	buff clayey silty sand with small flints and chalk fragments
0.9–2.1 m (3–7 ft)	as above but paler; some larger angular flints
2.1–2.7 m (7–9 ft)	as above but grey, and with very small flints and chalk fragments
2.7–4.3 m (9–14 ft)	dark grey chalky boulder clay, becoming paler near the base
4.3–9.1 m (14–30 ft)	light brown boulder clay with many chalk pebbles

F. Height: 24.1 m (79 ft) O.D.

0–0.9 m (0–3 ft)	pale yellow-brown clayey sand with small flints
0.9–1.8 m (3–6 ft)	as above but paler and with chalk fragments
1.8–3.7 m (6–12 ft)	pale grey-brown silty clayey sand with small flints and chalk fragments and some chalk pebbles
3.7–4.3 m (12–14 ft)	dark grey boulder clay with chalk fragments and pebbles
4.3–9.1 m (14–30 ft)	as above but paler, and becoming very pale near the base

G. Height: 24.4 m (80 ft) O.D.

0–0.9 m (0–3 ft)	buff clayey sand with small flints and chalk fragments and pebbles
0.9–1.8 m (3–6 ft)	as above but paler and without chalk pebbles
1.8–3.2 m (6–10 ft)	yellowish-white clayey sand with small flints and many chalk fragments and pebbles

3.2–3.4 m (10–11 ft)	yellowish-white chalky sandy clay with very many chalk fragments and pebbles. Auger stuck at 3.4 m (11 ft)

H. Height: 24.4 m (80 ft) O.D.

0–0.3 m (0–2 ft)	brown slightly silty coarse sand with small flints
0·3–1.8 m (2–6 ft)	buff clayey sand with flints and chalk fragments
1.8–2·4 m (6–8 ft)	yellow clayey sand with chalk fragments and pebbles
2.4 (8 ft)	chalk

I. Height: 24.7 m (81 ft) O.D.

0–0.15 m (0–0.5 ft)	orange coarse sand
0.15–4.6 m (0.5–15.0 ft)	yellow-brown clayey sand with small flints
4.6–9.1 m (15.0–30.0 ft)	as above, with many chalk pebbles

J. Height: 26.8 m (88 ft) O.D.

0–0.9 m (0–3 ft)	brown slightly silty sand with small flints
0.9–1.8 m (3–6 ft)	buff silty clay with chalk fragments and some small flints
1.8–2.7 m (6–9 ft)	as above but a little sandy
2.7–3.7 m (9–12 ft)	as above but paler, and with chalk pebbles which become more abundant near the base
3.7–4.6 m (12–15 ft)	pale buff silty clay with chalk fragments and small flints
4.6–4.9 m (15–16 ft)	as above but grey
4.9–5.2 m (16–17 ft)	whitish-buff clayey sand with many chalk fragments
5.2 m (17 ft)	chalk

K. Height: 30.4 m (99 ft 6 in) O.D.

0–2.7 m (0–9 ft)	coarse brownish-orange sand and subangular flint gravel
2.7–4.3 m (9–14 ft)	coarse brownish-orange sand
4.3–4.6 m (14–15 ft)	as above but with some fine gravel
4.6–7.3 m (15–24 ft)	yellow-brown clayey sand
7.3–9.1 m (24–30 ft)	white silty clay
9.1 m (30 ft)	chalk

APPENDIX 6. SAMPLE NUMBERS FROM THE BARFORD AND DUNSTON COMMON BOREHOLES

The Institute of Geological Sciences Palaeontology Department sample numbers and the levels of the samples from the Barford and Dunston Common boreholes are given below.

Barford borehole

	depth below surface			depth below surface	
sample no.	cm	ft	sample no.	cm	ft
SAL 3890	198	6.50	SAL 3909	631	20.75
SAL 3891	244	8.00	SAL 3910	655	21.50
SAL 3892	274	9.00	SAL 3911	670	22.00
SAL 3893	302	10.00	SAL 3912	685	22.50
SAL 3894	336	11.00	SAL 3913	692	22.75
SAL 3895	366	12.00	SAL 3914	707	23.25
SAL 3896	380	12.50	SAL 3915	746	24.50
SAL 3897	396	13.00	SAL 3916	775	25.50
SAL 3898	412	13.50	SAL 3917	821	27.00
SAL 3899	426	14.00	SAL 3919	852	28.00
SAL 3900	442	14.50	SAL 3920	875	29.00
SAL 3901	457	15.00	SAL 3921	914	30.00
SAL 3903	487	16.00	SAL 3922	944	31.00
SAL 3904	534	17.50	SAL 3923	975	32.00
SAL 3905	549	18.00	SAL 3924	990	32.50
SAL 3906	564	18.50	SAL 3925	1005	33.00
SAL 3907	580	19.00	SAL 3926	1032	34.00
SAL 3908	608	20.00			

The grains of Type X illustrated in figure 18, plate 1, are on slides SAL 3899 (MPK 849), SAL 3901 (MPK 850) and SAL 3906 (MPK 851).

Dunston Common borehole

	depth below surface			depth below surface	
sample no.	cm	ft	sample no.	cm	ft
SAL 3929	579	19.00	SAL 3937	1189	39.00
SAL 3930	640	21.00	SAL 3938	1280	42.00
SAL 3931	732	24.00	SAL 3939	1371	45.00
SAL 3932	822	27.00	SAL 3940	1462	48.00
SAL 3933	914	30.00	SAL 3941	1553	51.00
SAL 3934	975	32.00	SAL 3942	1646	54.00
SAL 3935	1067	35.00	SAL 3943	1738	57.00
SAL 3936	1158	38.00	SAL 3944	1798	59.00

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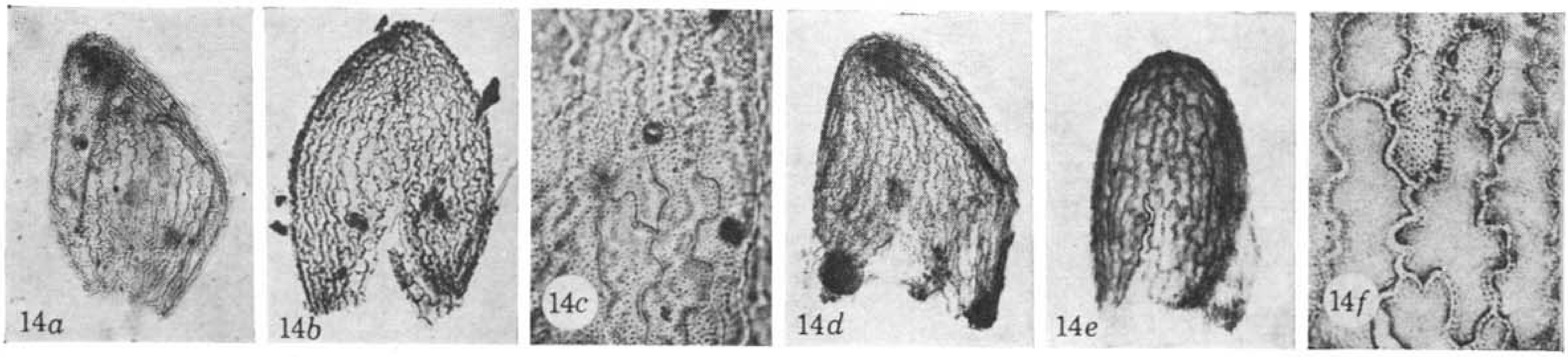

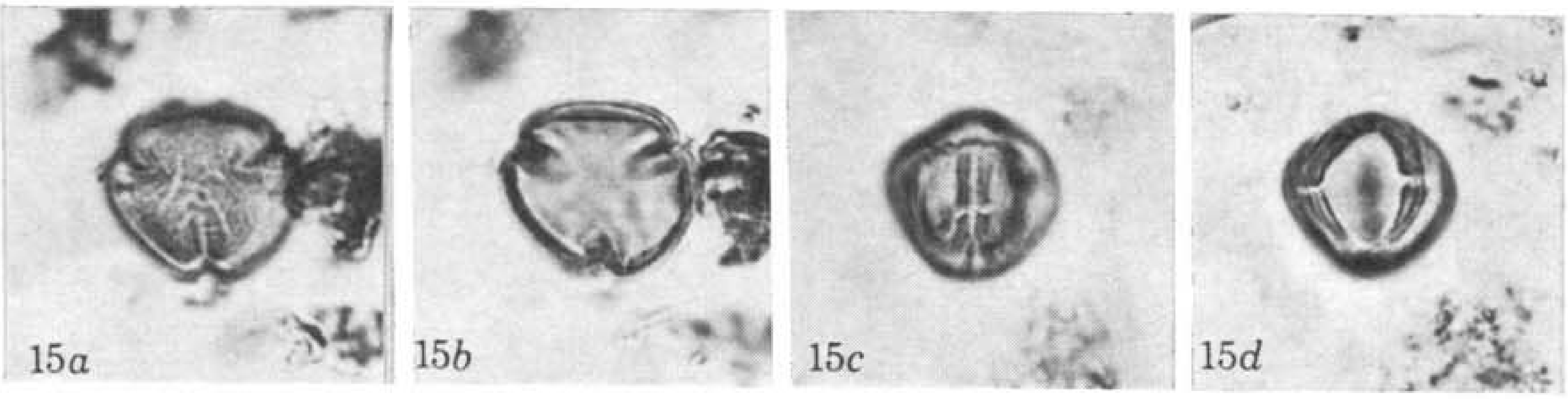

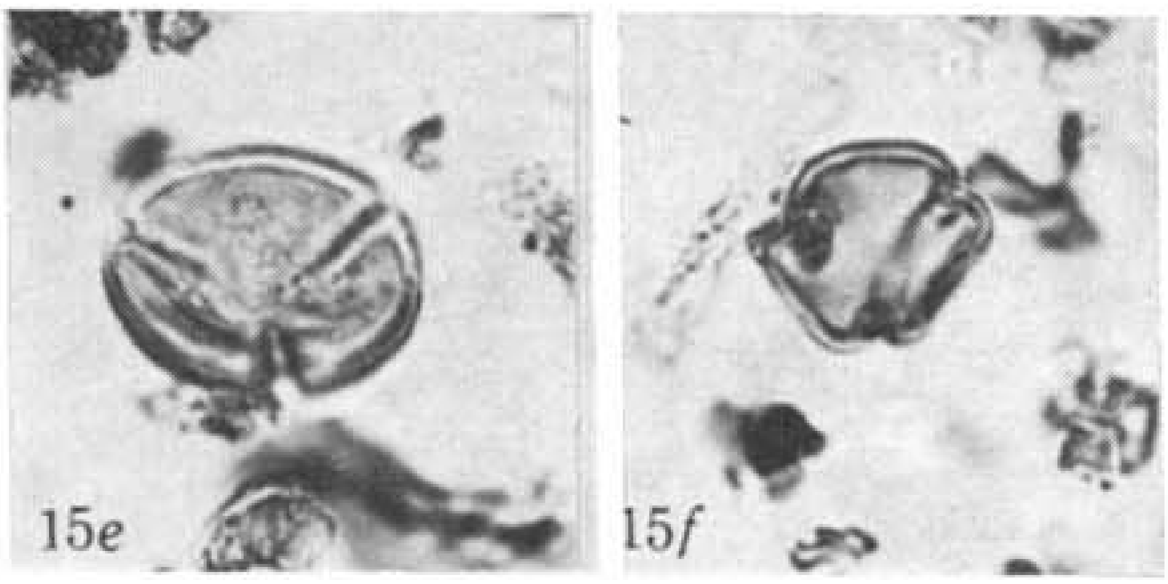

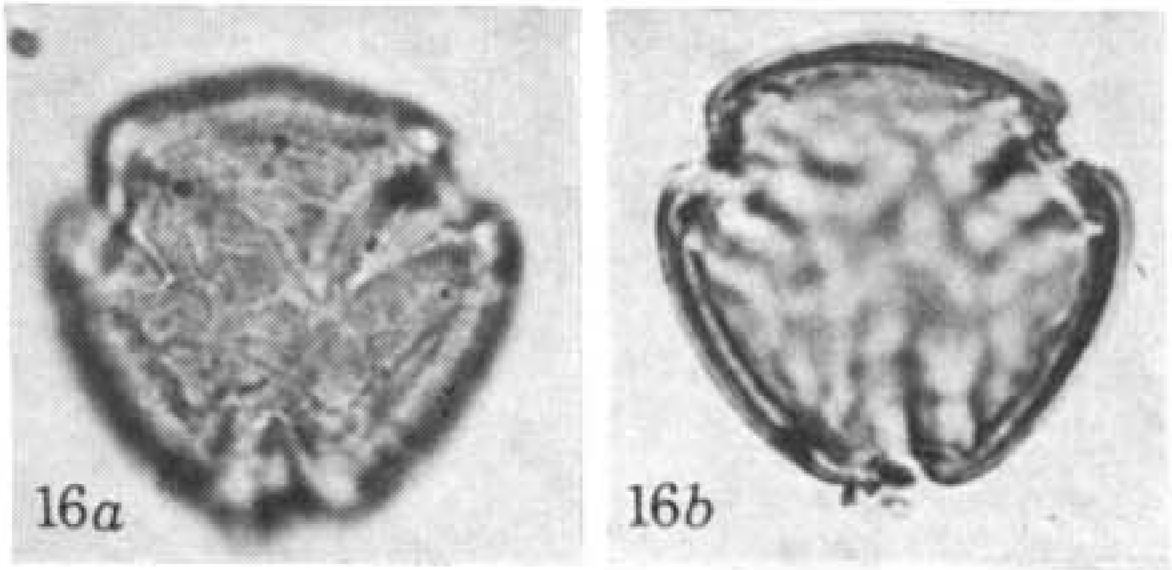

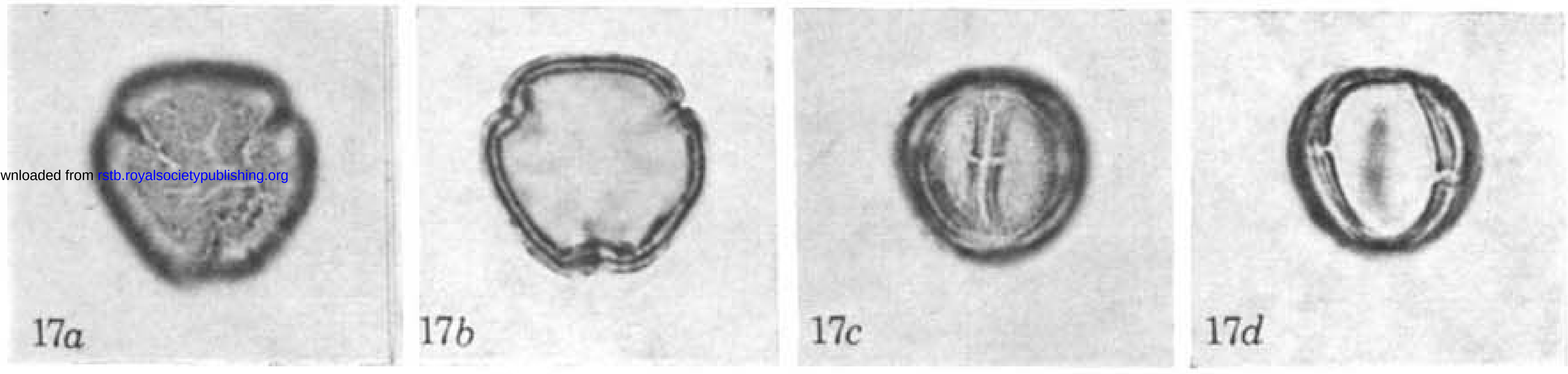

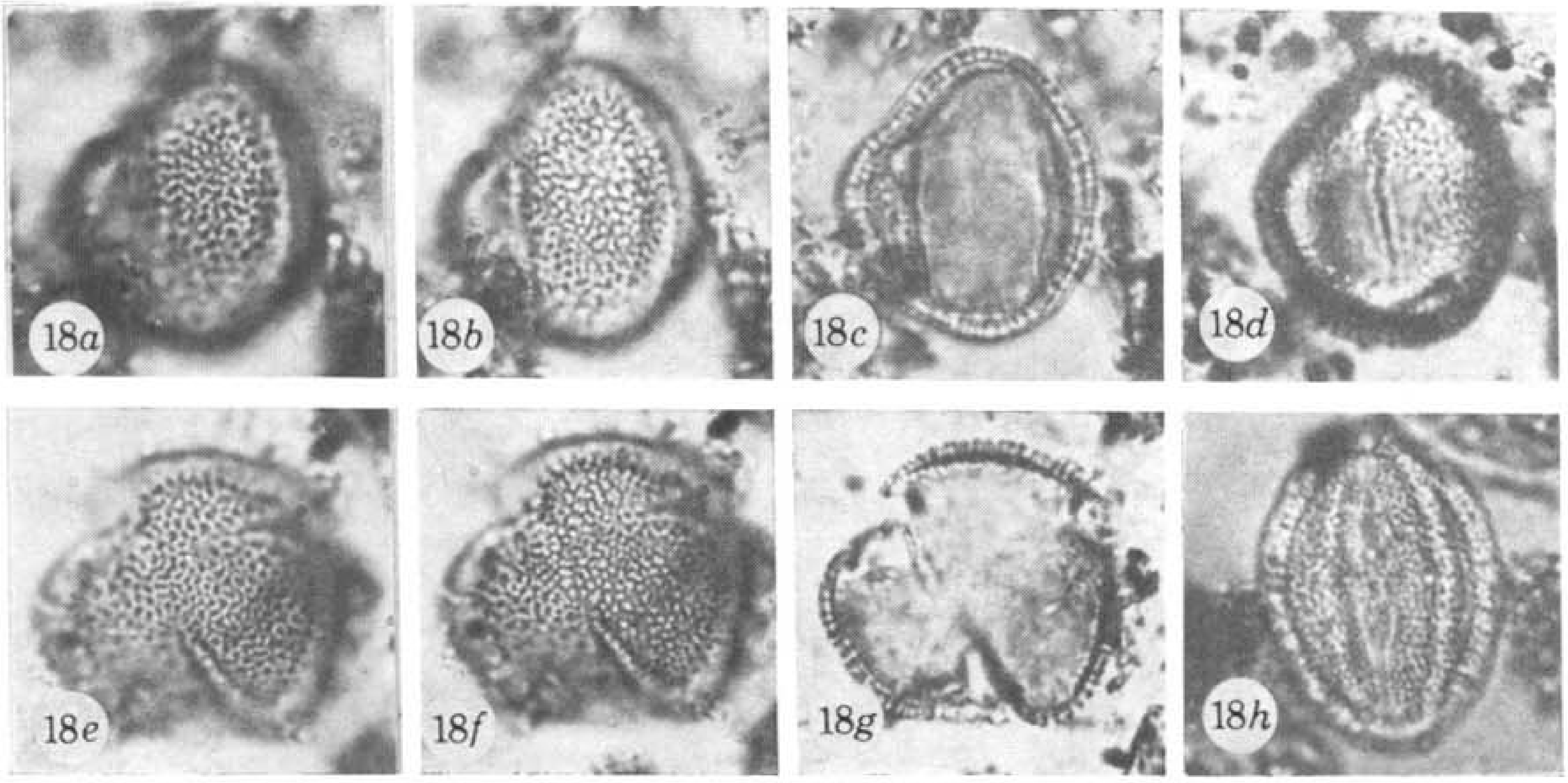

Figure 14. (*a–c*) *Bruckenthalia spiculifolia* seeds from Beetley D. (*d–f*) *Bruckenthalia spiculifolia* seeds, modern. Magnification of figures *a*, *b*, *d* and *e*, × 50; figures *c* and *f*, × 150.

Figure 15 (*a–f*). *Bruckenthalia* pollen from Beetley D.

Figure 16 (*a–b*). *Erica terminalis* pollen, modern.

Figure 17 (*a–d*). *Bruckenthalia* pollen, modern.

Figure 18 (*a–h*). Type X pollen from Barford (I.G.S. ref. nos: *a–d*, MPK 850; *e–g*, MPK 849; *h*, MPK 851). (Magnification of figures 15–18, × 750.)