Palynology of the Interglacial deposits at Little Oakley, Essex, and their Correlation

P. L. Gibbard and S. M. Peglar

Email alerting service	Receive free email alerts when new articles cite this article - sign up in the box at the top right-hand corner of the article or click **here**

PALYNOLOGY OF THE INTERGLACIAL DEPOSITS AT LITTLE OAKLEY, ESSEX, AND THEIR CORRELATION

By P. L. GIBBARD and S. M. PEGLAR

Subdepartment of Quaternary Research, Botany School, University of Cambridge, Downing Street, Cambridge CB2 3EA, U.K.

CONTENTS

Pollen analyses of sediment samples from five boreholes in the Little Oakley Silts and Sands provide evidence of contemporary vegetational development. Although the sequence is fragmentary, the succession can be reassembled based on the well-established subdivisions of vegetational development during temperate stages in northwest Europe.

The earliest vegetation represented is of late-glacial herb-dominated character. This is followed by an expansion of *Betula*, and subsequently *Pinus*, which together with *Picea*, *Alnus*, and later, *Ulmus* form the pre-temperate forest. After the decline in *Pinus*, *Ulmus* becomes dominant in the early temperate substage. The later expansion of *Quercus* and accompanied decrease in *Ulmus* marks the development of fully temperate deciduous forest. Other temperate trees such as *Tilia* and *Fraxinus* are rare. Throughout, the neighbouring river floodplains supported widespread herb-

23–2

dominated grassland. The latter may have been maintained by alluvial aggradation and large vertebrate activity.

Pollen analysis from a *Megaloceros* cf. *dawkinsi* antler base collected by S. H. Warren shows that the find dates from the early temperate substage of the interglacial.

Comparison of the Little Oakley pollen sequence with others obtained from Britain, The Netherlands and neighbouring countries suggests probable correlation with the Cromerian *sensu stricto* of West Runton, England and 'Interglacials III or IV' of the Dutch 'Cromerian Complex'. The preceding possible late-glacial spectrum should therefore equate with the late Beestonian.

1. INTRODUCTION

Palynological investigations at Little Oakley were undertaken from five boreholes (LOA, LOH, LOM, LOO and LOS), the locations and lithologies of which are shown in Bridgland *et al.* (1990, figures 1–3). Preparation procedures used throughout followed the standard chemical method used in the Subdepartment of Quaternary Research in Cambridge (cf. Faegri & Iversen 1975; West 1977). The pollen assemblages obtained are expressed as percentages of total land pollen and spores and are shown in the pollen diagrams (figures 1–4) and in table 1. Pollen type conventions follow those of Andrew (1970), together with some additional types listed by Birks (1973). Indeterminable pollen and spores, pre-Pleistocene palynomorphs and acetic acid insoluble dinoflagellate cysts have also been counted and are expressed as percentages of each group plus the sum of total land pollen and spores.

Pollen and spore preservation was somewhat variable through the cores; this will be discussed under the appropriate sections. Because of the fragmentary nature of the vegetational succession obtained, the pollen sequences from each individual borehole will be described first and then compared with others and correlated. Local pollen assemblage biozones (l.p.a.b.) have been defined in each case to assist this correlation.

2. BOREHOLE LOA

All the samples analysed from this borehole yielded well-preserved pollen and spores (figure 1). The sediment is predominantly a light grey to brownish grey sandy silt with occasional fine to medium sand bands. Two local pollen assemblage zones could be distinguished:

Aa. *Ulmus*–Gramineae–*Pinus*–*Betula* l.p.a.b. (310–385 cm). The pollen of *Ulmus*, *Pinus* and *Betula* dominate the arboreal spectra; *Picea* and *Alnus* are represented only by single grains. Low frequencies of *Corylus* and *Salix* pollen also occur. Pollen of Gramineae and, to a lesser extent, Cyperaceae is very frequent, the former comprising approximately 30% of the total land pollen. A diverse assemblage of other herbs includes plants reflecting a floristically rich open community on soil of varying moisture content. The pollen of aquatic plants is rare. The high frequency of pre-Pleistocene microfossils in the basal sample shows that reworking was in progress and continues into the subsequent biozone.

Ab. *Ulmus*–Gramineae–*Quercus*–*Corylus* l.p.a.b. (160–310 cm). The boundary between this and the previous zone is placed at the marked rise in *Quercus* pollen. This biozone contains significant amounts of tree pollen, but there are lower frequencies of *Betula* and *Pinus* than in the preceding l.p.a.b. They are replaced by the pollen of *Quercus* and *Corylus*. In addition, low
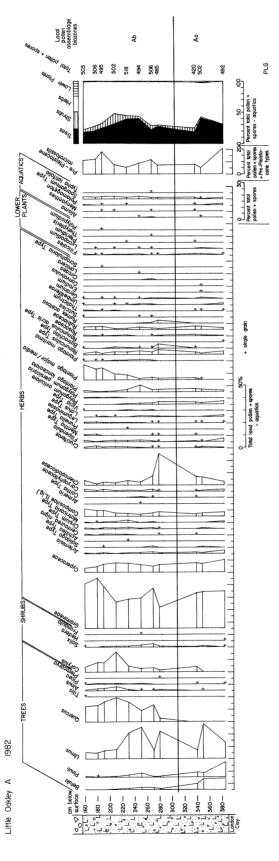
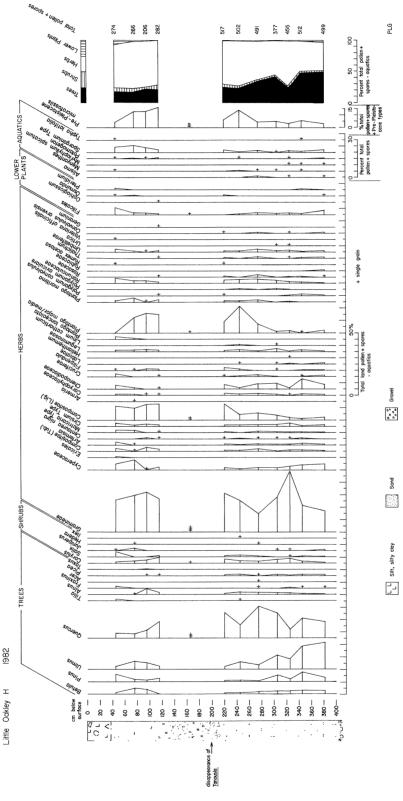FIGURE 1. Pollen diagram from borehole LOA. Sediment symbols used are shown in figure 2.

FIGURE 2. Pollen diagram from borehole LOH. The disappearance of the prosobranch mollusc *Tanousia* cf. *stenostoma* is shown (Preece 1990).

frequencies of *Alnus* and *Picea* pollen are also recorded. There is a marked decline in *Ulmus* pollen in the uppermost four spectra, although this may be an artefact of the sharp rise in Gramineae and *Plantago major/media* type pollen in these levels. This biozone is again characterized by a diverse herb pollen assemblage. In the basal sample, Chenopodiaceae pollen rises to 25 % and this is followed by the appearance of *Plantago maritima* and *Armeria* type pollen, which could reflect a brackish influence. However, evidence from other fossil groups, particularly the Mollusca and Ostracoda (Preece 1990; Robinson 1990) suggests that this is unlikely.

3. BOREHOLE LOH

The pollen assemblages from this borehole are shown in figure 2. Pollen preservation in the grey sandy silt sediments was poor with some levels containing a large proportion of degraded and crushed grains, a factor possibly associated with or resulting from the high sand content. The pebbly sand band between 120–215 cm yielded only a few degraded pollen grains in a silt lamina at 165 cm.

All the spectra comprise similar assemblages and can therefore be assigned to a single *Ulmus–Quercus*–Gramineae–herb l.p.a.b. (45–382 cm).

Throughout the profile the pollen spectra are dominated by herbs which increase upwards as tree and shrub pollen decline. *Ulmus* and *Quercus* are the most abundant tree taxa, both of which decline in frequency upwards. Low numbers of *Pinus*, *Betula*, *Alnus* and *Picea* grains are also present. Pollen of *Corylus* and *Salix* occurs in small quantities and *Juniperus* is also recorded. Of the herb taxa, high percentages of Gramineae are found, together with a diverse range of other herbs, including taxa showing both dry- and wet-ground environments. The assemblage is broadly uniform in composition. However, the striking peak in *Plantago major/media* type pollen accompanied by a small contemporary rise in Compositae (Liguliflorae) pollen may reflect inwash of local bank material. Spores of damp ground ferns such as *Osmunda* and *Ophioglossum* occur at some levels. A slight rise of *Sparganium* type occurs, possibly indicating establishment of these emergent aquatics as the channel silted-up. The increase in pre-Pleistocene microfossils in the central portion of the profile closely mirrors the input of coarser sediment and the increases in the herb taxa already mentioned.

4. BOREHOLE LOM

The sequence in this borehole can be divided into two subsections (figure 3). A grey silty clay (300–335 cm) is separated from an upper brown grey silty clay (195–248 cm) by an unfossiliferous sand unit. Two l.p.a.b.s can be recognized in these assemblages.

Ma. *Betula–Pinus*–Gramineae l.p.a.b. (300–335 cm). The pollen assemblages in this zone are not well preserved, all the samples containing a proportion of degraded, broken and indeterminate grains. The spectra include up to 40 % tree pollen, in particular that of *Betula* and *Pinus*, with smaller quantities of *Picea* and *Alnus*. *Ulmus* pollen appears in the upper part of the zone. In the lowest sample Gramineae pollen represents over 60 % total land pollen and remains frequent throughout. Herbs are present in low numbers, while Filicales spores are well represented (30–40 %) in the uppermost two samples. The latter may however, be the result of differential preservation as these spores are very resistant.

The frequency of pre-Pleistocene palynomorphs, dinoflagellate cysts and indeterminable pollen remains virtually constant through the sediments and shows contemporary local erosion.
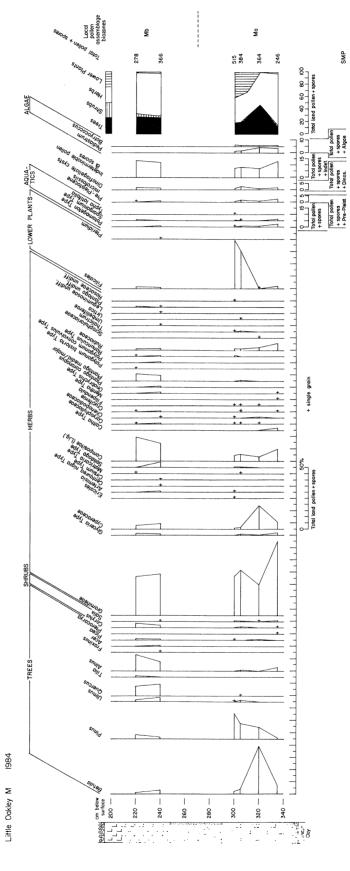
FIGURE 3. Pollen diagram from borehole LOM. Sediment symbols used are shown in figure 2.
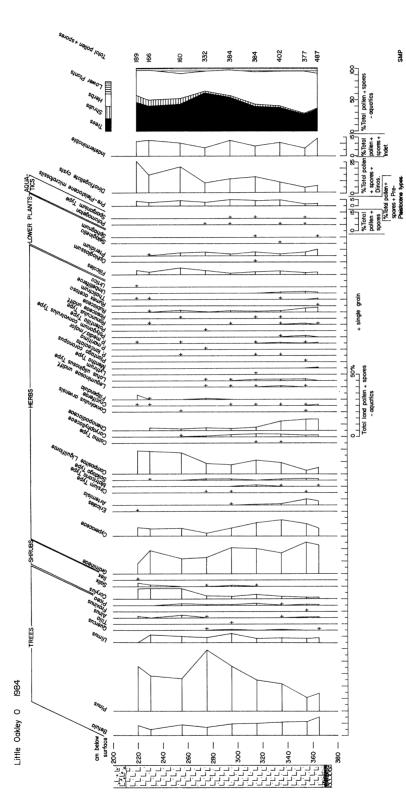
FIGURE 4. Pollen diagram from borehole LOO. Sediment symbols used are shown in figure 2.

Mb. *Quercus–Alnus*–Gramineae l.p.a.b. (220–240 cm). The sediments of this zone again contain rather poorly preserved, slightly degraded pollen. In contrast to the lower part of the profile, low values of *Pinus* and *Betula* pollen are found accompanied by high values of *Quercus* and *Alnus* pollen. For this reason these upper assemblages are assigned to a separate biozone. Also present are *Ulmus*, *Tilia*, *Acer* and *Picea* pollen. In common with other l.p.a.b.'s, the pollen of Gramineae and herbs are an important component of the spectra. The high number of Compositae (Liguliflorae) grains, together with *Plantago major/media* type pollen, may be an artefact of the pollen preservation or possibly a result of inwash of bank material. These interpretations are supported by the abundance of the indeterminable pollen in the counts.

5. Borehole LOO

The sediments comprise grey silty clay, mottled brown in the upper 30 cm. Pollen preservation is generally good, but none was found above 220 cm. The spectra are broadly uniform (figure 4) and can be assigned to a single *Pinus–Betula–Ulmus*–Gramineae l.p.a.b. (220–368 cm).

Throughout, *Pinus* is the predominant tree pollen, with subordinate *Betula* and *Ulmus*. The frequency of *Pinus* increases upwards, whereas there are only sporadic occurrences of other tree taxa. Although rather sparsely represented, *Picea* is present throughout. Towards the upper part of the sequence, *Corylus* pollen increases. Of the non-tree component, Gramineae are again abundant, together with a wide variety of herbs. In the top four to five levels there is a distinct decline in *Artemisia*, Chenopodiaceae and Rubiaceae, possibly an artefact of the increased *Pinus* pollen percentages. The remaining herb assemblage is consistent with that in other diagrams, with the exception of a greater frequency of Compositae (Liguliflorae) in levels 260–220 cm. Lastly, very little aquatic plant pollen was recovered and it is completely absent above 280 cm. This evidence supports that from the Mollusca (Preece 1990) for the progressive development and drying of marshy ground in this sequence. Although pre-Pleistocene microfossil frequencies remain unaffected, there is a substantial increase of reworked dinoflagellate cysts in the upper three levels. The reason for this is not clear, but it may result from sedimentary sorting or more probably from post-depositional drying of the sediments; the cysts possibly being more resistant to decay.

6. Borehole LOS

Two samples were counted from this borehole, 290 cm from grey sandy silt and 365 cm from grey clay (table 1). In both samples pollen preservation was good and both can be assigned to a *Quercus–Ulmus*–Gramineae l.p.a.b.

In both counts the pollen of *Quercus* and *Ulmus* are most frequent among the tree taxa. Other tree and shrub pollen present in low frequencies include *Picea*, *Alnus*, *Pinus*, *Betula* and *Corylus*. In keeping with assemblages from other boreholes, Gramineae pollen dominates the spectra, accompanied by a diverse range of herbs. The aquatics, *Sparganium* type and *Alisma* type pollen are also recorded.

TABLE 1. POLLEN ANALYSES FROM BOREHOLE LOS AND FROM SEDIMENT ADHERING TO AN ANTLER BASE OF *MEGALOCEROS* CF. *DAWKINSI*

(+, single grain.)

	LOS 290	LOS 365	*Megaloceros* cf. *dawkinsi* antler	
Betula	3.3	0.8	5.2	% total land pollen
Pinus	4.6	2.5	1.3	and spores (TP)
Ulmus	6.1	4.6	26.7	
Quercus	10.9	9.1	15.3	
Alnus	2.0	0.8	+	
Fraxinus	·	·	+	
Picea	1.0	1.1	0.7	
Corylus	4.1	1.3	0.7	
Salix	+	·	+	
Gramineae	44.3	40.1	26.7	
Cyperaceae	2.3	3.6	5.5	
Ericales	·	+	·	
Artemisia	1.3	0.3	·	
Cirsium type	·	·	+	
Matricaria type	0.5	0.8	+	
Solidago type	2.3	1.3	+	
Compositae (Liguliflorae)	4.1	2.9	2.0	
Caltha type	·	+	·	
Caryophyllaceae	0.5	0.3	0.7	
Chenopodiaceae	+	1.6	4.9	
Convolvulus arvensis	0.5	·	·	
Cruciferae	·	0.7	1.0	
Filipendula	0.5	1.0	·	
Leguminosae undiff.	·	1.3	+	
Lotus type	·	0.7	·	
Trifolium	·	0.7	·	
Vicia/Lathyrus	·	+	·	
Linum bienne type	·	+	·	
Mentha type	·	+	·	
Peplis	·	+	·	
Plantago lanceolata	1.8	0.3	+	
P. maritima	+	·	·	
P. media/P. major	4.8	10.8	0.7	
P. undiff.	·	+	+	
Polygonum convolvulus type	·	0.8	+	
Poterium sanguisorba	+	+	·	
Ranunculus type	1.0	1.0	0.7	
Rosaceae undiff.	+	0.5	·	
Rubiaceae	1.5	0.7	2.3	
Rumex acetosa type	·	1.0	1.0	
R. crispus type	·	+	·	
cf. *Samolus*	·	4.2	·	
Succisa	+	·	·	
Umbelliferae	0.5	1.3	·	
Urtica	·	+	0.7	
Filicales undiff.	2.5	2.0	·	
Lycopodium	+	·	·	
Pteridium	0.5	0.3	0.7	
Alisma type	·	0.3	·	% TP+sum aquatics
Myriophyllum spicatum	·	·	1.0	
Sparganium type	·	0.5	·	
Pre-Pleistocene microfossils	1.8	3.0	+	% TP + Pre-Pleistocene microfossils
Dinoflagellate cysts	3.7	2.2	·	% TP + Dinoflagellate cysts
indeterminable pollen and spores	6.7	5.5	13.0	% TP + Indeterminate pollen and spores
unknown	+	0.3	+	
total number of and pollen and spores (TP)	406	613	307	

7. Spectrum from the *Megaloceros* cf. *dawkinsi* antler base

An antler base collected by S. Hazzledine Warren in 1939 and stored in the British Museum (Natural History) (registration no. M 20414) was found to have some original brownish grey clayey silt adhering to its surface. A sample of this sediment scraped from the specimen was analysed (table 1).

The assemblage contains high values of tree pollen with *Ulmus* and *Quercus* as the major components, with subordinate *Picea*, *Fraxinus*, *Pinus* and *Betula*. Pollen of *Corylus* and *Salix* is also present. Gramineae pollen dominates the assemblage, although the herb flora is more restricted compared with those obtained from some of the boreholes. Indeterminate pollen is abundant, possibly reflecting the destruction of pollen caused by drying out of the sediment, although the reworked pre-Pleistocene component is rather low compared with other spectra obtained. The overall assemblage compares closely with that found in the upper part of borehole LOA or in borehole **LOH** and indicates that this spectrum should be assigned to an *Ulmus–Quercus*–Gramineae l.p.a.b.

8. Correlation of the diagrams

The pollen assemblages found in these sediments contain a range of thermophilous trees and frost-sensitive plants such as *Hedera* and *Ilex* (Iversen 1944), indicating they accumulated during a temperate stage. The consistently high proportion of herb taxa compared with values normally recovered from Flandrian lake sediments is a feature typical of fluviatile sequences (West 1980a; Phillips 1974; see below). Pollen diagrams from temperate stages in mid-latitude northwest Europe can be divided into four substages (Turner & West 1968). This scheme describes the vegetational succession of a temperate (interglacial) period and reflects control by external factors such as climatic and edaphic changes (Turner & West 1968; West 1980a). By using this scheme, the vegetational succession at Little Oakley can be assembled to form a logical sequence.

The earliest pollen-bearing sediment preserved in the channel appears to be that at the base of borehole LOM, 300–348 cm (figure 3) near the southern margin of the channel (Bridgland *et al.* 1990: figure 1). One spectrum from this sediment is dominated by *Betula* with subordinate *Pinus*, *Picea* and *Alnus*. There is also a suggestion that the lowermost sample (335 cm) may represent a preceding treeless late-glacial phase. The transition from a treeless flora to one dominated by birch is typical of that reflecting climatic amelioration at the beginning of a temperate stage (West 1980a). The *Betula*-dominated phase may therefore represent the earliest part of a pre-temperate substage of the interglacial. In the uppermost part of this biozone *Pinus* frequencies begin to rise. However, the sequence is truncated by erosion at the base of the sand unit in borehole LOM.

The next oldest sediments, again near the southern margin of the channel, are almost certainly those in borehole LOO (figure 4), in which *Pinus* pollen is dominant, with decreasing percentages of *Betula*. By the *Pinus–Betula–Ulmus*–Gramineae l.p.a.b., *Ulmus* is already established. The decline in *Pinus* and increase of *Corylus* pollen in the upper levels of borehole LOO suggest that the pre-temperate to early temperate transition is imminent.

This transition may occur near the base of borehole LOA (figure 1) where a decline in *Pinus* is followed by a rise in *Ulmus* pollen. The Aa/Ab biozone boundary is placed above at the

appearance of *Quercus* pollen together with the occurrence of other tree pollen, which together indicate the establishment of fully temperate deciduous forest. In the upper part of borehole LOA, *Quercus* replaces *Ulmus* as the dominant tree pollen. This rise in *Quercus* is accompanied by a marked increase in Gramineae and *Plantago major/media* type pollen, a sequence of events that closely matches that found in the basal half of the LOH sequence (figure 2). It seems likely therefore that the upper part of borehole LOH represents the youngest part of the interglacial sequence recovered.

The sediments represented in the upper part of borehole LOM (biozone Mb: 220–240 cm) contain higher frequencies of *Quercus* than *Ulmus* pollen (figure 3). They also contain high Gramineae, but relatively low counts for *Plantago major/media* type. These assemblages therefore closely resemble those from the upper 50 cm of borehole LOA (figure 1) or the lower part of LOH (figure 2) and are of early temperate character. Similarly, the counts from the lower part of borehole LOS (table 1) appear to represent a similar period on the basis of the higher frequencies of *Quercus* compared to *Ulmus* pollen.

The correlations discussed above are summarized in figure 5. From this evidence, the earliest sediments consistently seem to occur on the southern side of the channel with the basal channel sediments becoming progressively younger northwards.
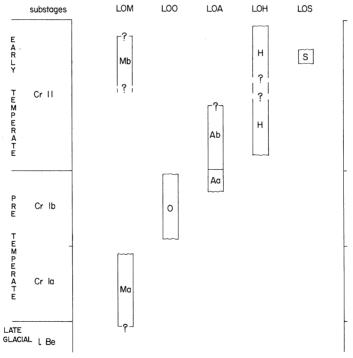

FIGURE 5. Correlation of Little Oakley borehole sequences, based on their pollen assemblages shown by local pollen assemblage biozones (l.p.a.b.). The substages follow Turner & West (1968) and the subdivisions of the Cromerian Stage (*sensu stricto*) follow West (1980*a*).

9. VEGETATIONAL HISTORY OF THE LITTLE OAKLEY SILTS AND SANDS

The reconstructed succession presented makes possible a discussion of the vegetational history recorded in the channel sediments at Little Oakley. However, before beginning this discussion, the origin or taphonomy of the pollen assemblages should be considered.

As shown by Bridgland *et al.* (1990), the sediments fill a wide channel and were laid down by a large river. A number of taphonomic problems are inherent in the interpretation of pollen assemblages from fluvial sediments. It is now generally accepted that the largest component of pollen recruitment into water bodies is water transported and not airborne (Peck 1973; Bonny 1976; Jacobson & Bradshaw 1981); estimated at *ca.* 90% in modern lakes in temperate Britain. The factors influencing pollen deposition in alluvial settings may include variable derivation, size of river catchment, presence or absence of local bank or channel erosion, selective sorting and preservation, and variation of sediment facies (cf. West 1973). These factors in turn may potentially, although not necessarily, give rise to biases such as over- or under-representation of particular taxa or groups of taxa in the preserved pollen spectrum. These are in addition to biases arising from differential pollen production and areal dispersal properties. There is a lack of detailed work on palynological taphonomy in river sediments, and furthermore, studies that have been undertaken offer alternative interpretations (cf. Fall 1987; Hall 1989). In the absence of reliable criteria, it is essential to bear these problems in mind, and to interpret assemblages with caution.

As already mentioned, the basal spectrum in borehole LOM may represent late-glacial herb-dominated vegetation, which is replaced by *Betula* scrub. Birch domination lasted until the arrival and expansion of *Pinus*. This pre-temperate forest community may also have included *Picea*. The appearance of this low pollen producer with pine suggests that spruce may have been growing in the local catchment from very early in the pre-temperate substage. In addition, areas of the floodplain may have been colonized by alder. Moreover, an abundant herb flora probably grew on the river floodplain, where there was minimal competition from forest trees.

Subsequently, the early arrival of *Ulmus* marked the establishment of deciduous forest and a pine–elm vegetation seems to have dominated the area. However, it is unlikely that these two trees colonized precisely the same area, but that pines probably occupied dry, sandy soils developed on the local gravel and crag sediments, while the elms grew on moist ground, closer to the river. Sparse evidence of other tree taxa (for example, *Tilia* and *Alnus*) might imply that elm was the most important element in the regional vegetation. However, the high frequencies of elm pollen could have been, in part, derived from local stands on the river floodplain and therefore the role of *Ulmus* in the regional vegetation is less certain.

Throughout the first half of the early temperate substage *Betula* also continued to flourish. The low frequencies of *Corylus* pollen present suggest that it may have immigrated at a similar time to elm, but did not succeed in expanding until later.

Oak does not seem to have entered the area until the early temperate substage, although the minor records for *Quercus* pollen in LOO suggest that low numbers of trees were present in the catchment, possibly near the locality (cf. Bennett 1985). The expansion of oak later in the substage was accompanied by an increase in other trees such as *Corylus*, *Tilia* and *Fraxinus*, so that a species-rich deciduous forest was established by the end of the period. This development was mirrored by an apparent decline in elm, although this may be solely an artefact of the percentage calculations. Events later in the sequence, recorded in the upper part of LOH, are difficult to interpret and may be partially a result of sediment texture, sorting and/or preservation as there is a general decline in deciduous tree pollen. Despite this, the records of *Taxus*, *Fraxinus*, *Tilia*, *Corylus*, *Juniperus* and *Hedera* suggest that deciduous forest still persisted.

Throughout all the sequences there is a consistently high frequency of non-tree pollen. This component is dominated by grass and includes a range of dry to moist ground plants. They

show that herb-rich grassland was an important element of the local vegetation that almost certainly colonized the floodplain, which could have been extensive. Local dry grassland, possibly on the well-drained sandy soils on the gravels and crags, supported a variety of plants including *Centaurea nigra*, *Helianthemum*, *Linum catharticum*, *Geranium*, *Plantago* and *Erodium*.

A range of plants characteristic of moist ground grew beside channels and pools or on the emergent areas of the floodplain, whereas the muddy channels themselves provided a habitat for aquatic plants such as *Typha latifolia*, *Sparganium* and/or *Typha angustifolia*, *Menyanthes*, *Myriophyllum spicatum* and *Alisma plantago-aquatica*. The presence of slightly acidic soils in the area is suggested by the records for *Pteridium*. The composition of this herb vegetation does not seem to have varied greatly through the period represented, although it may have become slightly more diverse in the later part of the sequence.

High values for non-tree pollen in temperate pollen assemblages have been repeatedly recorded from fluvial sediments. Comparable assemblages were obtained from Ipswichian sites at Aveley (West 1969), Swanton Morley (Phillips 1974), Barrington (Gibbard & Stuart 1975) and Trafalgar Square (Gibbard 1985). At these sites high non-tree pollen frequencies were related to the maintenance of riverside floodplains by alluviation and/or large vertebrate activity, because of the occurrence of vertebrate remains in the sediments. Either or both of these factors could be invoked to explain the herb pollen percentages found at Little Oakley. However, the occurrence of the remains of large vertebrates in the sediments (Lister *et al.* 1990) suggests that grazing and trampling may have helped maintain the herbaceous communities on the local floodplain. Significantly, the pollen of plants that colonize trampled and disturbed ground such as Compositae (Liguliflorae), *Plantago major/media* type and *Urtica* is abundant.

This interpretation is further supported by the continuous curves for pre-Pleistocene microfossils and indeterminate pollen (figures 3 and 4; table 1), already interpreted as indicating active bank and channel erosion. The form of these frequency curves shows some correspondence with herb-pollen percentages, implying a possible causal link between them. If the non-tree pollen frequencies indicate local floodplain vegetation, then irregular fluctuations shown by various taxa, for example, *Plantago major/media* type or Chenopodiaceae, presumably result from periodic inwash of bank material and possibly sedimentary sorting.

10. Comparison with other sites and age of the Little Oakley Silts and Sands

The Little Oakley Silts and Sands accumulated during the pre-temperate (I) and early-temperate (II) substages of a temperate stage. The lowermost sediment analysed in LOM (i.e. below *ca.* 327 cm), however, may have been laid down during the latest part of the previous cold stage. The absence of *Hippophaë* pollen from this late-glacial sediment implies that the overlying interglacial sequence is unlikely to be of Hoxnian age. Indeed, the occurrence in substages I–II of *Picea* pollen, the early appearance and subsequent expansion to dominance of *Ulmus* and the late rise in *Corylus* are all features which suggest a pre-Hoxnian age (cf. West 1980 a). Equally, the diagrams differ markedly from those of Pastonian age (West 1980 a, b), which include significant percentages of *Carpinus* pollen in the early temperate substage, accompanied by both *Ulmus* and *Quercus*, both of which rise at a similar time. Correlation with earlier stages can be rejected, in part, because of the absence of certain taxa, such as *Eucommia* and *Tsuga*, which are now 'exotic' to western Europe.

Comparison with the early Middle Pleistocene type Cromerian succession at West Runton (West 1980*a*, *b*) shows several features in common with that from Little Oakley. These include the first half of the pre-temperate substage (Cr I a), which is characterized by *Betula-Pinus* forest with *Ulmus* making an early appearance. This is followed in Cr I b by the expansion of *Pinus* together with *Ulmus* and *Alnus*, with *Picea* present at low frequencies. By Cr II *Quercus* becomes established and *Pinus* declines. A range of deciduous forest taxa are represented, particularly by the latter half of the substage (Cr II b), including *Tilia*, *Alnus* and *Fraxinus*, while *Picea* still persists. There is therefore a close resemblance between the two sequences, which strongly suggests that they should be correlated. However, the low frequency of *Tilia* at Little Oakley implies that only the first half of the early temperate substage (Cr II a) is represented (figure 5).

Regarding other sites of broadly Cromerian age, little can be concluded. For example, organic deposits at Nettlebed, Oxfordshire also span the pre- and early temperate substages of an early Middle Pleistocene interglacial stage (Turner 1983). They were assigned to a 'Nettlebedian' stage by Gibbard (1985) who thought they might equate with 'Interglacials II' or 'III' of the Dutch 'Cromerian Complex'. The Nettlebed pollen spectra contain no Tertiary relicts and low frequencies of *Ulmus* throughout, and so differ markedly from those of both West Runton and Little Oakley. For the present, the correlation of Nettlebed must therefore remain open. Moreover, as only the pre- and early temperate substages are represented at Little Oakley, comparison cannot be made with British localities of possible Cromerian age that represent later parts of the stage, for example, Sugworth (Gibbard & Pettit 1978).

The more complete early Middle Pleistocene, so-called 'Cromerian Complex', sequence in The Netherlands and neighbouring countries includes four interglacials (Zagwijn *et al.* 1971; Zagwijn 1974, 1975, 1985; Turner 1975; de Jong 1988). The main features of these stages and the names of some of the more important localities (shown in Bridgland *et al.* 1990, figure 9), are given in table 2. Comparison of the East Anglian evidence with that from sites on the adjacent Continent is fully justified as almost all are of fluvial origin. Moreover, during this time, continuous land linked Britain and the Continent across the southern North Sea (Zagwijn 1979; Cameron *et al.* 1987).

In The Netherlands the first half of 'Cromerian Interglacial I' is lacking and the remainder has reversed geomagnetic polarity (Zagwijn *et al.* 1971; de Jong 1988). However, at Osterholz near Hannover in Germany, a complete sequence was obtained by Grüger (1968). In the early part of this interglacial, *Picea* is present at low frequencies, *Ulmus* rises early and becomes dominant with *Quercus* and *Carpinus* is also present. *Corylus* arrives very late, increasing only after the middle of the stage. In the second half of the interglacial a *Carpinus–Eucommia* association is characteristically developed (Zagwijn *et al.* 1971; Turner 1975; de Jong 1988). The first half of 'Cromerian Interglacial II' is known from Westerhoven (Zagwijn & Zonneveld 1956) and from the Danish sites of Harreskov and Ølgod (Andersen 1965). At these sites values for *Ulmus* pollen are again very high throughout the first half, as are those of *Alnus*. High values of *Taxus* are present later in first half, whereas *Picea* occurs throughout the interglacial. 'Cromerian Interglacial III', known from Rosmalen (de Ridder & Zagwijn 1962) and Het Zwinkel (de Jong 1988), has a vegetational succession rather similar to that of the Holsteinian, with which it was formerly confused. It differs in having high values for *Ulmus* pollen in its earliest parts, but low *Picea* throughout the first half of the interglacial. Later, much higher *Picea* frequencies occur. Characteristically, *Carpinus* is present in substages II and III.

TABLE 2. CHARACTERISTICS OF THE 'CROMERIAN COMPLEX' (EARLY MIDDLE PLEISTOCENE) INTERGLACIALS OF THE NETHERLANDS AND NEIGHBOURING COUNTRIES. BASED IN PART ON ZAGWIJN (1974, 1975, 1985 AND PERSONAL COMMUNICATION) AND TURNER (1975)

stage	main pollen stratigraphical characteristics	main sites and authors
'IV'	high frequency of *Ulmus* in first half, accompanied by low *Picea* values, *Quercus* important co-dominant in early temperate period. Later part includes important *Abies* phase	Noordbergum (Zagwijn 1974, 1975, 1985); Roswinkel (de Jong 1988); Voigt-stedt (Erd 1965, 1970); ?West Runton-type Cromerian (West 1980a, b)
'Glacial C'		
'III'	high values for *Ulmus* in first half, low frequencies of *Picea* in early part *Quercus* important co-dominant part *Ulmus* in substage II, *Carpinus* present in substage II	Rosmalen. (de Ridder & Zagwijn 1962; Zagwijn 1974, 1975); Het Zwinkel (de Jong 1988)
'Glacial B'		
'II'	high values for *Ulmus* in first half, *Picea* present throughout. *Alnus* very high throughout first half. Very high values of *Taxus* in substage II. No Tertiary relics present	Westerhoven (Zagwijn & Zonneveld 1956); Harreskov & Ølgod (Andersen 1965)
'Glacial A'		
'I'	high values of *Ulmus* in early part, *Corylus* only in later part (III/IV), in *Picea* present low frequencies. *Carpinus* appears in substage II. Second half of interglacial characterized by *Carpinus–Eucommia* association	Waardenburg (Zagwijn *et al.* 1971; Zagwijn 1974, 1975); Osterholz (Grüger 1968)

'Interglacial IV', unlike the other sites just mentioned, is known from estuarine sediments at Noordbergum, as well as freshwater sediment at Roswinkel, both in the northern Netherlands (Zagwijn 1974, 1975, 1985; de Jong 1988). This interglacial also contains high frequencies of *Ulmus* pollen in its early part. They are accompanied by low *Picea* and later by rising frequencies of *Quercus*, giving rise to an *Ulmus–Quercus* assemblage. Unlike the previous interglacials of the 'Cromerian Complex', *Abies* is abundant in the latter part and for this reason this interglacial has previously been correlated with the British Cromerian Stage (*sensu stricto*) of West Runton, Norfolk (Zagwijn 1974, 1985; West 1980b).

On the basis of the evidence summarized above and in table 2, the older interglacials can therefore be rejected as equivalents of the Little Oakley sequence. The absence of Tertiary relicts precludes a pre-'Cromerian Interglacial I' age for the Little Oakley sediments as the Bavel and Leerdam Interglacials (Bavelian) in The Netherlands contain *Pterocarya*, *Eucommia*, and particularly, *Tsuga* in the first half of these periods (Zagwijn & Doppert 1978; Zagwijn & de Jong 1983–84; de Jong 1988). The virtual absence of *Corylus* from the first half of 'Cromerian Interglacial I' implies that correlation with this period is also unlikely. This is confirmed by the fact that Little Oakley has normal geomagnetic polarity (Austin, in Bridgland *et al.* 1990) whereas 'Interglacial I' is reversed. Of the other 'Cromerian interglacials', the absence of high values of *Carpinus* and/or *Taxus* in substage II implies that Little Oakley is not equivalent to 'Interglacial II'. It is possible, however, that the high frequencies of these taxa, particularly the latter, could result from local factors and may therefore be of limited regional significance.

In summary, the Little Oakley sequence represents the first half of an interglacial during which *Ulmus* is important initially, followed by the expansion of *Quercus*, and the occurrence of low frequencies of *Corylus* and *Picea*, but *Carpinus* is absent throughout. On balance therefore,

the evidence would favour correlation with either 'Cromerian Interglacials III or IV'. Despite the vegetational similarity with 'Cromerian Interglacial IV', there is a problem with the direct correlation of West Runton (and hence Little Oakley) with the stratotype at Noordbergum. This concerns the occurrence of the vole *Arvicola cantiana* at Noordbergum (van Kolfschoten 1988). This species is thought to have descended from *Mimomys savini*, the form present at both Little Oakley and West Runton (Lister *et al.* 1990). Therefore, unless the transition took place during the interglacial (cf. Stuart & West 1976), correlation with 'Interglacial IV' seems to be incorrect. Thus Little Oakley (Cromerian *sensu stricto*) is either equivalent to the first half of 'Interglacial III' or 'IV' or else there is an additional intervening interglacial event that has yet to be identified in The Netherlands, containing both the vole *Mimomys savini* and high frequencies of *Abies* pollen, as recently suggested by Zagwijn *et al.* (unpublished data).

It can be concluded therefore that the interglacial deposits at Little Oakley are Cromerian *sensu stricto* in age, but cannot yet be reliably equated with the 'Cromerian Complex' of The Netherlands. The local biozones at Little Oakley can thus be correlated with the Cromerian (*sensu stricto*) substages CrI and CrIIa of West (1980b) (figure 5). This correlation implies that the possible late-glacial spectrum (borehole LOM; figure 3) at Little Oakley is immediately pre-Cromerian and therefore is of late Beestonian age.

The minor vegetational differences between the Little Oakley and West Runton sequences probably result from facies and taphonomic differences attributable to the size of river involved at each site. The former was a large energetic river, predominantly lacking organic muds rich in plant detritus. The West Runton stream, by contrast, was slow flowing, its channel being rich in organic sediment and plant debris (West 1980b).

References

Andersen, S. Th. 1965 Interglacialer og interstadialer i Danmarks kvartaer. *Medd. fra Dansk Geologisk Forening* **15**, 486–506.

Andrew, R. 1970 The Cambridge pollen reference collection. In *Studies in the vegetational history of the British Isles* (ed. D. Walker & R. G. West), pp. 225–231. Cambridge University Press.

Bennett, K. D. 1985 The spread of *Fagus grandifolia* across eastern North America during the last 18000 years. *J. Biogeogr.* **12**, 147–164.

Birks, H. J. B. 1973 *Past and present vegetation of the Isle of Skye – a palaeoecological study*. Cambridge University Press.

Bonny, A. P. 1976 Recruitment of pollen to the seston and sediment of some English Lake District lakes. *J. Ecol.* **64**, 859–887.

Bridgland, D. R., Gibbard, P. L. & Preece, R. C. 1990 The geology and significance of the early Middle Pleistocene interglacial sediments at Little Oakley, Essex. *Phil. Trans. R. Soc. Lond.* B **328**, 307–339. (This volume.)

Cameron, T. D. J., Stoker, M. S. & Long, D. 1987 The history of Quaternary sedimentation in the UK sector of the North Sea Basin. *J. geol. Soc. Lond.* **144**, 43–58.

Erd, K. 1965 Pollenanalytische Untersuchungen im Altpleistozän von Voigtstedt in Thüringen. *Paläont. Abhandl.* A **II**, 259–272.

Erd, K. 1970 Pollen-analytical classification of the Middle Pleistocene in the German Democratic Republic. *Palaeogeogr., Palaeoclimat., Palaeoecol.* **12**, 129–145.

Faegri, K. & Iversen, J. 1975 *Textbook of pollen analysis*, 3rd edn. Oxford: Blackwell.

Fall, P. L. 1987 Pollen taphonomy in a canyon stream. *Quat. Res.* **28**, 393–406.

Gibbard, P. L. 1985 *The Pleistocene history of the Middle Thames Valley.* Cambridge University Press.

Gibbard, P. L. & Pettit, M. 1978 The palaeobotany of the interglacial deposits at Sugworth, Berkshire. *New Phytol.* **81**, 465–477.

Gibbard, P. L. & Stuart, A. J. 1975 Flora and vertebrate fauna of the Barrington Beds. *Geol. Mag.* **112**, 493–501.

Grüger, E. 1968 Vegetationsgeschichtiche Untersuchungen an cromerzeitlichen Ablagerungun im nordlichen Randgebiet der deutschen Mittelgebirge. *Eiszeitalter Gegenw.* **18**, 201–235.

Hall, S. A. 1989 Pollen analysis and paleoecology of alluvium. *Quat. Res.* **31**, 435–438.

Iversen, J. 1944 *Viscum, Hedera,* and *Ilex* as climatic indicators. *Geol. fören. Stockh. förh.* **66**, 67–78.

de Jong, J. 1988 Climatic variability during the past three million years, as indicated by vegetational evolution in northwest Europe and with emphasis on data from The Netherlands. *Phil. Trans. R. Soc. Lond.* B **318**, 603–617.

Jacobson, G. L., Jr & Bradshaw, R. H. W. 1981 The selection of sites for paleovegetational studies. *Quat. Res.* **16**, 80–96.

van Kolfschoten, Th. 1988 The Pleistocene mammalian faunas from the Zuurland boreholes at Brielle, The Netherlands. *Meded. Werkgr. Tert. Kwart. Geol.* **25**, 73–86.

Lister, A. M., McGlade, J. M. & Stuart, A. J. 1990 The early Middle Pleistocene vertebrate fauna of Little Oakley, Essex. *Phil. Trans. R. Soc. Lond.* B **328**, 359–385. (This volume.)

Peck, R. M. 1973 Pollen budget studies in a small Yorkshire catchment. In *Quaternary Plant Ecology* (ed. H. J. B. Birks & R. G. West), pp. 43–60. Oxford: Blackwell.

Phillips, L. 1974 Vegetational history of the Ipswichian/Eemian interglacial in Britain and continental Europe. *New Phytol.* **73**, 589–604.

Preece, R. C. 1990 The molluscan fauna of the Middle Pleistocene interglacial deposits at Little Oakley, Essex, and its environmental and stratigraphical implications. *Phil. Trans. R. Soc. Lond.* B **328**, 387–407. (This volume.)

de Ridder, N. A. & Zagwijn, W. H. 1962 A mixed Rhine–Meuse deposit of Holsteinian age from the south-eastern part of The Netherlands. *Geologie Mijnb.* **41**, 125–130.

Robinson, J. E. 1990 The ostracod fauna of the interglacial deposits at Little Oakley, Essex. *Phil. Trans. R. Soc. Lond.* B **328**, 409–423. (This volume.)

Stuart, A. J. & West, R. G. 1976 Late Cromerian fauna and flora at Ostend, Norfolk. *Geol. Mag.* **113**, 469–473.

Turner, C. 1975 The correlation and duration of Middle Pleistocene interglacial periods in northwest Europe. In *After the Australopithecines* (ed. K. W. Butzer & G. Ll. Isaac), pp. 259–309. The Hague: Mouton Publishers.

Turner, C. 1983 Nettlebed. In *Diversion of the Thames Field Guide* (ed. by J. Rose), pp. 66–68. Cambridge: Quaternary Research Association.

Turner, C. & West, R. G. 1968 The subdivision and zonation of interglacial periods. *Eiszeitalter Gegenw.* **19**, 93–101.

West, R. G. 1969 Pollen analyses from interglacial deposits at Aveley and Grays, Essex. *Proc. Geol. Ass.* **80**, 271–282.

West, R. G. 1973 Introduction. In *Quaternary plant ecology* (ed. H. J. B. Birks & R. G. West), pp. 1–3. Oxford: Blackwell.

West, R. G. 1977 *Pleistocene Geology and Biology.* (2nd edn.) London and New York: Longman.

West, R. G. 1980a Pleistocene forest history in East Anglia. *New Phytol.* **85**, 571–622.

West, R. G. 1980b *The pre-glacial Pleistocene of the Norfolk and Suffolk coasts.* Cambridge University Press.

Zagwijn, W. H. 1974 Les problèmes de la subdivision du Pléistocène moyen des Pays-Bas. *Bull. Ass. Français Étude Quat.* **40–41**, 105–107.

Zagwijn, W. H. 1975 Variations in climate as shown by pollen analysis, especially in the Lower Pleistocene of Europe. In *Ice ages: ancient and modern* (ed. A. E. Wright & F. Moseley) *Geol. J.* **6**, 137–152.

Zagwijn, W. H. 1979 Early and Middle Pleistocene coastlines in the southern North Sea Basin. In *The Quaternary history of the North Sea* (ed. E. Oele, R. T. E. Schittenhelm & A. J. Wiggers) *Acta. Univ. Ups. Symp. Univ. Ups. Annum Quingentesimum Celebrantis* **2**, pp. 31–42.

Zagwijn, W. H. 1985 An outline of the Quaternary stratigraphy of The Netherlands. *Geologie Mijnb.* **64**, 17–24.

Zagwijn, W. H. & Doppert, J. W. Chr. 1978 Upper Cenozoic of the southern North Sea Basin: palaeoclimatic and palaeogeographic evolution. *Geologie Mijnb.* **57**, 571–588.

Zagwijn, W. H. & de Jong, J. 1983–84 Die Interglaziale von Bavel und Leerdam und ihre stratigraphische Stellung im Nederlandischen Früh-pleistozän. *Medd. Rijks Geol. Dienst* **37–43**, 155–169.

Zagwijn, W. H., Montfrans, van, H. M. & Zandstra, J. G. 1971 Subdivision of the 'Cromerian' in The Netherlands: pollen analysis, palaeomagnetism and sedimentary petrology. *Geologie Mijnb.* **50**, 41–58.

Zagwijn, W. H. & Zonneveld, J. I. S. 1956 The interglacial of Westerhoven. *Geologie Mijnb.* **18**, 37–46.