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The Middle Pleistocene of North Birmingham

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THE MIDDLE PLEISTOCENE OF NORTH BIRMINGHAM

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[Plate 9]

CONTENTS

The Older Drift of north Birmingham infills a system of pre-glacial valleys. Its stratigraphy has been worked out, chiefly from borehole records, showing it to comprise the deposits of two separate glaciations—the Lower and Upper Glacial Series, and an intervening Interglacial Series. It records the deposition during the Lower Glacial Series of fluvioglacial sediments followed by those of a glacial lake during the late-glacial period. A small remnant of the latter persisted into the Interglacial as a lake at Nechells and was gradually infilled with lake muds. After a temporary period of low water the level subsequently fell again, largely draining the lake which became covered with fen-wood and marsh receiving some fluviatile sediment. Other thin interglacial beds exist at Cardigan Street and possibly Washwood Heath. Elsewhere the period is represented by an unconformity. The Upper Glacial Series records the triple advance into the area of valley glaciers, accompanied by the formation of glacial lakes. In the intervening periods of retreat the valleys were receiving fluvioglacial sediment, and in one period were occupied by a second large glacial lake. A fourth advance of an ice sheet covered the area and completed the infilling of the valleys.

A detailed study of the pollen and macrofossils from the Interglacial Series has enabled the reconstruction of the plant communities in the vegetation, and their succession throughout the Interglacial. This records a combination of changes due to the seral, edaphic and climatic development. Following an amelioration of climate temperate deciduous forest developed from open 'sub-arctic' scrub and grass/herb communities, with *Alnus* and *Taxus* later becoming locally important when the climate perhaps became wetter. Deterioration of soils during the long period of mild humid conditions led to the subsequent spread of heath and coniferous forest, which perhaps, as *Abies* forest, occupied the area during the period of optimum temperatures (summer). Later deterioration of the climate resulted in *Pinus* forests and heaths, the vegetation becoming increasingly open as the next glaciation approached.

The Interglacial Series are correlated with Holsteinian interglacial sites elsewhere in Britain and on the Continent. This dates the Lower and Upper Glacial Series to the Elster and Saale Glaciations respectively, confirming their correlation with neighbouring areas.

1. Introduction

(*a*) *Description of the area*

This study covers an area of approximately 12 square miles of the central and northern parts of the city of Birmingham in the English Midlands. The area is almost completely built-up, much of it with factories and workers' houses dating from the last century. The present form of the land surface, now much disguised by the works of man, is shown in figure 1.

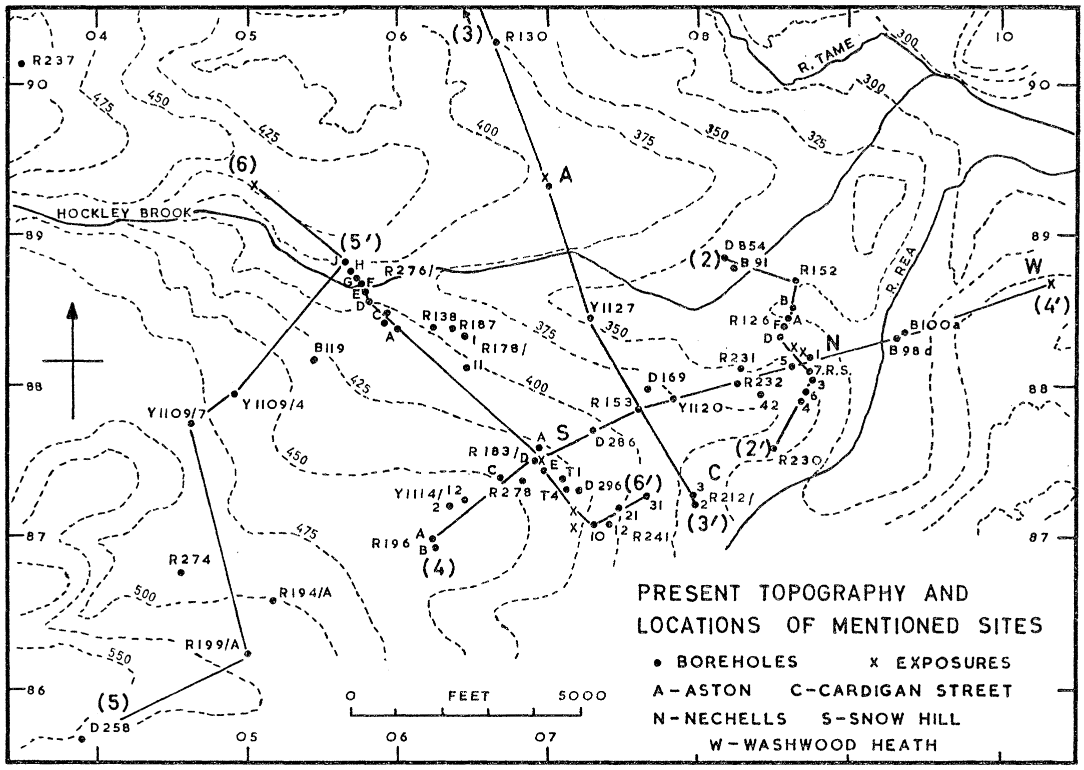

Figure 1. Present topography with the locations of sites mentioned in the text and the lines of sections illustrated.

(*b*) *History of previous research*

Pleistocene deposits cover a wide area of the central Midlands, and though in north Birmingham they are often of considerable thickness, their stratigraphy here has never been described in any detail. The Geological Survey (Eastwood, Whitehead & Robertson 1925) considered that the complexity of the lithology and position of the drifts in Birmingham rendered their succession 'obscure', and the two subdivisions of 'bedded' and 'unbedded drift' on the published geological map (Geological Survey, Sheet 168, Drift 1924) were only intended as a lithological classification without stratigraphical significance. However, their detailed records of exposures, as well as those of earlier workers, are an important source of information (for reference to the earlier work see Eastwood *et al.* 1925).

Wills (1937) provided the first synthesis of the history of the drifts by applying the concept of the 'Older' and 'Newer Drifts' to the west Midlands. He demonstrated that in the area which includes Birmingham, the Newer Drift was represented by terrace deposits belonging to the present river system, whereas the distribution of the Older Drift showed no relationship to the present topography. Furthermore, he originated the idea that the latter comprised the deposits of two glaciations, the First and Second Welsh, a concept which the evidence of the present study supports.

The distribution of the Older Drifts in Birmingham has been shown by Pickering (1957) to be associated with a system of valleys, now completely infilled and unrelated to the present drainage pattern. On recognizing this Pickering was able to establish the succession of the Older Drifts above the 400 ft. O.D. level in south Birmingham, in an area adjacent to that of the present study. The major part of this succession was dated to the Saale Glaciation by comparing it with the standard succession for the south Midlands (Shotton 1953), largely through the similarity of the height of lake deposits at Birmingham to those of the Saale glacial lake, Lake Harrison.

A Saale age for the upper Older Drifts was confirmed by the discovery beneath these of deposits of the preceding interglacial at Nechells, Duigan (1956) considering these beds to be Holsteinian in age, from her pollen analysis of a major part of them.

(*c*) *The present study*

The area is now almost devoid of natural exposures, but in recent years extensive slum clearance and redevelopment schemes by the city authorities, and industrial development, have necessitated many site-investigation boreholes and temporary excavations and these have been the main source of information. The locations of boreholes which are mentioned in the text are shown on figure 1, and National Grid References are quoted for the exposures (the figures in parentheses after their localities).

In the Nechells district of Birmingham, a series of boreholes and excavations have yielded material from the interglacial beds. Their existence was first revealed by site-investigation boreholes in 1950 (boreholes 1 to 6) and they were subsequently partly exposed in excavations for foundations for flats. In 1951 these sections (Sections A and B), extended by an auger hole, were sampled, covering in all about two-thirds of the interglacial beds. These were palynologically studied and the results published by Duigan (1956). Later development in the area (1960–61) involved excavations for a sewer, which exposed part of the beds in a tunnel (Sections C, 1–3) and a deep trench (Section D, boreholes 8 and 9).

In 1961 Professor Shotton obtained a grant from the Royal Society for a borehole to prove the full sequence of the interglacial beds, and this produced a virtually complete core of 6 in. diameter from them (borehole 7). Work for a new road in 1962 yielded a borehole (borehole 10) and small exposures (Section E). Information and samples from all these sites have been utilized in the detailed description of the stratigraphy and palaeobotany of the Nechells interglacial beds (for their locations see figure 4).

The original discovery of these beds provided a dateable horizon within the drift succession, separating the deposits of two glaciations. It has been found that this important horizon can be traced over a wide area beyond Nechells, though it usually only exists as a disconformity embracing the period of the Interglacial. In these areas where the interglacial beds are absent, this interpretation has been made possible by the recognition, usually from borehole records, of the glacial lake deposits which precede the interglacial beds in the Nechells type succession. By thus establishing the broad stratigraphy of the drifts of the area, more detailed successions could be compiled for the deposits of the two glaciations and the Interglacial.

In the local names of the glaciations no origin is stated (cf. Wills) since there were probably elements of Welsh, Irish Sea and Pennine ice in the ice-sheets from the north-west. However, the north European nomenclature (largely after Wolstedt 1962) is used as a general terminology where possible.

local	N. European	(Alpine)
Post-glacial	Flandrian	
Irish Sea glaciation	Weichsel	(*Würm.*)
—	Eemian	—
2nd glaciation	Saale	(*Riss*)
Nechells Interglacial	Holsteinian	—
1st glaciation	Elster	(*Mindel*)
—	Cromerian	—

2. Stratigraphy of the Older Drift

(*a*) *Introduction*

A generalized succession for the Pleistocene deposits in the area is:

	Alluvium
Newer Drift	River terraces
Older Drift	4. Upper Glacial Series—sands and gravels, tills and lake-clays
	3. Nechells Interglacial Series
	2. Late-glacial lake Series
	1. Lower Glacial Series—sands and gravels (and tills?)

Only the Older Drift is here considered. Its major divisions are further subdivided on the basis of their lithology, and these are discussed in the following sections; but first the pre-glacial topography which influences the distribution of them all is described.

(*b*) *Preglacial topography*

The form of the preglacial land surface is displayed by contours on the base of the Older Drift (figure 2); the information is derived chiefly from borehole data, but includes several heights from temporary exposures and a few from the published Drift map of the Geological Survey.

The area is traversed by a major valley running from north-west to south-east which is joined in the west by a large tributary valley from the south. These were named by Pickering (1957), the 'proto-Tame' and 'proto-Rea' respectively. Other small tributaries join it from the north and south.

In cross-section the valleys have an open V-shape with convex slopes (figure 3), demonstrating their fluviatile origin. The section shown, taken from where there is most information available, clearly shows that it has the form of a double curve with a break at *ca.* 350 ft. O.D. Furthermore, the map suggests that this bench is well developed along most of the southern side of the valley. It is believed that this feature is the result of valley widening during the Holsteinian Interglacial since the land surface of that period is known to have been at about this level (see figure 7). Thus in this 'valley in valley' profile it is the upper valley form which is the younger.

This broad pattern of drainage was maintained during two glaciations and an interglacial, re-establishing itself approximately along its earlier lines after each period of occupation of the area by ice or glacial lakes, until the valleys were finally infilled.

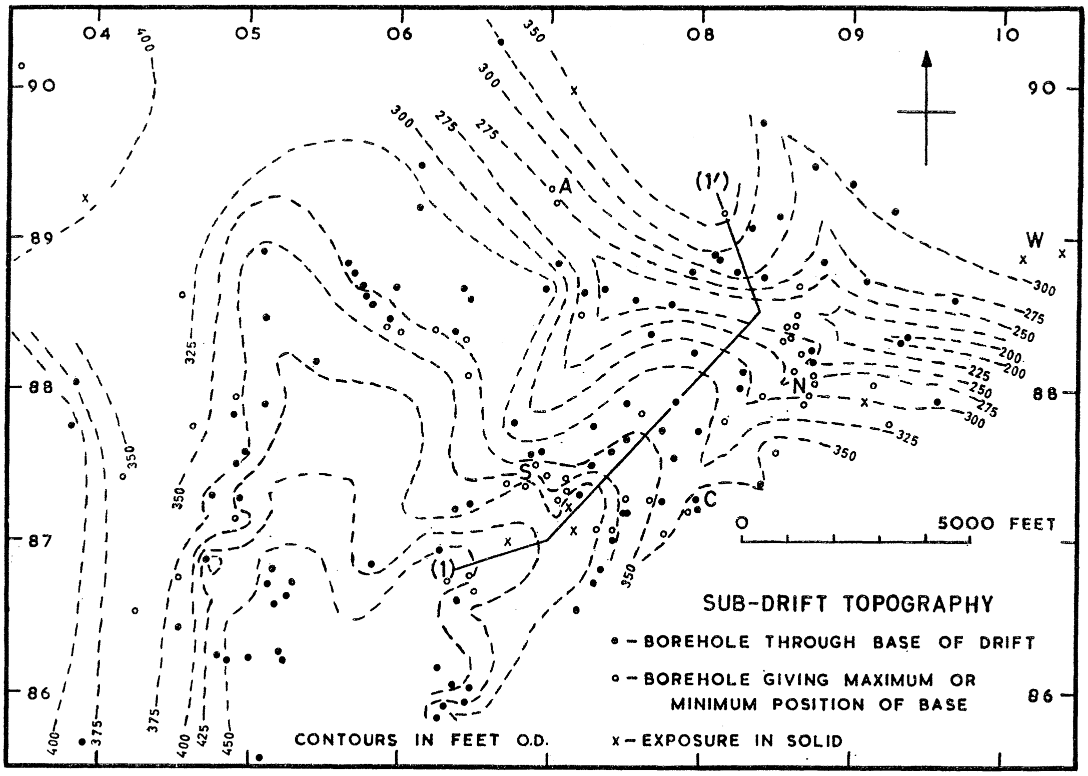

FIGURE 2. Sub-drift topography.

(*c*) 1. *Lower Glacial Series*

The units of this formation vary considerably with position in their detailed lithology and thickness but within the limited area about Nechells a general succession can be compiled from various boreholes:

		maximum thickness ft.
1*d*.	Clean medium sand, locally with gravel	*ca.* 33
c.	Interbedded silts and sands	*ca.* 38
b.	Coarse sands and fine gravels	*ca.* 12
a.	Coarse gravels	75

Their greatest preserved thickness (*ca.* 100 ft.) is recorded from water-well borings (B. 98*d* and B. 100*a*) which lie close to the centre of the pre-glacial valley. Though the succession in these boreholes—gravels on Triassic marls—would seem to leave little scope for the misinterpretation of the stratigraphy here, the low elevation for the valley floor which this thickness means, introduces a problem in the location of the downstream portion of the valley. The lowest 75 ft. are described as coarse gravels with only a single thin sandier unit. In B. 98*d* these rest on Keuper Marl at 271·5 ft. O.D. Above the gravels are sands and fine gravels (beds 1*b*) which appear to be the basal beds reached in the boreholes 1, 4, 7 and 9. In borehole 7 these were seen to be coarse sands with fine gravel and fine sand laminae. The top 14 ft. of B. 98*d* are coarse gravels most of which probably belong to the terrace deposits of the Newer Drift.

Between beds 1*b* and the varved clays (i.e. up to 297·6 ft. O.D.) in borehole 7, were horizontally bedded alternating layers of silt or very fine sand, and medium to coarse sand, a double unit varying from 1 to 12 in., with an average of about 4 in. Both included much coal detritus from silt to pebble grade. Beds of a similar lithology are much thicker on either side of the depression occupied by the interglacial beds; extending up to 321 ft. O.D. in borehole 4, and apparently to a similar height on the opposite side in the bottom of borehole 9. Presumably these sands are similar in appearance to the strongly horizontally

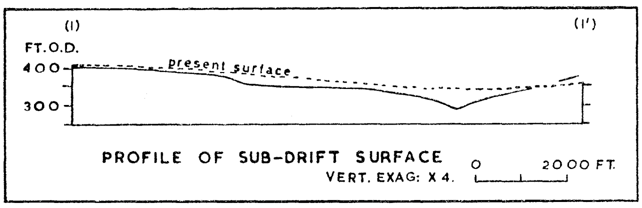

FIGURE 3. Profile of sub-drift surface along section line shown on figure 2.

laminated sands, of younger age, seen in exposures, where their lithology suggested deposition in ponded water (p. 553). Pickering (1957) has also included similar lithologies in his 'Still Water Deposits'. If the beds in the different boreholes are equivalent then the reduction in thickness (*ca.* 25 ft.) may be due to the burial of ice within the sediments of this group, similar but on a larger scale to that postulated for an exposure in the sediments of 4*e* (p. 554). The subsequent melting of the ice could form the depression in which the later varved clays and interglacial beds lie. The hypothesis that this originated as a kettle-hole is independently invoked in the next section.

Above these silts and sands in borehole 9 were 12 ft. of 'clean' medium sands (beds 1*d*), in turn overlain by the varved clays. Further west, in boreholes R. 232, R. 231 and 42 these sands are thicker but are not uniform in character, and can be micaceous fine sandy silts to silty, fine to medium sands with occasional pebbles. Their maximum elevation is 354 ft. O.D. in borehole 42. A succession of borehole records between here and R. 153 suggest that there is a gradual change in facies of 1*d* up-valley, and by R. 153 and Y. 1120 they are coarse sands and gravels, to boulder grade, with a little silt. To the north they can be traced as far as R. 130 where they rest on the Keuper sandstone forming the north-eastern side of the valley (see figure 8).

Theoretically the deposits may exist farther to the north-west, but they can not be distinguished as such where the marker horizon of the overlying varved clays is absent. However, since the level of the interglacial valley surface in the Nechells area, *ca.* 340 to 350 ft. O.D. (figure 7), sets the limit for upstream erosion, all arenaceous deposits in the valleys to the west below this elevation will belong to the Lower Glacial Series.

The glacial character of this group is partly inferred from their position below the late-glacial lake deposits and also from their thickness and coarse lithological character which is suggestive of fluvioglacial deposition. However, their detailed interpretation is not yet possible since they have not been exposed and only small samples of them have been seen from borehole 7. There is no direct evidence that ice of this glacial period covered the area but the thick coarse gravels of 1*a* may well include unrecognized tills as they have only been described from old borehole logs.

(*d*) 2. *Late-glacial lake Series*

The Royal Society borehole (7) provides the type succession for this group. This was:

		thickness ft.	in.
2*c*.	Varved clays interbedded with silty fine sands	2	1·75
b.	Varved clays	4	3·75
a.	Finely laminated silts and fine sands	0	9·75
		297·6 ft. O.D.	
1.	Sands and gravels		

The whole of this series contains contemporaneous fossils, though sparsely, which gives added significance to the lithological change from the unfossiliferous beds below. However, no evidence was seen, within the limited exposure of the borehole core, to suggest an unconformable relationship between Series 1 and Series 2 (see below).

The laminated silts and fine sands of 2*a* probably belong to an initial coarser phase of sedimentation in the lake. A modern example of this has been described by Otto (1955) from the recently drained marginal glacial lake Hagavatn in Iceland, where a bed of stratified thin silt and fine sand laminae lay beneath varved lake-clays, overlying with a sharp junction the gravels below. Both the clays and the silts contained sparse quantities of the same pollen.

The beds above (2*b*) basically consist of alternations of silt and clay laminae which show a great variety in their thickness and character. A few units are regular pairs of laminae of fine buff-red silt and pink clay, forming well graded units 1 to 2 mm thick, which are interpreted as the normal annual varves of a glacial lake, with summer silt and winter clay components (figure 34*c*, plate 9). Most units, however, are complicated by additional silt films in the clay section. Similar complex laminations were described from the glacial lake clays of Steep Rock Lake, Canada, by Antevs (1951), who interpreted them as products of fluctuations in depositional environment of a shorter period than a year.

Other units are almost homogeneous with only a faint convolute 'tracery' and are probably formed of slumped and reconstituted sediment (figure 33*a*, plate 9). These also are frequently described from glacial lake deposits (e.g. Mathews 1956, Smith 1959). Small-scale reverse and normal faults exist in some units and give further instances of post-depositional movement (figure 34*b*, plate 9). The photographs show the edge deformation caused by the coring, and some shear planes associated with this, but the other structures are demonstrably penecontemporaneous, as they are developed within individual units or groups of units and are truncated by a succeeding lamina.

Despite their variable character, the Nechells varved clays have many of the features previously found in glacial lakes, fossil and actual, and will, therefore, have been deposited in ponded water under a glacial regimen.

Towards the top of 2*b* thin (< 0·5 mm) laminae of fine sand appear, a transition to the beds of 2*c* in which four thick units of fine sand are intercalated with varved clays. At the top of the uppermost bed (2*c*/8) is the horizon which yielded the earliest pollen in countable quantity representing Zone IN. 2 of the Interglacial. For convenience this is considered as the upper limit of Series 2 though they are only arbitrarily separated from the interglacial beds of Series 3 and a gradual transition exists between them.

The lithological sequence seen in borehole 7 above 302·7 ft. O.D., is also found in sections in the marginal area of the interglacial beds (Section D and borehole 9) 35 ft. higher up. The top beds of the two successions both contain similar pollen (of Zone IN. 2) and can, therefore, be correlated directly. An arrangement of the beds in descending order below this then correlates like lithologies, and equates the two thick varved clays at the bottom (2*b*), e.g.:

	borehole 7	in.	borehole 9 and Section D	ft. in.
2*c*/8.	Clay and silt	4·75	Silty clay	1 1
7.	Fine sand	4·50	Sand and silt	1 7
6.	Varved clay, varves *ca.* 2 mm	3·25	Clay	0 6
5.	Fine silty sand	1·25	Silty sand	0 8
4.	Varved clay, varves *ca.* 1 mm	2·25	Clay	0 9
3.	Silty fine sand	0·25	Silty fine sand	0 11
2.	Varved clay	8·00	Clay	2 1
1.	Silty sand	0·25	Fine sand	2 0
		302·7 ft. O.D.		337·5 ft. O.D.
2*b*.	Varved clay	4 ft. 3·75 in.	Varved clay	5 ft. 0 in.

The comparison reveals a thickening of the beds towards the margins with the increase in thickness proportionately greater in the sands.

Beyond the neighbourhood of Nechells the varved clays can be traced at about the level of their elevation at Section D, 336 to 339 ft. O.D.; to the west to borehole Y. 1127

Description of plate 9

Figures 20, 21. *Sambucus* cf. *nigra*, pollen at two phases of focus (magn. × 1000).
Figure 22. *Ceratophyllum demersum*, marginal spine (magn. × 750).
Figure 23. *Stellaria neglecta*, seed (magn. × 20).
Figure 24. *Stellaria graminea*, seed (magn. × 20).
Figure 25. *Chrysosplenium alternifolium*, seed (magn. × 30).
Figure 26. *Aphanes microcarpa*, achene (magn. × 20).
Figure 27. *Geum* cf. *rivale*, half carpel and achene (magn. × 15).
Figure 28. *Euphorbia stricta*, seed (magn. × 20).
Figure 29. *Matricaria chamomilla*, achene (magn. × 20).
Figure 30. *Pimpinella saxifraga*, carpel (magn. × 15).
Figures 31, 32. *Eleocharis* cf. *carniolica*, fruit (magn. × 20).
Figures 33, 34. Cellulose peels of late-glacial varved clays, borehole 7, Nechells (magn. × 1). *a*, Slumped sediment; *b*, contemporaneous faulting; *c*, normal varves.

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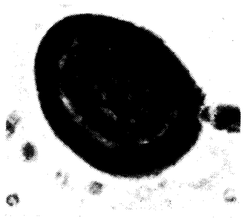

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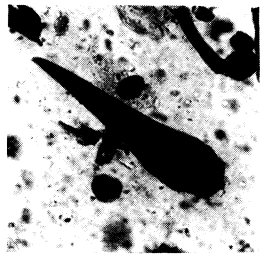

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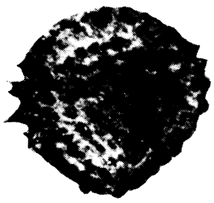

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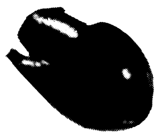

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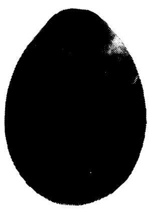

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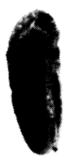

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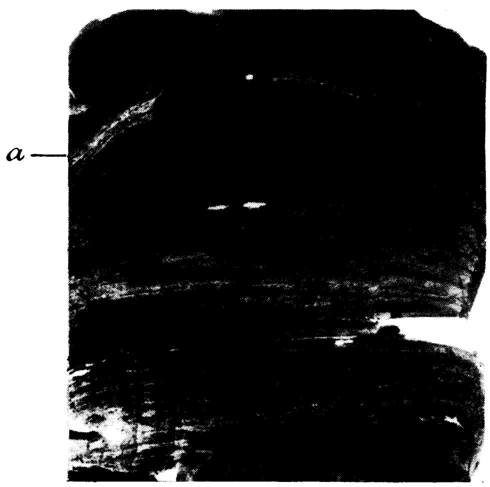

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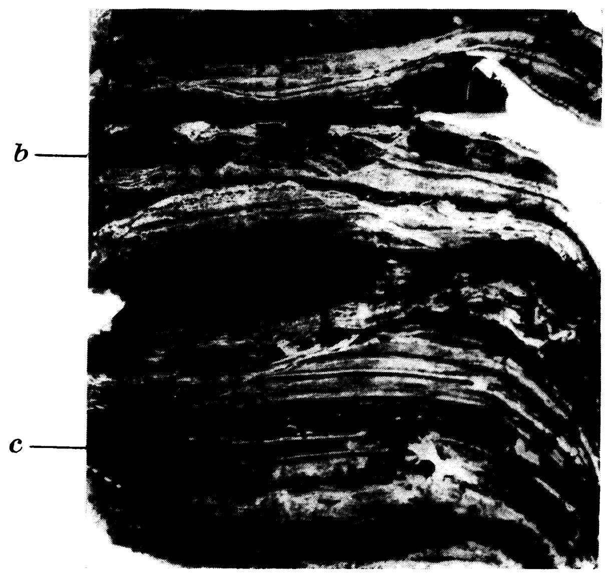

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and to the north-west to the exposures at Aston, and beyond to borehole R. 130 (figure 8). To the west-south-west they continue to rise to above 360 ft. O.D. at borehole 42; whilst a line of boreholes to R. 153/4 show them at an intermediate height of 351 to 354 ft. O.D. They may also occur farther west in R. 187, at this height, but its isolation makes it uncertain.

Recent boreholes have proved the existence of this series on the north side of the present River Tame (outside the area of figures 1 and 2) between boreholes D. 120 and M 6·83 (42/062925 and 42/057943), occupying a small northern tributary of the pre-glacial Tame.

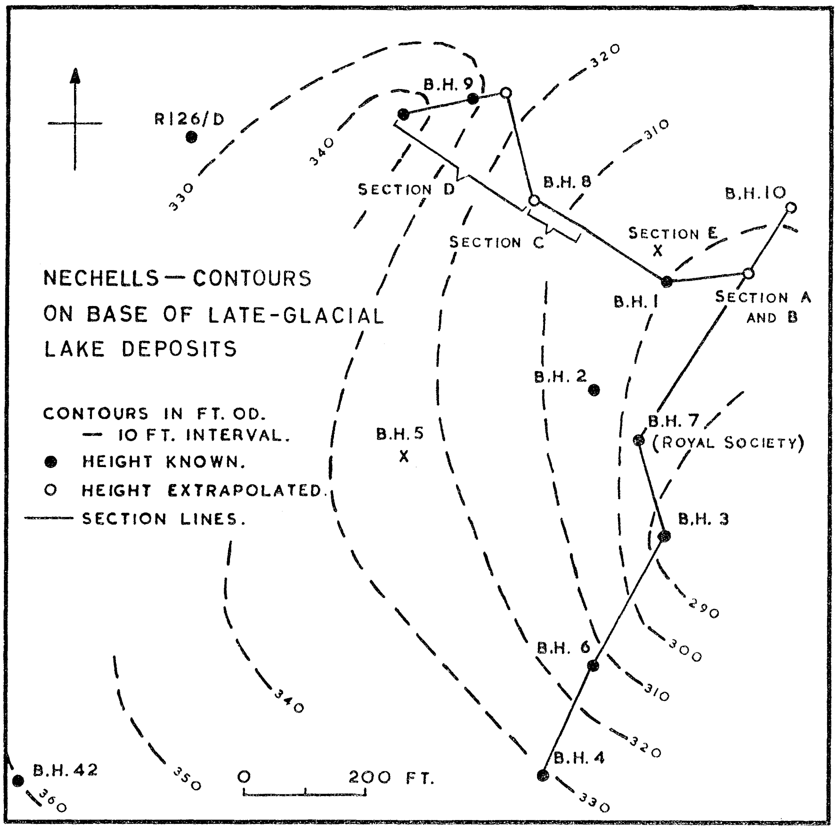


FIGURE 4. Contours on the base of the late-glacial lake clays at Nechells.

At a solitary locality to the east, at Washwood Heath (42/0794), 6 ft. of clays and silts above 354 ft. O.D. are possibly also deposits of this period.

This variation in height and its distribution shows that the lake clays were laid down on a valley-shaped surface of some relief, with a trend similar to that of the pre-glacial valley whose upper slopes would still be exposed at this time. There must, therefore, have been some erosion during or after the deposition of the earlier outwash sands.

At Nechells, however, the lake deposits occupy an isolated hollow (down to 294 ft. O.D.) which seemingly is too low to be part of a general pre-lake river system, since the valley surface immediately to the north-west was at about 330 ft. O.D. (figure 7). Recent erosion has cut across the hollow, but the contours on the base of the varved clay suggest a semi-circular plan for the remnant (figure 4). That it was a closed depression is indicated by the limnic character of the late-glacial and interglacial sediments and by the presence of abundant remains of limnophytes in the latter.

The most obvious origin for such a depression would have been as a kettle-hole, but without more adequate information this can only remain a tentative suggestion. As explained, buried ice could be accommodated in the sands of 1*c*, requiring ice to have been present in the area; for which there is also no independent evidence, though tills may well exist undescribed in the 'gravels' of 1*a*. However, if the still accepted, though tenuously based idea of Wills that the 'First Welsh' ice sheet had a maximum extent comparable to the 'Second Welsh' is true, then it is likely that it extended over Birmingham. To this chain of circumstantial evidence must be added the fact that ice was certainly close enough in the immediately succeeding period to impound the lake during the deposition of Series 2. The disposition of these lake deposits requires water to have been pounded up in the valley to 370 ft. O.D. at least, which would need a re-advance of the ice from the north or north-east to dam up the lower reaches of the valley.

The main lake was drained when this ice retreated but left a small lake in the depression at Nechells. There is no evidence of the time when this occurred, but it would need to have been during the period represented by the lake deposits in this depression, perhaps at the time of the sedimentation of the coarser upper beds of this Series.

(*e*) 3. *Interglacial Series*

This Series is very locally preserved and is known from only three sites.

(i) *Nechells*

The interglacial beds are most extensively developed here, though of limited lateral extent. The cores from the Royal Society borehole (7) provided the type section with the following simplified succession:

		depth in borehole ft.	in.
	Made ground	6	3·00
4.	Sand and gravel	19	6·00
3*g*/4.	Slightly humic silty clay	20	9·75
3.	Humic, silty fine sands with coarse organic debris, and clean medium sands	22	2·25
2.	Slightly humic silty clays, fine organic detritus	23	7·25
1.	Slight humic, silty fine-medium sands, with coarse organic detritus	24	2·50
f.	Humified wood detritus peat, argillaceous	25	3·00
e/5.	Humic clay, fine and coarse organic detritus	26	10·5
4.	Clean fine sand	27	3·50
3.	Humic clays/silts, fine organic detritus	29	5·00
2.	Humic fine-medium sand, fine organic detritus	30	2·25
1.	Humic silty clays, fine organic detritus	30	7·75
d.	Humified wood detritus peat, argillaceous	34	1·00
c.	Humic clays, fine-coarse organic detritus	44	3·50
b.	Humic silty clays, laminated, fine organic detritus	*ca.* 47	9·00
a.	Clayey silts, laminated, humic content decreasing downwards, fine organic detritus	51	4·75
		304·75 ft. O.D.	
2.	Varved clays		

The variation in organic content in these sediments is represented graphically in figure 5. The curve is actually drawn for the loss in weight on ignition of the samples, with a deduction for the carbonate content. This is considered a convenient method of expressing it (Hansen 1959), especially in relative terms, though it does not provide an accurate estimation of the organic carbon content even, apparently, using the standard conversion factors (Andersen 1961).

The interglacial beds are only arbitrarily separated from the varved clays below (Series 2) and the lowest beds provide a complete transition in lithology from these to normal lake-muds. The palaeobotanical upper boundary for the late-glacial (itself arbitrary) is actually placed within beds 3*a*, at 49 ft. 7·5 in.

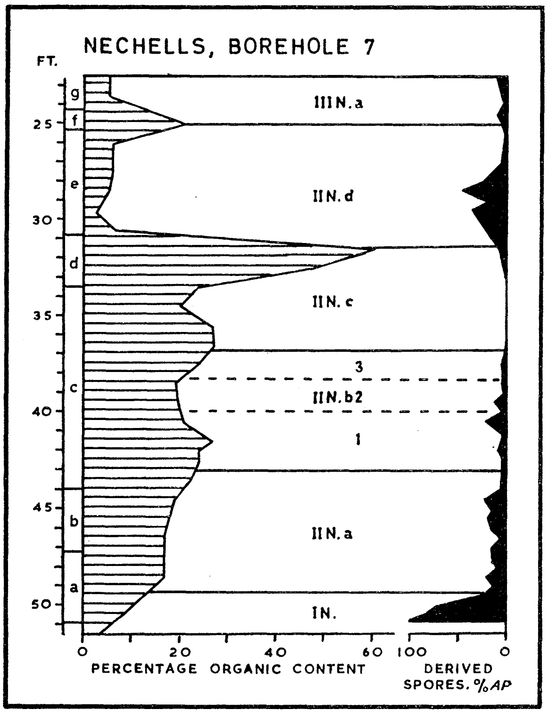


FIGURE 5. Variation in content of organic matter and derived microspores in borehole 7.

The beds of 3*a* are clayey silts in which the lamination due to grain size differences, which is typical of the varved clays, becomes less distinct as the thin clay laminae of < 1 mm, which are present at the bottom of the beds, become thinner and rarer upwards. This is replaced by a fine scale colour lamination: an alternation of dark brown and grey-buff silts, in laminae pairs of 0·5 to 1·0 mm. On exposure to the atmosphere the silts were rapidly oxidized, the colours becoming ochreous-brown and grey-buff, the post-depositional anaerobic decomposition of the organic content having produced a reducing environment in the sediment. The silts have a moderate carbonate content: 19·6% (by weight of air-dried sample) at 51 ft. 0 in. and 14·5% at 49 ft. 0 in.

The beds of 3*b* are similarly organic clayey silts (lake-muds) but have a more uniform appearance, the colour lamination becoming indistinct above the gradational boundary with 3*a*. The organic content increases towards the top whilst the carbonates decrease, from 10·6% at 47 ft. 0 in. to 5·1% at 45 ft. 0 in.

The beds of 3*c* have a fairly sharp junction with the beds below, having a higher clay and organic content than 3*b* and with no appreciable quantity of carbonates present. The organic component of the sediment shows a marked oscillation in the middle of these beds (38 ft. 6 in. to 39 ft. 6 in.) decreasing by 8% before returning to its earlier values. The upper 2 ft. of the beds are coarser and their organic content is again lower; mainly humic silty fine sands with fine to coarse organic detritus, the latter increasing upwards.

The peat of 3*d* consists of felted layers of partially humified comminuted wood fragments, chiefly 0·25 to 0·75 in. but including coarser fragments, of branches and logs, up to several feet long. A variable proportion of clay and silt forms a matrix to these, which increases in amount towards the top and bottom of the peat. It is apparently all of driftwood since no tree-stumps were seen *in situ* in the other sections.

The sediments of 3*e* are a group with a lower content of fine organic matter than the lake-muds, varying widely in lithology; chiefly fine sands with variable silt fraction, or silty clays. All contain macroscopic organic detritus.

The second wood detritus peat (3*f*) is similar to the lower but with a higher content of clay.

The beds of 3*g* are also a very variable group; they include humic silty clays but are chiefly of coarser grained sediments, humic silty fine sands and also 'clean' medium sands.

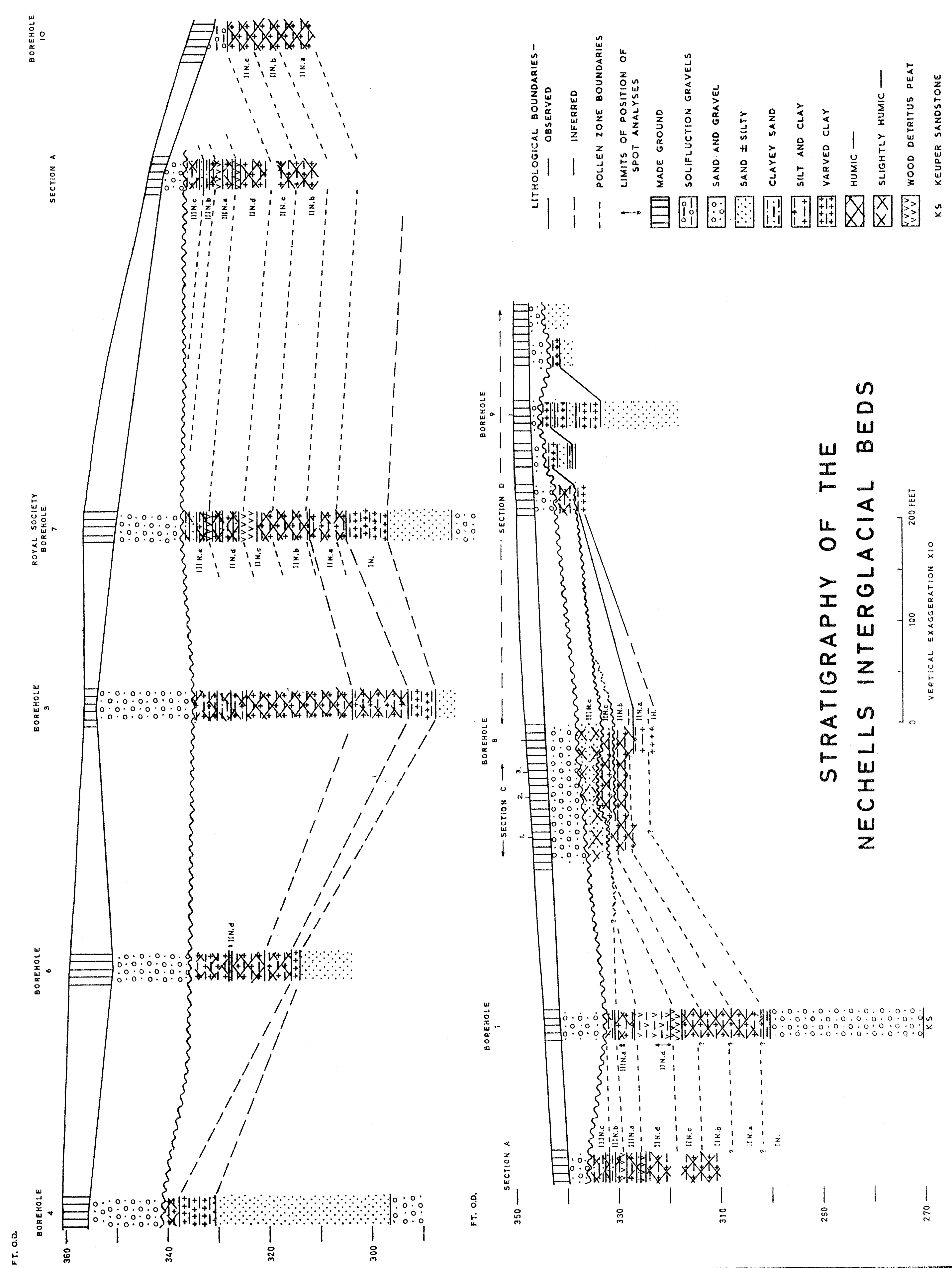
The sediments stratigraphically above the beds of 3*g*, which were not present at the site of borehole 7, are illustrated by the succession from Section A.

	depth in section ft.	in.
7. Sands and gravels and made ground	7	0
6. Laminated humic sands	12	0
5. Slightly humic clay	14	4
4. Humic silts to humified wood detritus peat	16	4
3. Humic silty clay	17	0
2. Clayey sand	18	0
1. Humic clay/silt	+23	0

The lithologies are similar to those of the upper beds of borehole 7. The pollen analyses show that, stratigraphically, the highest point reached in these in borehole 7 is level with the 14 ft. 3 in. depth in Section A. However, within the region of overlap they cannot be correlated lithologically, demonstrating the lateral impersistence of the units.

The form of the beds of the Interglacial Series at Nechells is shown by figure 6 for which pollen analysis has provided the data for correlation between the various boreholes and sections by establishing isochronous horizons, the zone boundaries.

They infill a hollow whose minimum proved extent is *ca.* 1100 × 620 ft. The lowest beds, 3*a*–*c*, with those of Series 2, represent a more or less normal succession of deposits within a closed basin, similar to that recorded from many Post-glacial sites. They are typically


STRATIGRAPHY OF THE NECHELLS INTERGLACIAL BEDS
LITHOLOGICAL BOUNDARIES – OBSERVED
INFERRED
POLLEN ZONE BOUNDARIES
LIMITS OF POSITION OF SPOT ANALYSES
MADE GROUND
SOLIFLUCTION GRAVELS
SAND AND GRAVEL
SAND ± SILTY
CLAYEY SAND
SILT AND CLAY
VARVED CLAY
HUMIC
SLIGHTLY HUMIC
WOOD DETRITUS PEAT
KS KEUPER SANDSTONE
0 100 200 FEET
VERTICAL EXAGGERATION X10
FT. O.D.
BOREHOLE 4
BOREHOLE 6
BOREHOLE 3
ROYAL SOCIETY BOREHOLE 7
SECTION A
BOREHOLE 10
BOREHOLE 1
BOREHOLE 8
BOREHOLE 9
SECTION C
SECTION D
360
340
320
300
350
330
310
290
270

lacustrine in character; uniformly fine grained without the rapid changes in lithology associated with fluviatile sediments. Their relatively high inorganic content, however, points to an active source of supply of mineral sediment by streams and/or slope wash.

The depth of the lake was apparently about 30 ft. when the varved clays were deposited (Zone IN.), with a water-level at *ca.* 340 ft. O.D., but became shallower as the sediments accumulated. Under the ameliorating climate and as the vegetation developed these changed from the varved clays of Series 2 through clayey silts (3*a*) to organic lake-mud (3*c*), the fairly abrupt change to the latter coinciding with the establishment of closed forest at the Zone IIN.*a*/IIN.*b* boundary. Continued sedimentation of this type was interrupted, however, by several changes in the environment of the lake.

The lake-muds cover both the floor and the sides of the basin but thin appreciably towards the margin, where their thickness is further reduced by the development of unconformities, detected by the pollen analyses (for details see p. 562). These increase in magnitude up-slope towards the edge and are probably both erosional and non-depositional, representing periods of lower water-levels in the lake.

The lower unconformity marks a drop in level which occurred in Zone IIN. *b*2. Within the deeper parts of the lake (at borehole 7) this is manifest as an increase in the inorganic content of the sediments, which may be due to the incorporation of reworked less organic marginal sediments.

In the following period there was a return to the deposition of lake-muds with a higher organic content, on the marginal areas as well, implying a restoration of the higher water-levels.

The date of the second unconformity is less closely determinable but probably correlates with the coarser, less organic facies at the top of 3*c* in the borehole. The water-level dropped then by about 10 ft. to end the history of the lake as a deep body of water, facilitating its rapid final infilling. However, it occurred at a time (middle IIN. *c*) when the pollen evidence suggests there had been an increase in precipitation. A possible explanation for this anomaly would be the destruction of an impounding barrier which had maintained the high water-level of the lake; perhaps by an increase in the outflow from the lake because of the greater precipitation.

The later sediments are more characteristic of shallow water environments and fluviatile deposition. Some open water did persist, as the botanical evidence suggests, within alluvial marshes and fen woods, in which the finer sediments and thick homogeneous argillaceous wood peats were accumulated. Other wood detritus peats exist as coarsely current-bedded layers of wood and sand (in Section B, personal communication, Professor F. W. Shotton) and are suggestive of deposition during periods of flood.

The highest beds present (Sections A, C and E) are medium sands, finely laminated in layers of varying humic content (black and grey) with fine to coarse organic detritus, especially of wood; a lithology which is comparable to that seen in modern alluvial deposits. These finally infilled the central part of the depression and overlapped on to the marginal parts.

(ii) *Cardigan Street, Duddeston*

Organic deposits belonging to the Interglacial period were also found at an isolated locality three-quarters of a mile to the south-west of Nechells, by a site-investigation borehole (R. 212/3 (42/07948725)). The succession was:

		thickness ft.	in.
	Made ground	4	6
Series 4.	Silty sands with gravel	13	9
3.	Highly humified peaty clay	3	3
1.	Find sand	1	3
		351 ft. O.D.	
	Keuper sandstone		

The organic beds were absent from a second borehole 100 yd. to the south where the sandstone surface is 5 ft. higher.

The samples from the core were too fragmentary for detailed investigation. They were mainly of well humified wood detritus peat with a varying argillaceous content, passing sharply at the top into black humic clay (1·5 in. thick) with thin sand laminae, above which were finely laminated silty sands. The humic clay is probably a weathered zone similar to that present at Nechells.

Pollen analysis showed that the peat is broadly equivalent to the highest beds at Nechells.

(iii) *Washwood Heath*

In 1879 a 'black band in the Drift' was recorded from an exposure in a new railway cutting (*c.* 42/103882) (Atkin 1879). Six inches thick, it lay on a thin clay lamina on sands and gravels at *ca.* 354 ft. O.D., and was underneath 12 ft. of sands. Its lithology was described as 'apparently resembles peat for it dries brown and contains sufficient vegetable matter to make it burn on the fire', and additional information indicates that it was well humified.

From its position it is suggested that this also belongs to the Interglacial in a manner similar to that of the Cardigan Street peat, with which it also seems to be lithologically similar.

(*f*) 4. *Upper Glacial Series*

These are everywhere unconformable on the older deposits. The unconformity is an irregular surface of erosion developed in an eastwardly draining valley system which existed in the upper levels of the pre-glacial valleys. By then these had become infilled with up to 100 ft. of sediments and the original valley sides were mantled with drift. A section across the valley in the vicinity of Nechells (figure 7) shows that the valley floor was at 340 to 350 ft. O.D., the lower elevation over the interglacial beds probably being due to their compaction. The erosion of this surface in part post-dates the youngest interglacial beds but these conditions are probably representative of the topography throughout the Interglacial, after the draining of the glacial lake.

At Nechells the unconformity is marked by a band of ochreous sandy clay which grades into the underlying interglacial beds, separating them from the gravels above. This is a zone of weathering belonging to the period of the erosion.

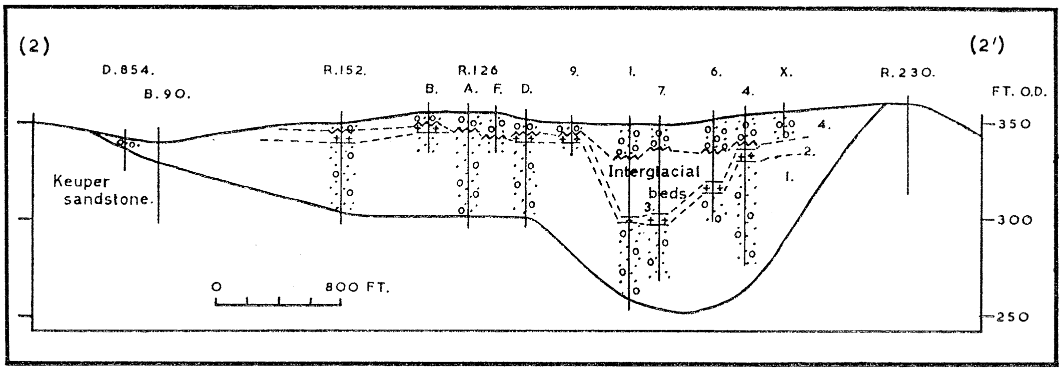


FIGURE 7. Stratigraphical profile across the axis of the main valley system which existed during the pre-late-glacial and Interglacial periods (for line of section see figure 1).

The deposits of Series 4 are widespread and it has been possible to establish a general succession for them from temporary exposures and borehole records. This is given below with their approximate thicknesses at localities where they are typically developed, though they may depart from this elsewhere (see figure 8).

		thickness ft.
4*h*.	Edgbaston till	+45 (D. 258)
g.	Sands and gravels	45 (R. 174)
f.	Brookfields till	17 (Y. 1109/7)
e.	Laminated sands and silts, clays, some gravel	10 (Y. 1109/4)
d.	Snow Hill till	10 (Y. 1109/4)
c.	Sands and gravels	20 (Snow Hill)
b.	Aston till	15 (Aston)
a.	Gravels	*ca*. 45 (D. 286)

Unconformity
Series 3, 2 or 1.

The distribution of the members of the succession is demonstrated by four sections across Birmingham (figure 8), as far as is allowed by the present state of knowledge about them. They are based on the correlation of known successions at the points indicated and are only intended as a generalized representation of a much more complex situation, a complexity which will involve a greater lithological facies variation and more complicated relationships between members. The tills, however, have been found to be fairly constant and they provide the marker horizons which are the basis of the correlations.

The lowest beds of the Series in the area are gravels, which at Nechells rest unconformably on the interglacial and earlier glacial deposits. Here they are up to 18 ft. thick, of fine to coarse, often densely packed gravel, chiefly of reworked pebbles, up to 9 in.,

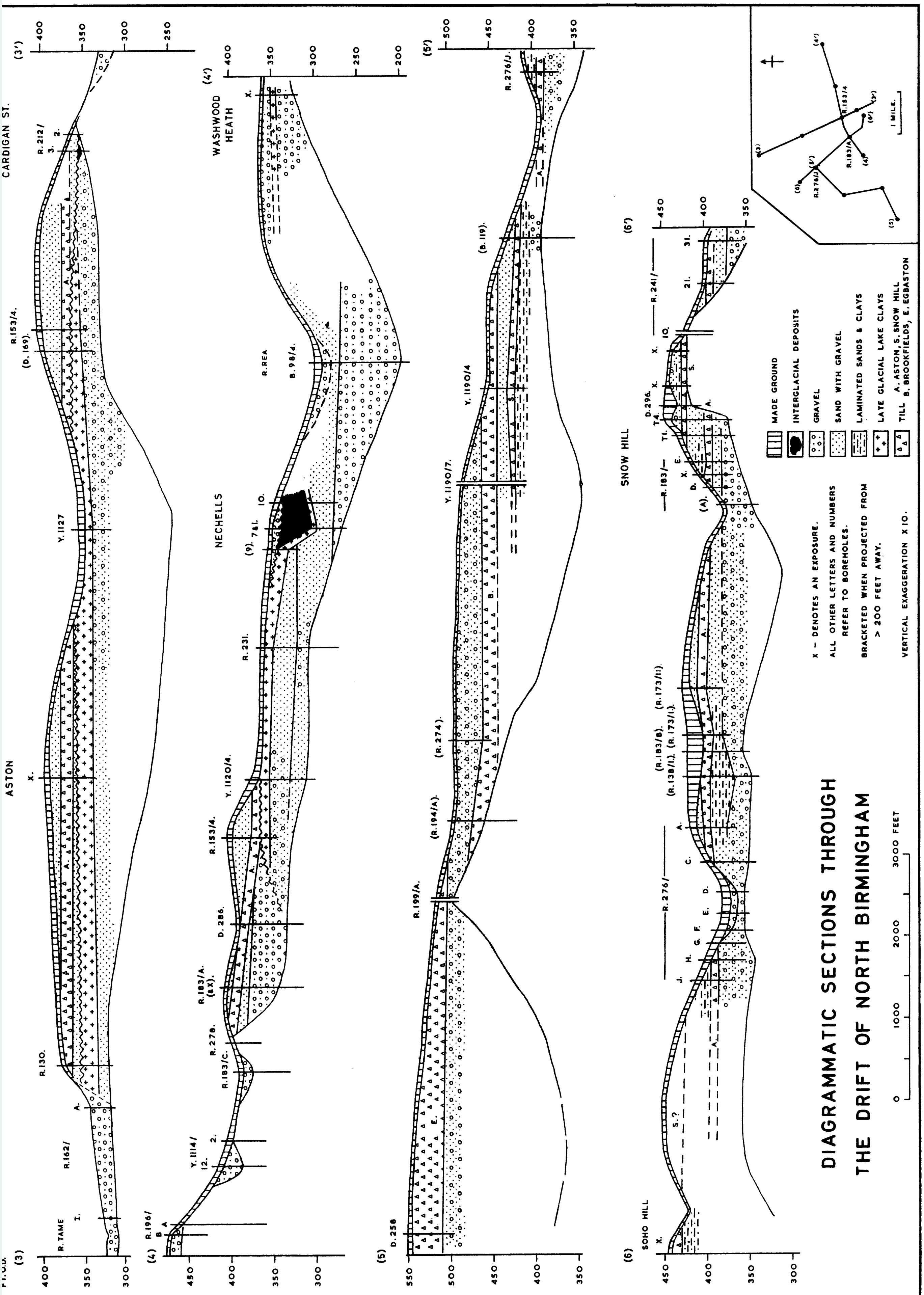


FIGURE 8. Diagrammatic sections through the Drift of north Birmingham.

from the Triassic Bunter Pebble Beds; in a medium to coarse sand matrix, occasionally somewhat clayey. They are impersistently bedded but the elongate pebbles show a distinct preferred orientation of their axes (figure 9), indicating derivation from up-valley.

The fabric diagram constructed at Section E (Nechells) has its major peak at 345°–165° with an associated subsidiary peak at 080°–260°, the peaks of 'sliding' and 'rolling' movement respectively. A second distinct minor peak 045°–225° is perpendicular to the present slope of the ground surface, suggesting that the gravels have been disturbed by creep, with an accompanying 'rolling' movement.

The gravels are much thicker (45 ft.) at borehole D. 286 farther to the west, where they infill a channel eroded through the varved clays of Series 2, extending down to 335 ft. O.D. where a basal boulder bed rests on Keuper sandstone. Since their base is close to the

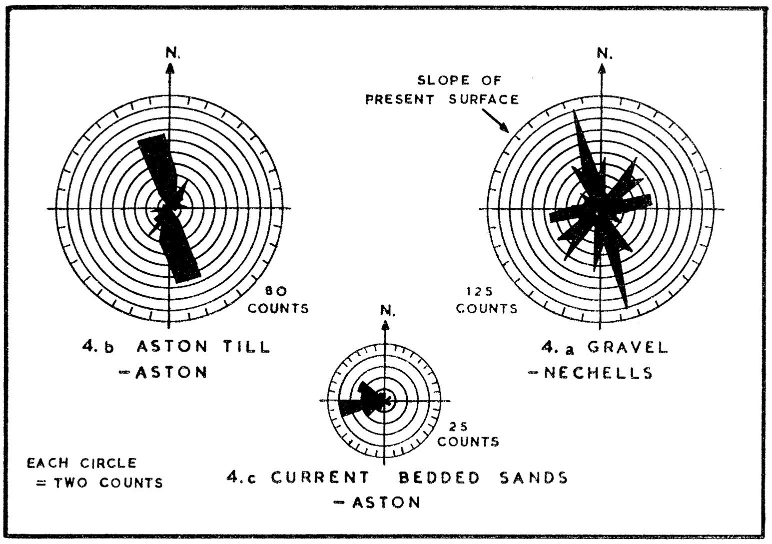


FIGURE 9. Fabric diagrams from the Upper Glacial Series.

postulated limiting height of the valley surface they may be composite in character, and include older gravels of Series 1. Similarly, the thick gravels (70 ft.) to the west of Snow Hill (42/069874) are probably not wholly formed of Series 4 deposits. This situation might well exist in the 'basal gravels' over much of the area.

The lower part of the gravels at Nechells are deformed by cryoturbation which has extended into the interglacial beds below. They show the typical convolutions with vertical and overturned boundaries, which develop to the extreme case where discrete 'bags' of gravel and sand are enclosed in the interglacial beds.

This evidence, and their coarse lithology, indicates that the gravels were deposited during the cold climatic condition associated with the advancing ice sheets, and in part will be the fluvioglacial outwash of these.

The coarse gravels are generally separated from the overlying till by finer grained sediments. In the south these thicken westwards from 5 ft. at D. 286 to 10 ft. at Snow Hill (p. 552). They are a mixed facies: coarse current-bedded clean sands at Snow Hill whilst elsewhere they are laminated silty sands and include clays at R. 173/3. It would seem that the advancing ice was locally ponding up water in which the laminated sediments were laid down whilst elsewhere currents brought in coarser material. At Snow Hill the current bedding gives a current direction from 255° N.; the sands deposited by the stream flowing down the small valley which lies in this direction (see figure 1).

4*b*. *Aston till.*

The sands and gravels of 4*a* in borehole D. 286 are succeeded, above 366 ft. O.D. by a till which is traceable to temporary exposures and boreholes at Aston (42/070894). These sections were critical since they demonstrated that undoubted till lay on lake clays correlated with those of Series 2, i.e. belonging to the previous glaciation. The latter lie at the appropriate elevations of this group and their occurrence can be followed, via intermediate boreholes, to the Nechells localities, but at Aston they are not succeeded by the interglacial beds. The tills above therefore have to be post-Interglacial and an unconformity must separate them from the lake clays. The demonstration of this enabled the occurrence of similarly juxtaposed lithologies, at this level in other boreholes, to be interpreted.

The exposures at Aston revealed that the tills can be complex in character. The succession was:

		thickness ft.	thickness in.
4*c*.	Buff fine sand, with occasional pebbles, current-bedded	13	9
4*b*/5.	Till; abundant small pebbles (to 0·5 in.) in matrix of red, plastic clayey fine sand	1	9
4.	Laminated silts and clays	0	3
3.	White coarse sand, coarsely cross-laminated, with coal and shale pellets	2	3
2.	Till; large pebbles (to 3 in.) in matrix of very clayey medium sand	1	9
1.	Till; stiff red, irregularly sandy clay to clayey sand, unevenly pebbly	*ca.* 9	0
		360·5 ft O.D.	
2.	Laminated silty clays and clays	12	0

Beds 1, 2 and 5 are typical tills, unsorted and with a high proportion of local erratic material, in addition to the ubiquitous Bunter pebbles. The high sand content of the tills is to be expected, derived from the extensive Trias bedrock outcrops, and the local suite of erratics includes Bunter and Keuper sandstones; Carboniferous siltstones, shales, marls, dolerites and coal. A fabric diagram for the lower till shows a strong orientation from a little west of north to east of south, indicating in this case deposition by ice moving in a southerly direction (figure 9).

The white sand of 4*b*/3 is dominantly a coarse quartzose sand with a particle size up to 1·5 mm, the larger grains, especially, being sharply angular. Coal sand, coal pebbles and shale flakes are concentrated towards the top of the cross-bedding units; a 'grading' due to differential rates of settling. The lithology suggests a rapid deposition of sorted glacially derived material. At least the top unit was exposed subaerially as its surface bears minute sun-cracks, preserved as casts in the overlying silt lamina. The thin clay and silt unit (4*b*/4) contains about 14 varves which become increasingly coarse in grain size upwards, and grade into the upper till.

The exposure records the deposition of till by ice moving from the north, which subsequently retreated to allow the deposition of outwash sands and then re-advanced, locally ponding up shallow water which it overrode to deposit a thin till before finally retreating. These events repeat, during a short period, a sequence that happened several times on a larger scale during the deposition of the Upper Glacial Series as a whole.

The tills can be traced at this horizon to the north to borehole R. 130 and beyond, north of the present River Tame, to borehole, M 6·83. To the south of Aston they are found in borehole R. 153/4. At all of these localities the general succession is similar to that at Aston (figure 8).

Farther to the south the tills rise with the slope of the ground, to reach 395 ft. O.D. at Snow Hill. Here the succession was:

		thickness ft.	in.
	Made ground	5	6
4*c*.	Laminated fine silty sands	5	0
4*b*/3.	Till; pebbly red clay	1	0
2.	Buff current bedded sand	2	10
1.	Till; pebbly red sandy clay	2	3
		395 ft. O.D.	
4*a*/2.	Current-bedded coarse sands	10	6
1.	Gravels	17	0

The tills are thinner than at Aston but are lithologically very similar and still have the same twofold character.

From here they are traceable westwards in boreholes to R. 276/J. Nearby, at Icknield Street (42/05888?), Crosskey (1882) described a temporary exposure which showed the till resting on Keuper sandstone. This bedrock had been disturbed by ice movement, with the dislodgment of large blocks of the sandstone which were incorporated in the adjacent till. Beyond here there is no record yet of the occurrence of this till.

4*c*.

At Aston the tills are overlain by buff fine sands, current-bedded on a fine scale. A count of 25 readings of the dip of the foresets from different units indicates a depositional current direction from the west (figure 9), i.e. along the line of the main valley.

At Snow Hill horizontally laminated silty fine sands rest on the till and laminated fine sands and clays are common at this level. The thick plastic clays described by Martin (1887) from the railway cutting at Soho Hill (42/051895) are probably also to be correlated with these deposits. The succession there, however, was complicated by the contortion of the beds by the succeeding ice readvance. The widespread occurrence of these lacustrine deposits (see Pickering 1957) suggests that there was an extensive lake, or lakes, in the area, sometime between the deposition of the two tills.

4*d*. *Snow Hill till*

A second till was seen in exposures over the shallowly buried ridge of Keuper sandstone beneath the centre of the city, and records from boreholes at the side of the ridge suggest that it overlies the silty sands of 4*c* and the lower till of 4*b*.

It appears that the ice, on overriding the exposed crest of the ridge, strongly eroded the outcropping sandstone. In an interesting exposure at Bull Street (42/07188705), the succession was:

		thickness ft.	in.
	Made ground	5	0
4*e*.	Sand	4	6
4*d*/3.	Till, red sandy clay with erratic pebbles, grading down into:	0	9
2.	'Till', red clayey fine sand with many unbedded pebbles	2	9
1.	Loose, micaceous red fine sand with angular fragments of sandstone	1	8
		ca. 420 ft. O.D.	
	Keuper sandstone, red, micaceous, fine grained		

Bed 2 is dominantly red micaceous fine sand, compact and with a small clay content. It contains pebbles of shales, sandstones, coal and Bunter pebbles as does the typical till above, into which it rapidly grades, and seemingly represents the lower part of the till heavily charged with sand from the bedrock. Between the till and the Keuper sandstone is a 'crush zone' of a breccia of angular sandstone fragments in a matrix of fine sand derived from the sandstone, which in patches has a very loose texture.

The succession is more complicated in a nearby exposure at Dr Johnson's Passage (42/07148720), where there are two tills separated by 4 ft. of coarse sands and sandstone-detritus grit, the lower till resting directly on the Keuper surface.

1·5 miles to the west, at boreholes Y. 1190 and B. 119, thin tills, 5 to 10 ft. thick, are recorded from horizons close to this level. They are also above lake deposits and seemingly are above the till (4*b*) which lies 40 ft. lower in boreholes farther east (R. 276), thus repeating the sequence of deposits at Snow Hill. On this evidence they are correlated with the Snow Hill till.

The separate identity of this till and its relationships with the other members are the least well substantiated of the four recognized tills.

4*e*.

The succession above the Snow Hill till at Dr Johnson's Passage was:

		thickness ft.	in.
	Made ground	4	6
4*e*/3.	Medium sand with pebbles	2	0
2.	Coarse gravel	2	0
1.	Finely horizontally laminated fine to medium sand, varying in coal and silt content	11	0
		ca. 424 ft. O.D.	
4*d*.	Till		

The lower sands are strikingly laminated in units of 1 to 3 in., contrasted by their colour differences: buff, red and black. They appear to be deposits of ponded water which were later covered by fluviatile gravels.

Within this exposure there was structural evidence of the local subsidence of the sediments suggestive of the melting of buried ice. At that point the upper part of the laminated sands dipped steeply inwards from the three visible sides, changing abruptly from the horizontal. This was associated with a normal fault and minor folds, which had increased the vertical movement of the beds. The hollow so formed is infilled with dense coarse gravels, up to 10 ft. thick, compared with their thickness of 2 ft. above the undisturbed sands. The ice would have been buried within the lower laminated sands and apparently melted during the deposition of the gravels.

In the boreholes to the west (Y. 1109 etc.) up to 21 ft. of silty fine sands with some fine gravel are present at this horizon.

4*f*. *Brookfields till*

Thick tills are found above sands of 4*e* in several boreholes but have not yet been found exposed. In Y. 1109/7 (42/04668773) the succession was:

		thickness ft.	in.
	Made ground	4	0
4*g*.	Sand and gravel	20	0
4*f*/3.	Till	8	0
2.	Sand, 'clean'	5	0
1.	Till	4	0
4*e*.	Silty fine sands	21	0
		425 ft. O.D.	

These tills can be traced farther west to where they rise up against the ridge on the east side of the proto-Rea valley (figure 8), but are not yet known from other parts of central Birmingham.

4*g*.

Borehole records show about 30 ft. of sands and gravels at this level, generally of coarse fluvioglacial sediments.

4*h*. *Edgbaston till*

A thick till caps the highest ground in the west of the area, more than 40 ft. thick in the south (D. 258) and more than 27 ft. in the north (R. 237).

Correlation with south Birmingham

The succession of the upper Older Drift as elaborated is of necessity provisional, limited by the scarcity of the exposures, and it is expected that it will receive some modification as new exposures are described. However, it does gain support from the close correlation which can be made between it and the succession given for south Birmingham by Pickering (1955, 1957). This is essentially a description of the deposits in the proto-Rea valley and though Pickering did include some observations on sections farther to the north the central Birmingham succession is based entirely on new information. Figure 10 illustrates the essence of the stratigraphy of the two areas, and their correlation.

However, the comparison of the two successions emphasizes the diachronous nature of the facies. In theory, lake deposits would be formed in front of the ice at successively higher elevations to the south where the advance, from the north, was against the slope of the ground. The resultant till would also be laid down at successively greater heights. On its retreat, the converse would occur and fluviatile deposits would spread down the valleys as the lake levels fell, to become universal if the retreat was a major one. In this complex situation the clearest correlation is provided by the tills. Of these, three of the four which were the datum horizons in the central Birmingham succession can be traced southwards, towards S. Birmingham, whilst the fourth is probably represented there only

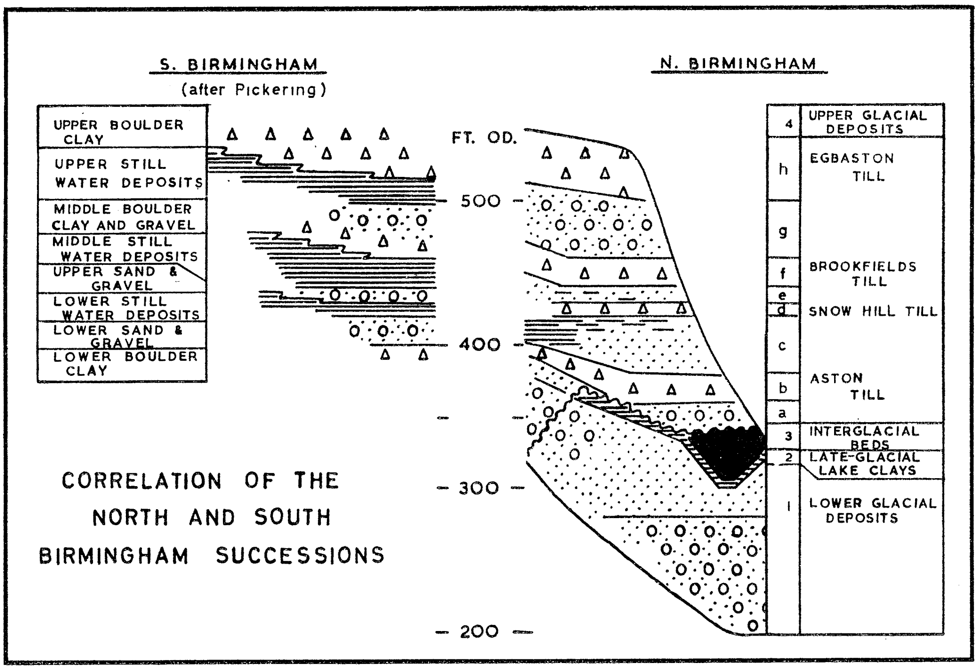


FIGURE 10. Correlation of the north and south Birmingham successions.

by lake deposits related to the period of ice advance. Lake deposits are also associated with the deposition of the other three tills since they mark the arrival of the ice at the mouth of the proto-Rea, damming up a lake in this valley. A result of this is a similarity in height of the base of the lake deposits in the one valley and the base of the tills in the other.

Pickering considered that his lowest till, at about 400 ft. O.D., belonged to an earlier glaciation, but it seems likely that it is part of the tills deposited by the first ice advance of the Second Glaciation, i.e. Aston till, which reaches this elevation on the southern slopes of the proto-Tame.

The third and fourth tills equate with Pickering's 'Middle Boulder Clay' and 'Upper Boulder Clay' respectively, but the second, if in reality an independent advance, would be correlated with the lake deposits at the same level: 'The Lower Still Water Deposits'. These, however, must probably also be in part the correlatives of the larger post-Aston till lake in the main valley. If it is a separate advance the margin of the glacier was within the lower part of the proto-Rea valley, somewhere within the 1·6 miles between the boreholes Y. 1109/7 and R. 172/G which passed through till and lake clays respectively. The Middle and Upper Still Water deposits date to the early stages of the last two advances.

The history of the Upper Glacial deposits

A period of erosion separates the interglacial beds from the earliest deposits, which were probably outwash associated with the advance of the ice sheets from the north-west towards the area. This ice of the 'Second Welsh Glaciation' of Wills (1937) in this region was probably of mixed Welsh, Lake District and Scottish origin since exotic erratics from all these have been recorded from unspecified horizons in the Upper Glacial deposits (Wills 1937). The first are by far the commonest though they themselves are rare amongst the local erratics. During the early period of the glaciation it seems that the local topography greatly influenced the flow of the ice and that the advances of its early phases were as valley glaciers, tongues of the ice sheet which lay to the north-west.

At the first advance the valley glacier moving from the north, approximately down-valley at Aston, deposited the Aston till up to 400 ft. O.D. On its retreat lakes were created where the movement of the ice was away from the southern valley slopes and tributaries, but normal drainage may have been reinstated before an extensive lake was formed in the upper 'proto-Tame' and 'proto-Rea' valleys (Pickering's lake at 431 ft. O.D. and beds of 4*c*). This required ice to dam up the lower proto-Tame valley at some point, which suggests it was ice of north-eastern rather than north-western origin. Re-advancing, the valley glaciers overrode the lower spurs of the high ground to the south, depositing the Snow Hill till up to 430 ft. O.D., but did not extend as far to the south as the first advance. At its maximum position the margin lay in the lower proto-Rea valley, its advance to there having raised the level of a lake in that valley to 440 ft. O.D.

The ice again retreated to an unknown but probably minor extent and local lakes were again formed. The next re-advance laid down the Brookfields till up to 470 ft. O.D. in central Birmingham and again dammed up a lake in the proto-Rea valley (Pickering's lake at 470 ft. O.D.). It continued its advance up this, overriding the lake deposits and raising the level of the lake in front of it to at least 480 ft. O.D. A fabric diagram in Pickering (1955) shows that the ice was moving directly down the valley, from due north. Later the ice retreated, probably to a greater extent than previously, with the consequent restoration of normal drainage and fluviatile deposition. This was ended by the last recorded advance, when an ice sheet deposited a thick till over the highest ground in the area. It also initially dammed up a lake in the proto-Rea which it gradually overrode, its level raised by the advance to a minimum of 545 ft. O.D. in a lake restricted to the southern end of the valley.

3. Palaeobotany of the Interglacial Series

(*a*) *Introduction*

Six sections or boreholes were sampled for macrofossils and pollen analysis, for both botanical and stratigraphical information.

The major part of the investigation was on material obtained from the Royal Society borehole (borehole 7). A percussion drilling rig was used to drive a core barrel, specially designed by Professor Shotton, through the deposit, producing cores of 6 in. diameter in units up to 3 ft. long, over a total length of 55 ft. The amount lost between the cores was considered to be negligible, since it was usually less than the basic pollen sample interval of 1·5 in. The pollen samples were taken from the centre of the cores on the site and the remainder split into convenient lengths and preserved for later examination.

As the succession in borehole 7 did not include the highest beds found in the original excavations of 1951, the samples which had been taken from here for Dr Duigan's analyses were borrowed and the samples covering the upper beds were reprepared and analyzed in greater detail than in the previously published diagram (Duigan 1956) (for the loan of these samples I am indebted to Dr Duigan and Professor Godwin of Cambridge). Three sections (Section C. 1–3) and two auger holes (boreholes 8 and 10) were sampled in less detail for stratigraphical information.

Samples were also taken from the incomplete remnants of a core from a civil engineering borehole (R. 212/3) at Cardigan Street, Duddeston.

(b) *Pollen analyses*

(i) *Preparation*

The samples were prepared by the following method:

(1) Treating with dilute hydrochloric acid if calcareous.

(2) Boiling with 10% potassium hydroxide for 10 min.

(3) Separation of the organic fraction using bromoform–acetone mixture of density *ca.* 2·25 g/cm^3 (after Frey 1955).

(4) Acetolysis, using 10 ml. of glacial acetic acid and 1 ml. conc. sulphuric acid and boiling for 20 min.

(5) Staining with safranin and mounting in glycerine jelly.

Treatment with hydrofluoric acid was tried on samples with low pollen frequencies but did not improve the results.

(ii) *Pollen diagrams*

The diagrams are based on a minimum count of 250 tree pollen (*AP*) and the individual pollen-curves are expressed as a percentage of this total (i.e. % *AP*). The pollen of the woody shrubs *Corylus*, *Hedera*, *Ilex*, *Salix*, *Sambucus*, *Juniperus* and *Hippophaë* are excluded from the *AP* total, but with the exception of *Corylus* are included with the pollen of herbaceous plants in the non-arboreal pollen total (*NAP*). *Corylus*, aquatic plants and Pteridophytes are excluded from the totals since they may all be over-represented in pollen diagrams. Where tree pollen is dominated by pollen of shrubs and herbaceous plants (i.e. $AP < NAP$) all the curves are expressed as a percentage of the total pollen ($AP + NAP$).

Duigan (1956), in the earlier work on Nechells, had considered that *Alnus* had been favoured ecologically and was over-represented in the pollen diagrams. To overcome this she drew a diagram in which *Alnus* was excluded from the *AP* total. This method of presentation has been supported by Janssen (1959) who demonstrated the influence of a local *Alnetum* on tree pollen percentages, concluding that *Alnus* should be excluded from the diagram, especially if its values fluctuated widely. The present diagrams, however, are constructed normally, as the predominance of *Alnus* is much reduced by the newly discovered *Taxus* curve.

(iii) *Zonation*

The fluctuations of the pollen curves are considered to express real changes in the composition of the vegetation due to seral and climatic development, so that the zones, though arbitrarily based on the fluctuations, describe the succession of the vegetation associations.

West (1961 *a*) proposed that within any interglacial this development of the vegetation was in four stages: Late glacial, Early temperate, Late temperate and Early glacial.

These stages were used as the basis of the zonation of the interglacial deposit at Hoxne (West 1956), with subdivisions based on features which had possibly only a local significance. The Nechells interglacial beds are the same age as those at Hoxne, and Duigan has demonstrated the overall similarity of the two, for the section then examined. The high degree of similarity allowed Duigan to use the same zonation but with modifications of it where the Nechells succession was the more complete.

The present more detailed work confirms this similarity and since it seems desirable to emphasize this, a similar scheme of zonation is used. However, regional differences do exist between Hoxne and Nechells such that the zones are often defined on different criteria, though remaining broadly correlatives. This has been implied in the addition of the suffix 'N' to the code numbers of the stages.

(iv) *Nechells, borehole* 7 *and Section A* (*figures* 11*, 12)

This is the standard diagram for the interglacial beds at Nechells. It is composite, compiled from diagrams from borehole 7 and Section A in order to obtain the fullest succession. There is, however, no significant break in the diagram since the two are essentially similar in detail where they overlap and are tied at the point of the expansion of *Picea*. In addition, the diagram from Duigan (1956, p. 376) which was prepared from a fuller sequence of Section A, shows its close similarity in its lower part to that of borehole 7.

Zone IN. 1–3 (49 ft. 7·5 in. to 59 ft. 5 in., borehole 7). The base of the diagram is where pollen first appears in countable quantity. Vegetation undoubtedly existed prior to this, since macrofossils were obtained from lower levels, but the small quantities of pollen which would be present are completely masked in the slides by the very high proportion of organic coal minerals and Carboniferous microspores present, and pollen was only encountered in isolated instances.

The zone is characterized by the dominant position of the curves for low shrubs and herbs. It is subdivided into three on the following criteria:

(1) (52 ft. 0 in. to 59 ft. 5 in.), covering the period of the earliest vegetation; its upper limit is defined by the initial rise of the *Betula* fruit curve (figure 18).

(2) (50 ft. 7·5 in. to 52 ft. 0 in.), though commencing below the base of the pollen diagram it mainly comprises the lower part of this. *Hippophaë* is dominant with moderate values for herbs and *Betula* is present.

(3) (49 ft. 7·5 in. to 50 ft. 7·5 in.), its base is drawn at the sharp decline of *Hippophaë*, where *Juniperus*, *Salix*, *Betula*, Gramineae, Cyperaceae and herbs increase.

The Hoxne subdivisions of Zone I are not recognizable and the short expansion of *Betula* in the middle of the zone there is absent.

Zone IIN. a (44 ft. 0 in. to 49 ft. 7·5 in., borehole 7). The division is placed, arbitrarily, at the point where *AP* exceeds *NAP* for the first time. The zone is characterized by high *Betula* values, with *Pinus*, *Juniperus* and *Salix* maxima and high *NAP* values, especially of Gramineae. This is equivalent to II*a* at Hoxne.

* Since the preparation of figure 11, *Populus* pollen has been found in low frequencies ($\angle 2\%$ *AP*) in Zones IIN. *a*, IIN. *b* and IIIN. *a*, *b* and *c*.

Zone IIN. b (37 ft. 3 in. to 44 ft. 0 in., borehole 7). The base is drawn at the rise of *Quercus* and the fall of *Betula*; also *Fraxinus* and *Pinus* are important. The *NAP* is still high and dominated by Graminae. It is subdivided into the following sub-zones:

(1) (40 ft. 3 in. to 44 ft. 0 in.), when *Quercus* with *Fraxinus* is high and *Betula* and *NAP* relatively low.

(2) (38 ft. 9 in. to 40 ft. 3 in.), when *Betula* and *Salix* increase and *Juniperus* reappears; also *Quercus* and *Fraxinus* decrease and *Ulmus* is absent; *NAP* increases greatly, especially the Graminae.

(3) (37 ft. 3 in. to 38 ft. 9 in.), when *Quercus* increases and *Betula* and *NAP* decrease; also *Alnus* increases and *Taxus* appears.

This zone is the equivalent of II*b* at Hoxne, with similarly defined boundaries. The sub-zones are also recognizable at Hoxne where the antipathetic oscillation of the *Betula* and *Quercus* curves and the associated oscillation of Graminae, which are the basis of the subdivision, can be clearly seen in the diagrams.

Duigan (1956, figures 3 and 4), however, places the II*b*/II*c* boundary at Nechells within this oscillation; which, since it is intended to be equivalent to Hoxne, is too low. Zone II*b* of Duigan should include all the oscillation, with the end of the zone at *ca*. 840 cm in her diagram.

Zone IIN. c (31 ft. 6 in. to 37 ft. 3 in., borehole 7). This begins at the rapid rise of the *Alnus* curve and the associated fall of *Quercus*. The zone is characterized by the importance of *Alnus* and *Taxus* with *Quercus*, and the presence of the shrubs *Corylus*, *Hedera* and *Ilex*. *NAP* is lower. It has two sub-zones:

(1) (35 ft. 0 in. to 37 ft. 3 in.), when *Alnus* and *Quercus* with *Betula* are dominant.

(2) (31 ft. 6 in. to 35 ft. 0 in.), when *Alnus* and *Taxus* are dominant; also *Corylus* increases and *Tilia* is present at the top.

This zone is approximately equivalent to II *c* at Hoxne but is without the development of the *Tilia* curve which is seen there. The sub-zones are only of local value since *Taxus* appears later at Hoxne (West 1962).

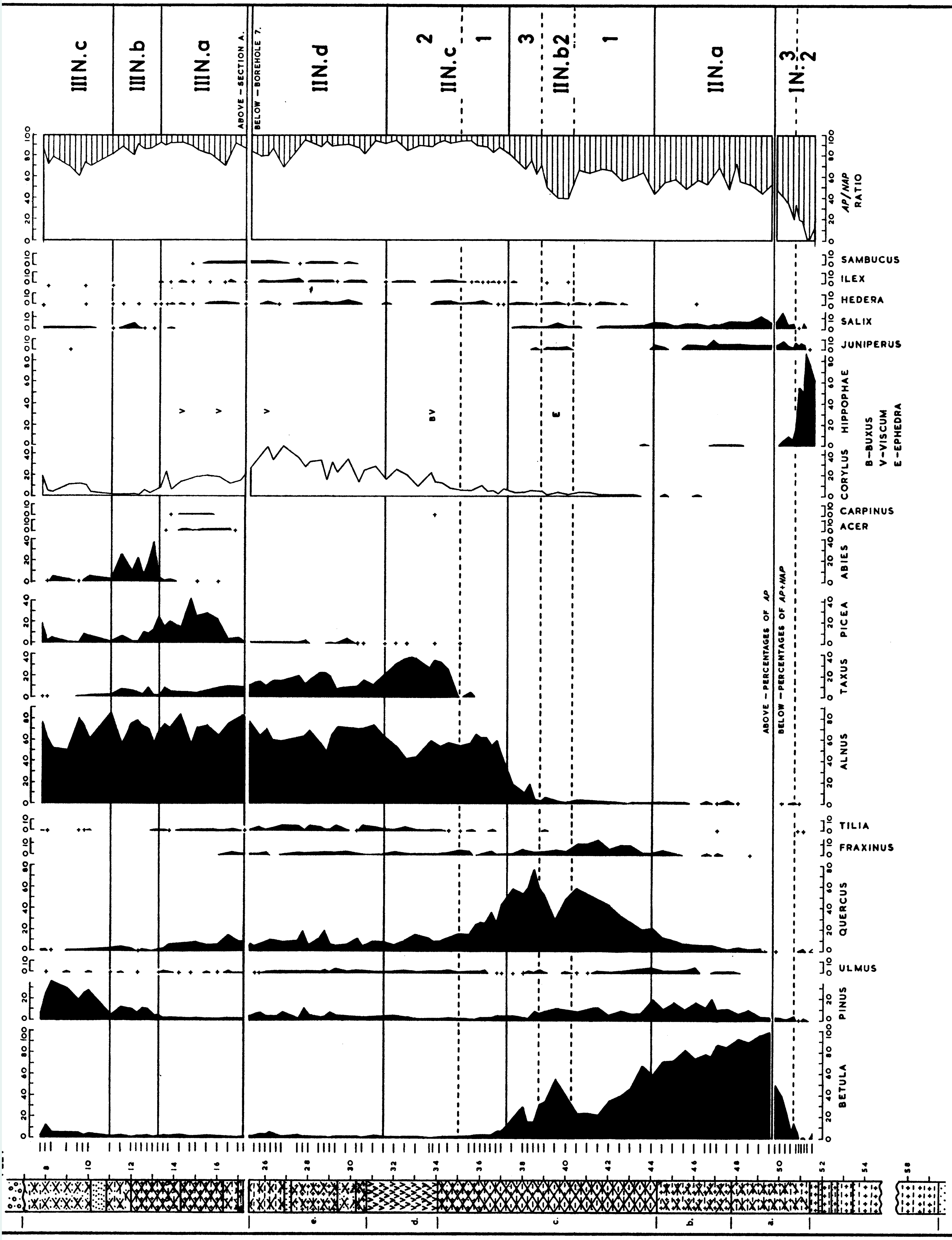
Zone IIN. d (25 ft. 0 in. to 31 ft. 6 in., borehole 7). The base of the zone is drawn at the rise of the *Alnus* and *Tilia* curves and at the decline of *Taxus*. It covers the main period of the development of *Corylus*, *Tilia* and *Alnus*.

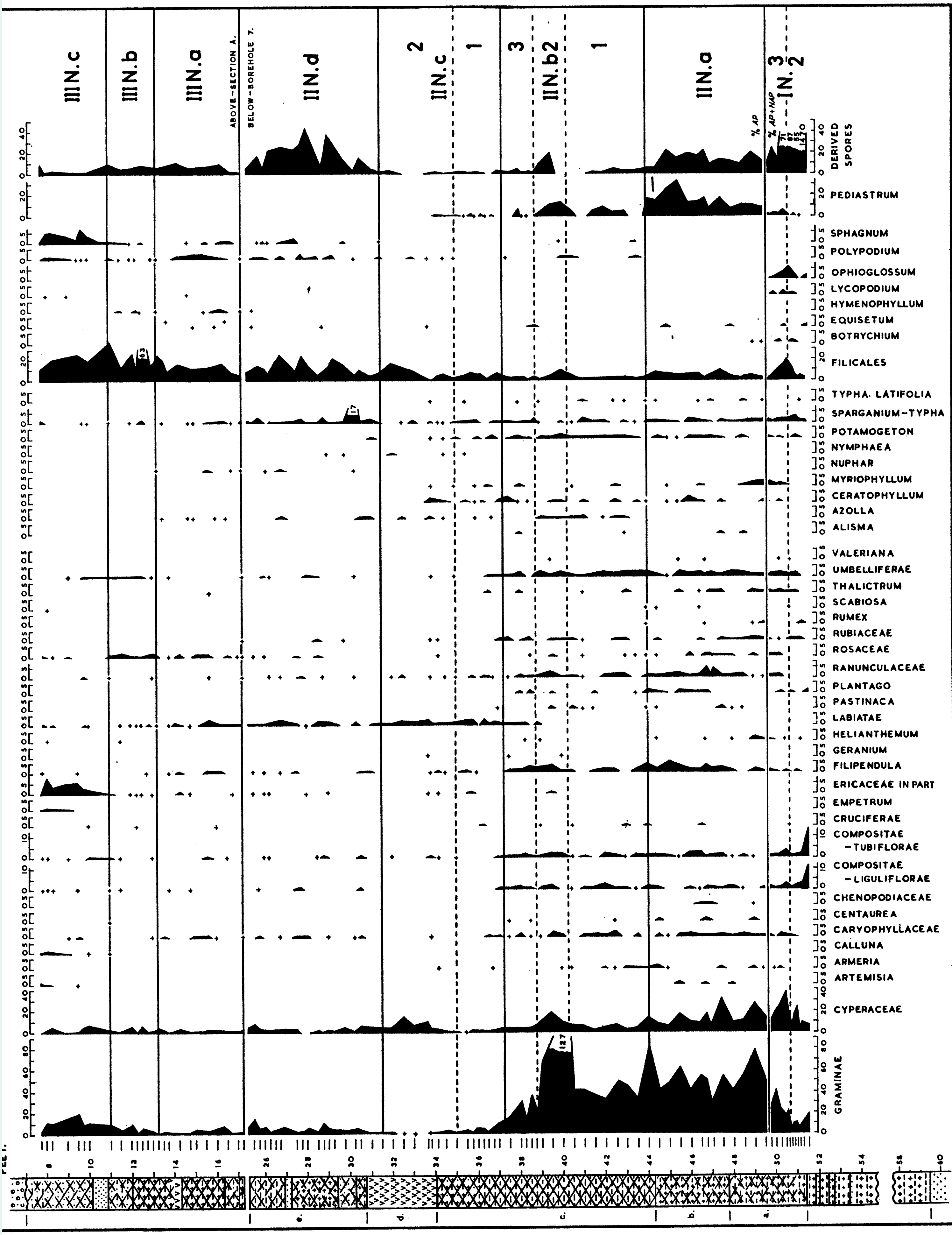
It is only approximately equivalent to II*c* at Hoxne where it is characterized by the decline of *Tilia* and rise of *Ulmus*, the behaviour of these curves contrasting completely with that at Nechells. However, the zone there also includes the main period of high values of *Corylus*.

Zone IIIN. a (13 ft. 3 in. to 16 ft. 6 in., Section A). This begins at the sharp rise of *Picea* with an associated fall of *Alnus*, *Taxus*, *Quercus* and *Corylus* curves. *Carpinus* and *Acer* appear in this zone.

Zone IIIN. b (11 ft. 0 in. to 13 ft. 3 in., Section A). The division is made at the abrupt rise of the *Abies* curve, when *Picea* decreases. *Pinus* and Graminae increase gradually during the zone.

Zone IIIN. c (7 ft. 9 in. to 11 ft. 0 in., Section A). The base of the zone is drawn at the abrupt fall of *Abies*; from this point *Pinus* increases, becoming the dominant species. *Betula* also increases gradually and Ericales and Graminae are important.


III N.c
III N.b
III N.a
ABOVE – SECTION A.
BELOW – BOREHOLE 7.
II N.d
II N.c
II N.b2
II N.a
I N.3
I N.2
AP/NAP RATIO
SAMBUCUS
ILEX
HEDERA
SALIX
JUNIPERUS
HIPPOPHAE
B–BUXUS
V–VISCUM
E–EPHEDRA
CORYLUS
CARPINUS
ACER
ABIES
PICEA
TAXUS
ABOVE – PERCENTAGES OF AP
BELOW – PERCENTAGES OF AP+NAP
ALNUS
TILIA
FRAXINUS
QUERCUS
ULMUS
PINUS
BETULA


III N.c
III N.b
III N.a
ABOVE – SECTION A.
BELOW – BOREHOLE 7.
II N.d
II N.c
II N.b2
II N.a
I N.
% AP
% AP+NAP
DERIVED SPORES
PEDIASTRUM
SPHAGNUM
POLYPODIUM
OPHIOGLOSSUM
LYCOPODIUM
HYMENOPHYLLUM
EQUISETUM
BOTRYCHIUM
FILICALES
TYPHA LATIFOLIA
SPARGANIUM–TYPHA
POTAMOGETON
NYMPHAEA
NUPHAR
MYRIOPHYLLUM
CERATOPHYLLUM
AZOLLA
ALISMA
VALERIANA
UMBELLIFERAE
THALICTRUM
SCABIOSA
RUMEX
RUBIACEAE
ROSACEAE
RANUNCULACEAE
PLANTAGO
PASTINACA
LABIATAE
HELIANTHEMUM
GERANIUM
FILIPENDULA
ERICACEAE IN PART
EMPETRUM
CRUCIFERAE
COMPOSITAE –TUBIFLORAE
COMPOSITAE –LIGULIFLORAE
CHENOPODIACEAE
CENTAUREA
CARYOPHYLLACEAE
CALLUNA
ARMERIA
ARTEMISIA
CYPERACEAE
GRAMINAE
FEET

At Hoxne most of these three zones are missing. The part of Stage III which is present is difficult to compare with the Nechells zones since the conifer curves are much lower, even allowing for the over-representation of *Alnus*, but it is apparent that it only includes a fraction of them.

Stage IV, the Early glacial, exists at Hoxne, its open sub-arctic character indicated by the macrofossils rather than by the pollen evidence, which is obscured by derived pollen. Its lower boundary would presumably be arbitrarily drawn at the point where *NAP* equalled *AP*. At Nechells this is being approached during IIIN. *c* and the indications are that Stage IV is the succeeding zone, though it is nowhere preserved.

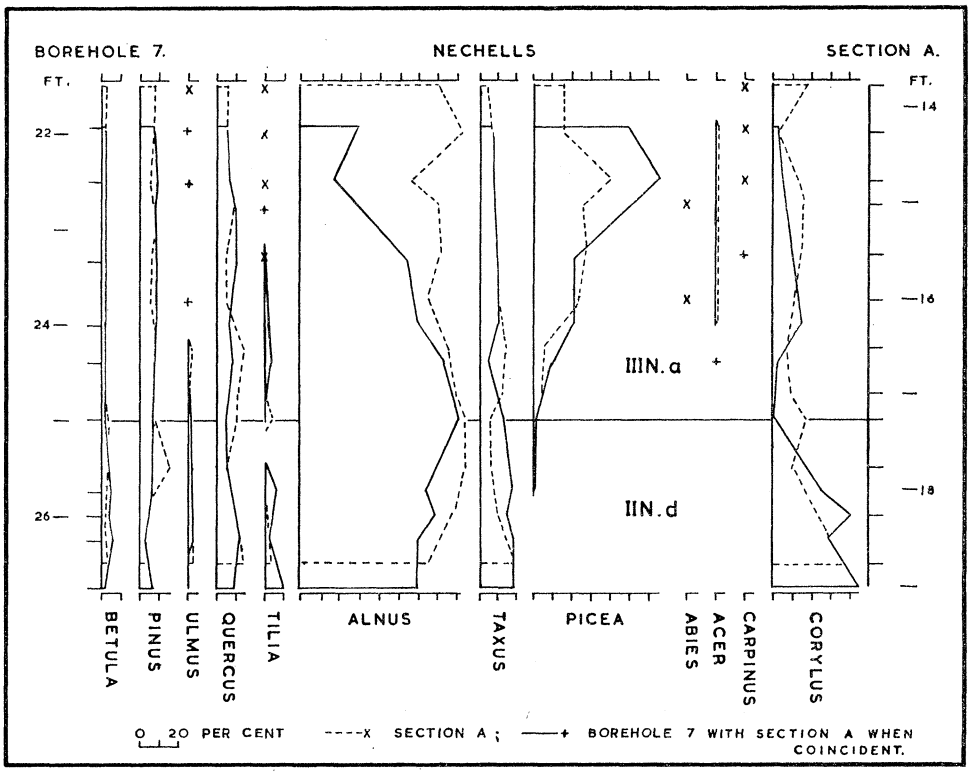


FIGURE 13. Pollen diagram, showing the overlap of diagrams from borehole 7 and Section A in Zone IIIN. *a*.

Figure 13 shows the overlap of the two diagrams from borehole 7 and Section A. Since the diagrams from the two sites are closely similar (including that of Duigan 1956, p. 376) the divergence of certain curves appears anomalous. As the top of the core from the borehole was visibly weathered and the pollen grains from this horizon were corroded it is thought to be a differential result of weathering. Thereby the larger, distinctive *Picea* are more easily recognized than the smaller *Alnus* when weathered.

(v) *Nechells, Section C*

These diagrams (figure 14) are from three sections exposed in a sewer tunnel (see figure 6 for their relationships). Together with figure 15 they illustrate the succession of zones present in the marginal part of the deposits. The curves display similar features to the appropriate parts of the main diagram and its zonation is applied to them.

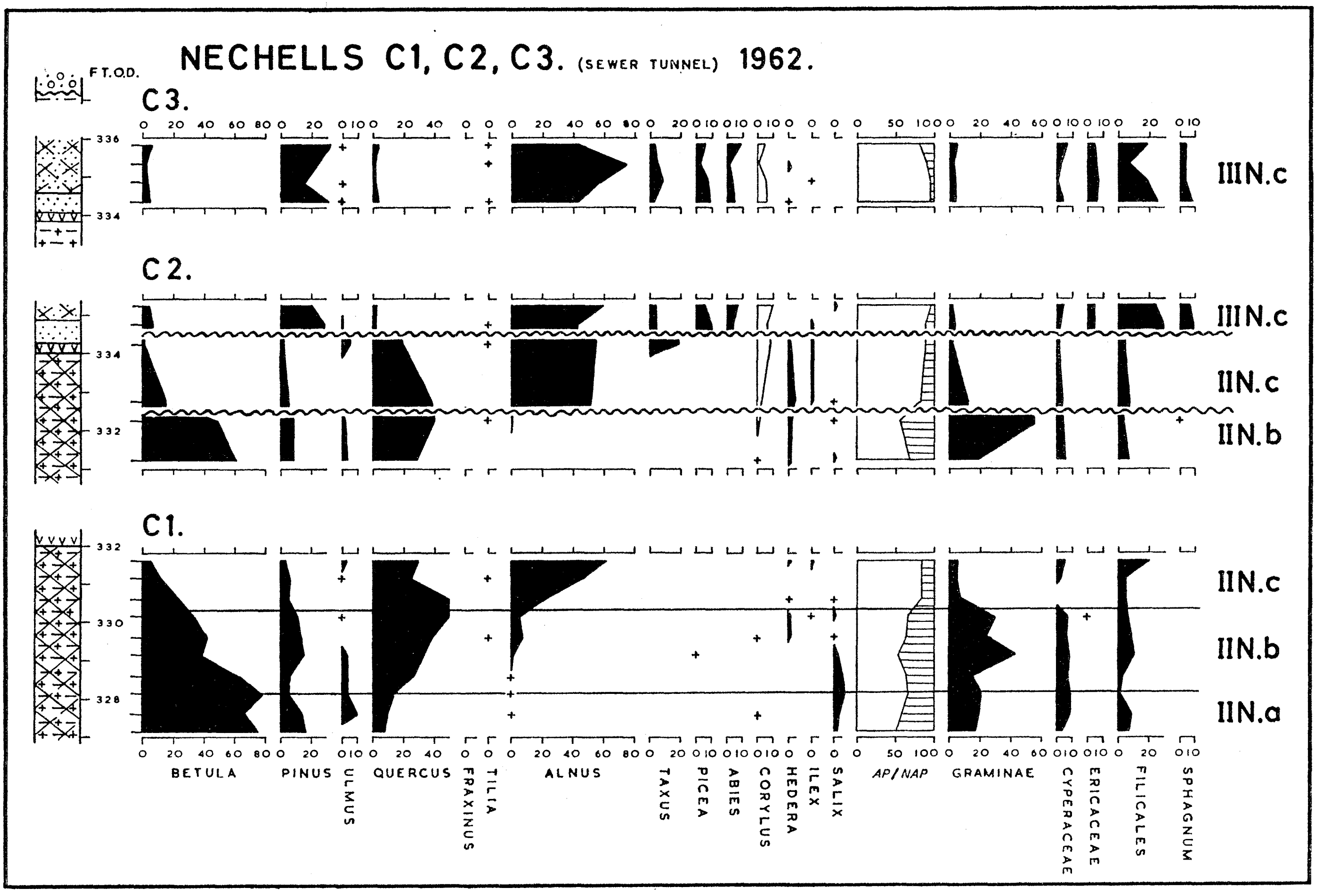


FIGURE 14. Pollen diagram from the marginal deposits, Section C.

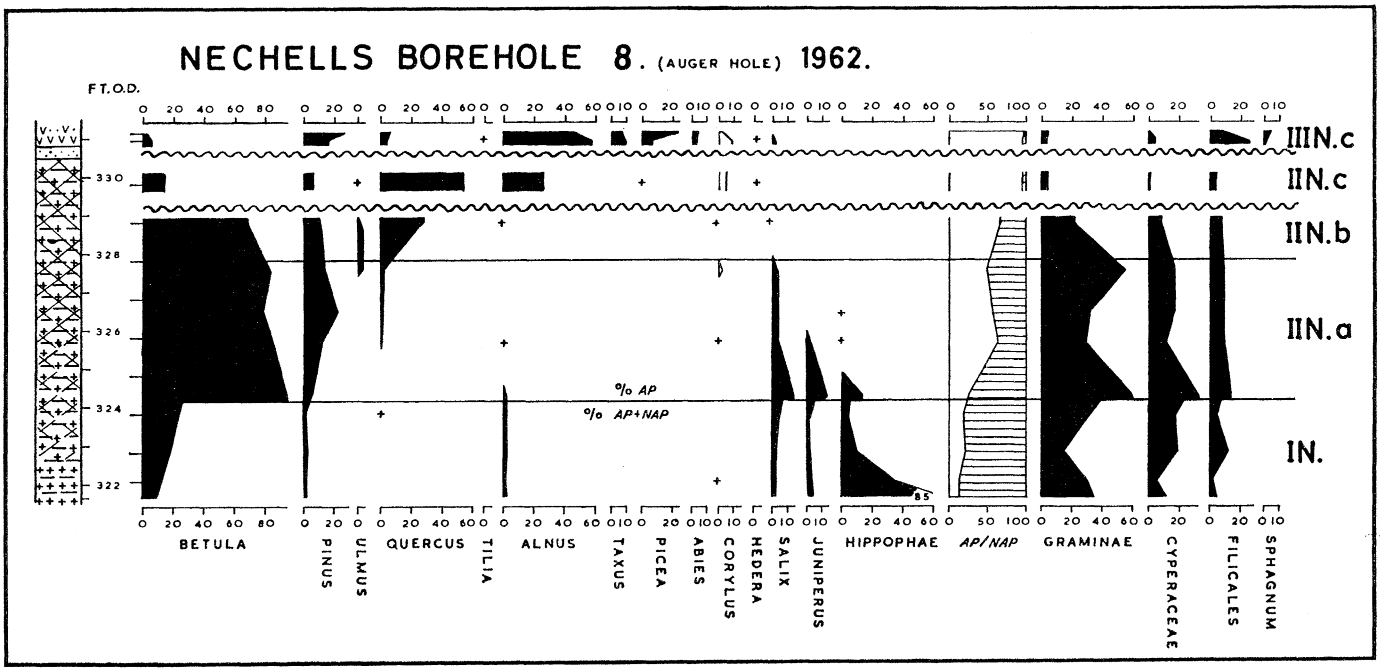


FIGURE 15. Pollen diagram from the marginal deposits, borehole 8.

C. 1

It begins within the upper half of IIN. *a*, with the *Betula* curve dominant, passing into IIN. *b* at the rise of *Quercus* and the fall of *Betula*, the *Quercus* curve remaining consistently high until the rise of *Alnus* in IIN. *c*. Zone IIN. *b* is here only 2 ft. thick, compared with a thickness of 6 ft. in borehole 7, the beds being condensed. The lower unconformity of C. 2 may be present here since there is no evidence of the IIN. *b* sub-zones of the main diagram, but most likely the condensed nature of the succession combined with the wide sample interval would obscure their presence.

C. 2

The lowest two samples are identified as belonging to IIN. *b* and the succeeding one to IIN.*c*. However, in the former the *Betula* values still exceed those of *Quercus* and it must represent the earliest phase of IIN.*b* (the presence of *Corylus* indicates that it is not IIN.*a*). Therefore, most of this zone is absent, and perhaps also the earliest part of the next. The top sample in IIN.*c* is low within that zone, with only moderate values for *Taxus* (low *Corylus* and Filicales precluding it from being IIN.*d*), but the samples above have the high values of *Pinus* with *Abies* and *Picea* characteristic of Zone IIIN.*c*. This reveals a second break in the succession wherein part of IIN.*c*, all of IIN.*d* and IIIN.*a* and *b*, and perhaps part of IIIN.*c* are missing.

*C.*3

The whole of this lies within IIIN.*c* with *Alnus* dominant, but with high values for *Pinus*, *Picea* and *Abies*.

(vi) *Nechells*, *Borehole* 8 (*figure* 15)

This diagram is complementary to those of Section C and shows that the succession here includes IN.2 and 3 and IIN.*a* apparently without a break, but has most of IIN.*b* missing, the samples in this zone belonging to its earliest phase, when *Betula* had very high values. The next sample belongs to lowest IIN.*c* where *Quercus* is still high, between the points where the *Betula* curve has become very low and the *Alnus* curve dominant. The upper samples are IIIN.*c*, and most of IIN.*c*, all of IIN.*d* and IIIN.*a* and *b*, and part of IIIN.*c* are missing.

Zone IIN.*a* at this point is condensed to about half its thickness in borehole 7, whilst, in contrast, IN.3 is somewhat thicker; a feature associated with the changed character of the sedimentation of the lake.

The diagrams from Section C and borehole 8 demonstrate the existence of two unconformities, which develop and increase in magnitude towards the edge of the interglacial beds.

The inception of the lowest is dated fairly closely to upper IIN.*b* by the sequence at C. 1. At this period erosion took place at the margins of the deposit, which is most likely to have been due to a fall in the water-level of the lake. More material was removed from the higher slopes and the unconformity trebles in magnitude (thickness of sediment absent) between Section C. 1 and borehole 8. At the latter it is probably complex in character with the period of IIN.*b* being an erosional gap and that of earlier IIN.*c* non-depositional. Subsequently normal deposition was restored.

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The formation of the upper unconformity cannot be dated more closely than that it is post early IIN.*c* and pre IIIN.*c*. However, lithological evidence (p. 546) suggests it was probably middle or late IIN.*c*.

(vii) *Nechells, Borehole* 10 (*figure* 16).

This diagram provides stratigraphical information on the heights of the zones illustrating their rise in elevation from Section A. It shows the presence of Zone IIN.*a*, IIN.*b* and part of IIN.*c*, and also suggests the existence of Zone IN just below the point reached by the samples.

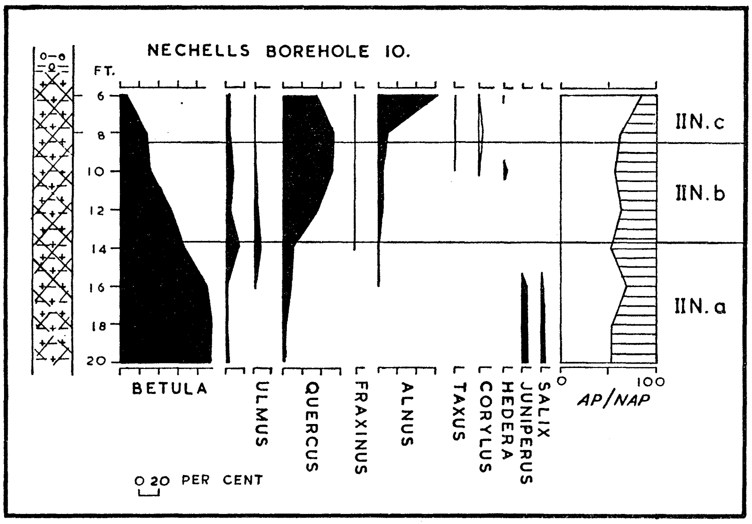

FIGURE 16. Pollen diagram from borehole 10.

(viii) *Nechells, Boreholes* 1, 2 *and* 6

Several slides were obtained which had been prepared by Dr Duigan in a preliminary investigation on a few samples from the boreholes that had first located the interglacial beds in 1950, and which had not been included in her published report. These were recounted to provide dated horizons within the borehole successions as they are otherwise difficult to interpret stratigraphically, because of insufficient data in the records and also because of the lateral variation in the beds. Unfortunately the sample points were not closely defined and the depths given below indicate the possible range of their position (table 1).

(ix) *Cardigan Street, Duddeston* (*figure* 17)

This diagram, on samples from a disturbed core, could only be prepared in an incomplete form. However, it is sufficient to indicate that all fall in Zone IIIN.*c*. The very high *Pinus* and the declining *Alnus* suggest that it is largely later than the highest beds at Nechells, though these features may be emphasized by ecological factors.

(*c*) *Macroscopic remains*

The material from the core of the Royal Society borehole was washed through sieves, down to B.S. no. 52 (aperture 295 μm), and sorted for macrofossils. From about 12 cu.ft. of core 8000 seeds and other plant fossils together with a large fauna of insects, molluscs, ostracods, etc. (Osborne & Shotton, awaiting publication) were obtained. From the plant macrofossils 90 taxa have been identified (see floral list).

The remains of certain species were common enough to allow 'frequency' curves to be plotted on the basis of the number per inch of core (figure 18). Though seed frequencies

TABLE 1

sample no.	B.H. 1/6 (330·8–329·1 ft. O.D.)	B.H. 1/8 (320·0–317·9 ft. O.D.)	B.H. 2/2 (336·1–332·7 ft. O.D.)	B.H. 2/3 (332·7–327·6 ft. O.D.)	B.H. 2/4 (327·6–315·1 ft. O.D.)	B.H. 6/5 (327·8–327·7 ft. O.D.)
Betula	2	2	1	1	2	—
Pinus	5	4	8	5	1	3
Ulmus	1	—	1	1	—	2
Quercus	7	7	5	7	28	6
Fraxinus	+	—	—	—	2	+
Tilia	—	+	1	1	—	+
Alnus	82	78	74	73	56	78
Taxus	+	9	9	12	11	10
Picea	3	+	1	+	—	1
Abies	+	—	—	—	—	—
Carpinus	+	—	—	—	—	—
Corylus	12	25	34	20	10	30
Hedera	+	+	—	—	2	1
Ilex	—	—	—	—	2	+
Graminae	3	3	8	3	1	2
Cyperaceae	15	1	2	1	1	1
Filicales	10	10	8	5	4	4
herbs	3	1	2	1	1	+
aquatics	+	1	3	4	1	+
NAP (% total pollen)	31	15	17	15	6	9
Zone	IIIN.	IIN.*d*	IIN.*d*	IIN.*d*	IIN.*c* middle	IIN.*d*

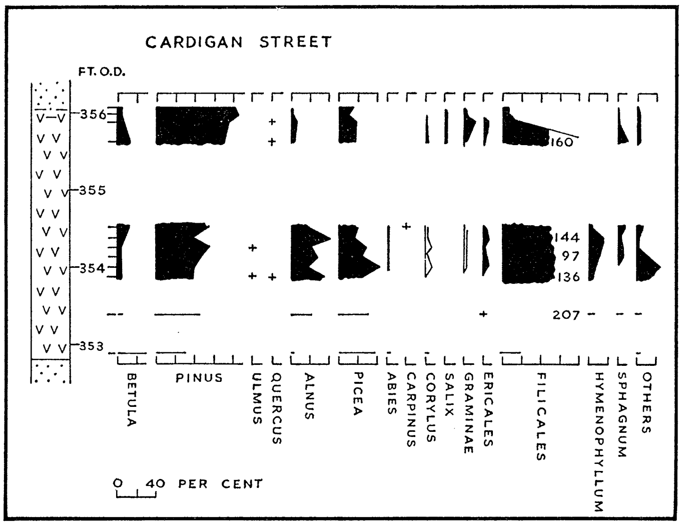

FIGURE 17. Pollen diagram from Cardigan Street.

will be much more likely to be influenced than pollen by secondary factors such as sorting, these curves are considered to have some significance in terms of local or regional plant distributions.

Within the diagram the *Betula* fruit curve shows a remarkable parallelism to the pollen curve, over Zones IN, IIN.*b* and IIN.*c*, including identical fluctuations within the

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subzones of IIN.*b*, notably with an expansion during the 'cold?' oscillation of IIN.*b*/2. Though their behaviour in IIN.*a* is dissimilar, the fruit curve may present a truer picture of the frequency of *Betula* since the pollen curve in IIN.*a* really only expresses its frequency in terms of itself. If this is so, it indicates that over most of IIN.*a* the 'tree species' of *Betula* were only moderately frequent, the early higher values probably largely due to

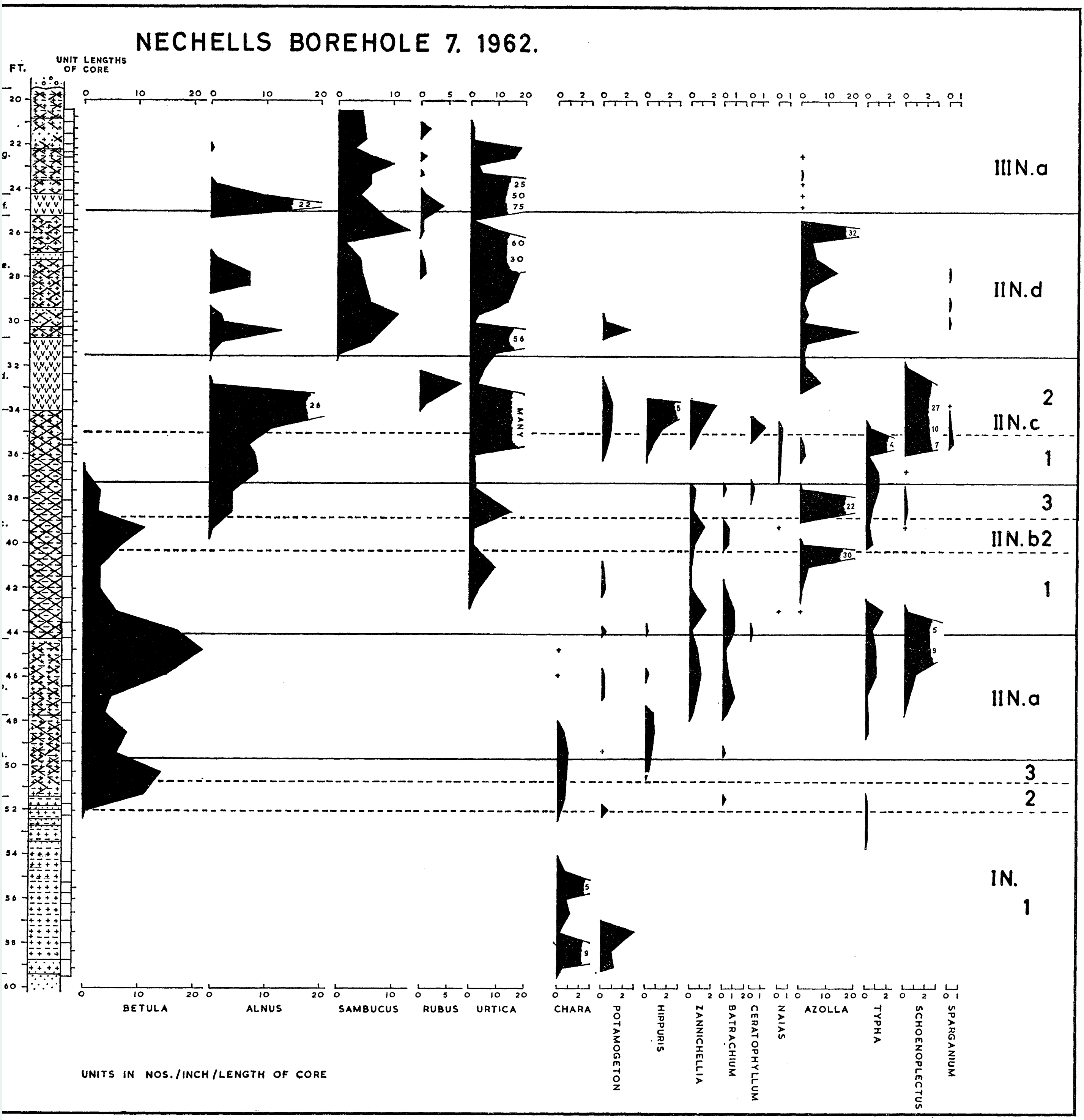

FIGURE 18. Macrofossil frequency diagram from borehole 7.

B. nana since wingless fruit of this species were not distinguished from those of the tree-birches. Later in the zone, significantly contemporaneous with the rise in *Quercus* pollen, the *Betula* fruit curve rises to its maximum at the zone boundary.

The Graminae pollen curve might be expected to demonstrate the frequency of *Betula*, as an expression of the 'openness' of the tree-cover, but its form suggests in fact that they responded similarly to the same controls and were in association rather than competition. Grasses would be dominant in wetter areas, and would also form the field layer of the birch wood. Hence the Graminae pollen curve, though fluctuating widely, does show the trends of the *Betula* fruit curve.

The *Alnus* fruit curve follows the pollen curve in its expansion from IIN.*b*/3, but rises more slowly to reach a maximum in the middle of the zone. As the fruit would most likely be from the local alder carr, the form of the curve is consistent with the idea that this only developed gradually (p. 583). In its upper part the *Alnus* curve fluctuates sharply.

The *Sambucus* seed curve increases at the base of IIN.*d* and from then on fluctuates widely, to a certain extent its maxima corresponding with minima in the *Alnus* curve. This may be significant since *Sambucus* probably grew on drying-out alder carr and the curve may then represent fluctuations in the water-table, at least locally.

Remains of limnophytes were common and their curves include several not represented in the pollen diagram; *Hippuris*, *Zannichellia*, *Najas* and *Chara*. Of those species represented by both curves the *Azolla* 'macrospore curve' is more complete than the 'massulae curve' whilst, in contrast, the *Ceratophyllum* 'spine curve' is more complete than the 'seed curve'. However, for both species the limits of the two sets of curves are similar. This points to the caution required in the interpretation of the curves.

As with the other curves, the fluctuations shown by those of the aquatic plants could just be a result of the successive incorporation of material of different provenance. They can, however, be interpreted in terms of a changing environment, within and about the lake, and this is found to be consistent with the lithological and pollen evidence when relevant.

(*d*) *List of the flora*

The floral list is given in table 2, and includes taxa of various rank, identified from macroscopic and microscopic remains. The nomenclature follows that of Clapham, Tutin & Warburg (1952) but the arrangement is alphabetical. '×' denotes a taxon's occurrence in a zone. '?' denotes an occurrence which is considered to be probably primarily or secondarily derived.

The following abbreviations are also used: *a*, achene; *c*, cone; *col*, colony; *fr*, fruit; *l*, leaf; *lh*, leaf hair; *Msp*, megaspore; *msp*, microspore; *n*, nut; *n*+*u*, nut with utricle; *o*, oogonia; *p*, pollen; *s*, seed; *sn*, spine; *sp*, spore; *st*, stone; *w*, wood.

(*e*) *Notes on certain species*

Information on the distribution of modern species is taken from Clapham *et al.* (1952) and Perring & Walters (1962) for the British, Hulten (1950) for the Scandinavian and Hegi (1906) for the central European. Fossil records, unless otherwise stated, are from Godwin (1956).

TABLE 2

plant	plant remains	zones: IIIN.*c*	IIIN.*a* and *b*	IIN.*d*	IIN.*c*	IIN.*b*2	IIN.*b*1 and 3	IIN.*a*	IN.2 and 3	IN.1
bies cf. *alba* Mill.	*p*, *l*	×	×	.	.	.	.	.	.	.
cer sp.	*p*	.	×	.	.	.	.	.	.	.
iuga reptans L.	*n*	.	×	×	.	.	.	.	.	.
lisma plantago-aquatica L.	*a*, *p*	.	.	×	×	.	×	×	.	.
lnus glutinosa (L.) Gaertn.	*fr*, *cs*, *w*, *p*	×	×	×	×	×	×	?	?	.
nagallis cf. *arvensis* L.	*s*	.	.	.	.	.	.	×	.	.
phanes microcarpa (Boiss. & Reut.) Rothm.	*a*	.	.	.	.	.	×	×	.	.
pium graveolens L.	*fr*	.	.	.	.	.	.	×	.	.
. *nodiflorum* (L.) Lag.	*fr*	.	.	.	.	.	×	×	.	.
renaria serpyllifolia L.	*s*	.	×	.	.	.	.	×	×	×
rmeria maritima (Mill.) Willd.	*p*	.	.	.	.	×	×	×	×	.
rtemisia sp.	*p*	×	.	.	.	.	.	×	×	.
etula nana L.	*fr*, *p*	.	.	.	.	×	.	×	×	.
. *pubescens* Ehrh.	*fr*, *cs*	.	.	.	×	.	×	×	×	.
. *verrucosa* Ehrh.	*fr*, *cs*	.	×	×	.	.	×	×	×	.
etula sp.	*fr*, *p*	×	×	×	×	×	×	×	×	.
idens tripartitus L.	*a*	.	.	.	×	.	.	.	.	.
uxus sempervirens L.	*p*	.	.	.	×	.	.	.	.	.
alluna vulgaris (L.) Hull.	*p*	×	.	.	.	.	.	.	.	.
arex flava agg.	*n*	.	×	.	.	.	.	.	.	.
. *pseudocyperus* L.	*n*+ *u*	.	×	×	×	.	×	×	.	.
. *riparia* Curt.	*n*+ *u*	.	×	×	×	.	×	×	.	.
arex sp.	*n*	×	×	×	×	.	×	×	.	.
arpinus betulus	*p*	.	×	.	.	.	.	.	.	.
aryophyllaceae	*p*	×	×	×	×	×	×	×	×	.
entaurea sp.	*p*	×	.	.	.	.	×	×	.	.
erastium vulgatum L.	*s*	.	.	.		×	.	.	.	.
eratophyllum demersum L.	*n*, *sn*	.	.	.	×	×	×	×	×	.
henopodiaceae	*p*	.	.	.	.	.	×	×	.	.
henopodium cf. *album* s.l.	*s*	×	.	.	.	.	.	.	.	.
. *rubrum* L.	*s*	.	.	.	×	.	.	×	.	.
hrysosplenium alternifolium L.	*s*	.	×	.	.	.	.	.	.	.
irsium arvense (L.) Scop.	*a*	.	.	.	.	.	.	.	×	×
ompositae sect. liguliflorae	*p*	×	×	×	.	×	×	×	×	.
ompositae sect. tubiflorae	*p*	×	×	×	×	×	×	×	×	.
orylus avellana L.	*n*, *p*	×	×	×	×	×	×	?	.	.
ruciferae	*p*	×	×	.	×	.	×	×	×	.
yperaceae	*p*	×	×	×	×	×	×	×	×	.
leocharis cf. *carniolica*	*n*	.	.	.	×	.	.	.	.	.
. *palustris* (L.) R.Br. emend. Roem. & Schult.	*n*	.	.	.	.	.	.	.	.	×
mpetrum nigrum L.	*p*, *s*	×	.	.	.	.	.	.	.	.
phedra distachya L.	*p*	.	.	.	.	?	.	.	.	.
rica sp.	*p*	×	×	×	×	×	.	.	.	.
upatorium cannabinum L.	*a*	×	.	.	×	.	×	×	.	.
uphorbia stricta L.	*s*	.	.	×	.	.	.	.	.	.
ilipendula ulmaria (L.) Maxim.	*p*	×	×	×	×	×	×	×	×	.
raxinus excelsior L.	*p*	×	×	×	×	×	×	×	.	.
eranium sp.	*p*	.	.	.	×	×	×	.	.	.
eum cf. *rivale* L.	*a*+ *s*	.	.	.	×	.	.	.	.	.
raminae	*p*	×	×	×	×	×	×	×	×	.
edera helix L.	*p*	?	×	×	×	×	×	?	.	.
elianthemum sp.	*p*	×	.	.	.	×	×	×	×	.
ippophaë rhamnoides L.	*p*, *lh*	.	.	.	.	.	.	×	×	.
ippuris vulgaris L.	*a*	.	.	.	×	.	×	×	×	.
ydrocharis morsus-ranae L.	*s*	.	.	.	×	.	.	.	.	.
ydrocotyle vulgaris L.	*fr*	.	.	.	.	.	×	×	.	.
ypericum hirsutum L.	*s*	×	.	.	.	.	.	.	.	.
ex aquifolium L.	*st*, *p*	?	×	×	×	?	.	.	.	.
uniperus communis L.	*p*	×	.	.	.	×	.	×	×	.
abiatae	*p*	×	×	×	×	.	×	.	.	.
apsana communis L.	*a*	.	.	.	×	.	.	.	.	.
eontodon autumnalis L.	*a*	.	.	.	.	.	.	×	.	.
inum catharticum L.	*s*	.	.	.	.	.	.	.	.	×
onicera sp. (Duigan 1956)	*p*	.	×	.	.	.	.	.	.	.
ychnis flos-cuculi L.	*s*	.	.	×	.	.	.	.	.	.
ycopus europaeus L.	*n*	.	×	×	×	.	.	.	.	.
Iatricaria chamomilla L.	*a*	.	.	.	.	.	.	×	.	.
Ientha cf. *aquatica* L.	*n*	×	×	×	×	.	.	.	.	
Iercurialis perennis L.	*s*	×	.	.	.	.	.	.	.	.
Ioehringia trinervia (L.) Clairv.	*s*	.	.	×	.	.	.	.	.	.
Iyriophyllum verticillatum L.	*n*, *p*	.	.	.	×	×	×	×	×	×
ajas marina L.	*fr*	.	.	.	×	×	×	.	.	.
uphar pumila Sm.	*p*	.	×	×	.	.	.	.	.	.
ymphaea alba L.	*p*	.	.	×	×	.	.	.	.	.
astinaca sativa L.	*p*	.	.	.	.	×	×	×	.	.
icea cf. *abies* (L.) Karst.	*p*, *c*	×	×	×	×	.	.	?	.	.

TABLE 2 (*cont.*)

plant	plant remains	zones: IIIN.*c*	IIIN.*a* and *b*	IIN.*d*	IIN.*c*	IIN.*b*2	IIN.*b*1 and 3	IIN.*a*	IN.2 and 3	IN.1
Pimpinella saxifraga L.	*fr*	.	.	.	×	.	.	.	.	.
Pinus sylvestris L.	*p*	×	×	×	×	×	×	×	?	.
Plantago media L.	*p*	.	.	.	.	×	×	×	×	.
Populus sp.	*p*	×	×	.	.	×	×	×	.	.
Potamogeton coloratus Hornem.	*st*	.	.	×	×	.	.	.	.	.
P. filiformis Pers.	*st*	.	.	.	.	.	.	.	.	×
P. lucens L.	*st*	.	.	.	×	.	.	.	.	.
P. cf. *natans* L.	*st*	.	.	.	×	.	.	.	.	.
P. pectinatus L.	*st*	.	.	.	×	.	×	×	.	×
P. pusillus L.	*st*	.	.	.	×	.	.	.	.	.
P. trichoides Cham & Schlecht.	*st*	.	.	.	×	.	.	.	.	.
Potamogeton sp.	*p*, *st*	.	.	×	×	×	×	×	×	.
Potentilla anserina L.	*a*	.	.	.	.	.	.	×	.	.
P. palustris (L.) Scop.	*a*	.	.	.	.	×	.	×	×	.
Prunella vulgaris L.	*n*	.	.	.	.	.	.	×	.	.
Quercus sp.	*p*	×	×	×	×	×	×	×	?	.
Ranunculus acris L.	*a*	.	×	×	×	.	.	.	.	.
R. flammula L.	*a*	.	.	.	.	.	.	×	.	.
R. hederaceus L.	*a*	.	.	.	×	×	×	×	?	.
R. repens L.	*a*	.	.	.	×	.	×	×	.	.
R. sceleratus L.	*a*	×	×	×	×	×	×	×	.	.
R. sect. *Batrachium*	*a*	.	.	.	.	×	×	×	?	.
Ranunculus sp.	*p*	×	×	×	×	×	×	×	×	.
Rosaceae	*p*	×	×	×	×	×	×	×	×	.
Rubiaceae	*p*	.	×	×	×	×	×	×	×	.
Rubus fruticosus agg.	*st*	×	×	×	×	.	.	.	.	.
Rumex acetosella L.	*n*	×	×	×	.	.	.	.	.	.
R. maritimus L.	*fr*	.	.	.	×	.	×	×	.	.
Rumex sp.	*p*	.	.	.	.	.	.	×	×	.
Sagittaria sagittifolia L.	*a*, *p*	.	.	.	×	×	×	×	.	.
Salix sp.	*p*	×	×	.	.	×	×	×	×	.
Sambucus nigra	*st*, *p*	×	×	×	×	.	.	.	.	.
Scabiosa sp.	*p*	×	.	.	.	.	.	×	×	.
Schoenoplectus lacustris (L.) Palla	*n*	.	.	×	×	.	×	×	.	.
Scirpus sylvaticus L.	*n*	.	×	×	×	.	.	.	.	.
Solanum dulcamara L.	*s*	.	.	×	×	.	.	.	.	.
Sonchus arvensis L.	*a*	.	.	.	.	×	.	×	.	×
Sparganium ramosum Huds.	*st*	.	.	.	×	.	.	.	.	.
S. simplex Huds.	*st*	.	×	×	×	.	.	×	.	.
Sparganium type	*p*	×	×	×	×	×	×	×	×	.
Stachys arvensis L.	*n*	×	×	×	×	.	.	.	.	.
Stachys cf. *sylvatica* L.	*n*	.	×	×	.	.	.	.	.	.
Stellaria graminea L.	*s*	.	.	.	×	.	.	.	.	.
S. media (L.) Vill.	*s*	.	.	.	.	.	.	×	.	.
S. neglecta Weihe.	*s*	.	.	.	×	.	.	.	.	.
Taxus baccata L.	*s*, *w*, *p*	?	×	×	×	.	×	.	.	.
Thalictrum flavum L.	*a*	.	.	.	×	.	.	.	.	.
T. minus L.	*a*	.	.	×	.	.	×	.	.	.
Thalictrum sp.	*p*	.	×	.	×	.	×	×	×	.
Tilia cordata Mill.	*p*, *w*	?	×	×	×	.	.	.	.	.
Typha latifolia L.	*p*	.	×	.	×	×	×	×	?	.
Typha sp.	*s*	.	.	.	×	×	×	×	?	.
Ulmus sp.	*p*	?	×	×	×	.	×	×	.	.
Umbelliferae	*p*	×	×	×	×	×	×	×	×	.
Urtica dioica L.	*fr*	×	×	×	×	×	×	.	.	.
Valeriana dioica L.	*s*	.	.	.	×	.	.	.	.	.
V. officinalis L.	*s*, *p*	.	.	.	.	×	.	×	×	.
Viola hirta or *odorata*	*s*	.	×	×	×	.	.	.	.	.
Viscum album L.	*p*	.	×	×	×	.	.	.	.	
Zannichellia palustris L. (s.str.)	*a*	.	.	.	×	×	×	×	.	.
Azolla filiculoides Lam.	*Msp*, *msp*	.	×	×	×	×	×	.	.	.
Botrychium lunaria (L.) Sw.	*sp*	.	.	×	×	.	×	.	.	.
Equisetum sp.	*sp*	.	×	×	×	.	×	×	×	.
Hymenophyllum tunbrigense (L.) Sm.	*sp*	×	×	.	.	.	.	.	.	.
Lycopodium annotinum L.	*sp*	×	×	.	.	.	.	.	×	.
Ophioglossum vulgatum L.	*sp*	.	.	.	.	.	.	.	×	.
Polypodium vulgare L.	*sp*	×	×	×	×	×	×	.	.	.
Selaginella selaginoides (L.) Link.	*Msp*	×	.	.	.	.	.	.	.	.
Thelypteris cf. *palustris* Schott.	*sp*	.	×	×	.	.	.	.	.	.
Sphagnum sp.	*sp*, *l*	×	×	×	.	×	×	.	.	.
Botryococcus sp.	*col*	.	.	.	.	×	×	×	×	.
Chara sp.	*o*	.	.	.	×	.	.	×	×	×
Pediastrum sp.	*col*	.	.	.	×	×	×	×	×	.
Derived Carboniferous spores	*Msp*, *msp*	×	×	×	×	×	×	×	×	×

Abies alba. *Abies* pollen occurs frequently in Zone IIIN.*b* and several needles from there indicate that this was the species present. They have marginal resin canals and stomata on the dorsal surface only. This is in agreement with the identification of *A. alba* from Gort (Jessen, Andersen & Farrington 1959). It was earlier considered that *A. fraseri* was the species typical of this Interglacial (Szafer 1953), but this now seems to have been amended in favour of *A. alba*.

Anagallis cf. *arvensis*. A single seed of Primulaceae type, 1·15 × 0·5 mm, compares well with modern *Anagallis*; it is three-faced, with a flat base and without the prominent dehiscence scar of other genera. It is tentatively suggested to be *A. arvensis* agg. since *A. tenella* is usually somewhat smaller (*ca.* 0·8 mm). *A. arvensis* is a common weed of very wide distribution but has not been recorded earlier than the Roman period of the Post-glacial. However, an occurrence as a heliophyte early in an interglacial, as at Nechells, would not be unexpected. Watts (1959*a*) recorded numerous seeds of *Anagallis* from this Interglacial at Kilberg which because of their small size he regarded as *A. tenella*.

Aphanes microcarpa (figure 26, plate 9). Four small seeds (0·80 to 0·95 mm) belonging to this genus were found at several horizons in Zone IIN.*a* and *b*1. The seeds of modern *A. arvensis* s.s. are consistently larger than the fossil (i.e. 1·2 to 1·7 mm), whilst the few seeds of *A. microcarpa* examined were 0·9 mm. One fossil seed preserved traces of the eight ribs of the sepals. Although this is the first reference to this species as a fossil, *A. arvensis* s.l. has been recorded from several interglacial and post-glacial deposits, including this Interglacial from Clacton. Since the species aggregate has not long been subdivided in this country it is possible that the records include *A. microcarpa*, and one figured seed from the Cromerian (C. & E. M. Reid 1907), with a size of 1·0 mm may belong to this species.

Today it is a plant of open ground and a weed of arable land with a scattered distribution to only 58° N. in Scandinavia.

Apium graveolens. To this species are assigned twelve separated carpels, 1·2 to 1·7 mm long and more or less semilunar in outline with the ridges thin and undulose, though these are only fragmentally preserved and mostly remain as scars. The surface has a reticulate pattern similar to that of *Apium* and differing from those of *Berula* which also has carpels of that size. At present this species, though found mainly by the sea, has a scattered widespread occurrence by rivers, etc. in southern England. Its distribution is markedly southern in Britain and there are only a few localities north of 56° N. in Scandinavia. In view of this its occurrence, early in the Interglacial at Nechells (Zone IIN.*a*) has some significance. This is its first record from this Interglacial.

Apium nodiflorum. Three compressed carpels, 2·1 to 2·3 mm long, agree with this species, having large ridges with pronounced vittae between. *A. inundatum* has coarser ridges and distinctly finer vittae. *A. nodiflorum* grows in shallow ponds etc., and also has a marked southern distribution: absent from north Scotland and all of Scandinavia. At Nechells it is present during the period of closed birch forest. This species has not previously been recorded from this Interglacial.

Azolla filiculoides. Remains of *Azolla* were abundant at Nechells; megaspores and massulae as macrofossils, and leaf hairs and massulae with microspores in the pollen slides; and were identified as *A. filiculoides* (West 1953). This species occurs frequently in interglacial deposits of this age (Holsteinian), Tralau (1959) listing over fifty sites, including four from Britain; however Duigan (1963) has found it in the Cromerian also.

A. filiculoides is a native of North America and is introduced in Britain today where it is limited to areas south of central England, being reported as suffering severely from cold winters here (Clapham *et al.* 1952) though it has also been stated to be capable of some survival under ice. Its appearance in the Interglacial is consistent with this, at a time when there is evidence that the winters had become mild.

It is a free-floating plant of placid water on which it will form dense mats. The Nechells material is interesting in its abundance, the filamented megaspores with massulae attached by their glochidia often occurring in felted masses of several hundreds.

Betula spp.

Macrofossils. These included fruit and female cone scales, both of which can be specifically identified.

Over 1500 fruits were obtained from the core but on only a small fraction are the wings preserved, though they are occasionally perfect. Fruits of both tree-birches, *B. verrucosa* and *B. pubescens*, were present throughout the lower half of the core, often together, but with the latter almost twice as abundant. Two fruits, 1·35 mm, with small crescentic wings, typical of the dwarf birch *B. nana*, were also found at different horizons.

Of twenty-two catkin scales one only agreed with those of *B. verrucosa*, with reflexed broad lateral lobes. The remainder are all considered to be *B. pubescens* though showing some variation, the lateral lobes more or less ascending, overlapping the triangular to lanceolate, long or short terminal lobe.

Pollen. Pollen of *Betula nana* is now satisfactorily and consistently separated from that of the tree-birch species, in this case *B. verrucosa* and *B. pubescens*, when well preserved.

Terasmaë (1951) observed differences between the species in the protuberance of the pores, expressed as the ratio: pore diameter to pore length. Walker (1955) with a modification of this, using the ratio: pore length to the diameter of the pollen grain, statistically demonstrated the presence of *B. nana* in British Late-glacial deposits. Investigation has also shown that a difference in the mean size of the diameter of the grain exists between the species (Eneroth 1951, etc.). Thus, by comparing the size-frequency distribution curves of modern pollen with those for fossil populations the species comprising the latter can be recognized. Andersen (1961) demonstrated the application of this to elucidate the composition of successive *Betula* populations, and this method has been used here.

The external diameter of undistorted pollen grains was measured and plotted in units of 0·33 μm. As a check, measurements were also made of pore protuberance on individuals close to the two population means in size. This was done for six successive horizons within the period when *Betula* was an important component of the vegetation (figure 19).

The sample from Zone IIN.*b* 3 has a symmetrical, normal distribution, suggesting the presence of a single species within the population, the mean size of which is 21·6 μm. In contrast the samples from IN.3 and IIN.*a* (lower) produce sharply bimodal curves suggesting that two species are present, the additional species having a mean size *ca.* 19·4 μm. Although clearly separated, the two mean sizes are only 2·2 μm apart, somewhat less than that previously recorded between *B. nana* and even the smallest tree-birch pollen, e.g. table 3 (for modern pollen).

However, the two values obtained at Nechells are of approximately the same order as *B. nana* and *B. verrucosa*. Furthermore, measurements of the pore protuberance for the two gave ratios comparable to those obtained by Walker (in Godwin 1956) for fossil and modern pollen (e.g. table 4) though the modern tree-species here is *B. pubescens*.

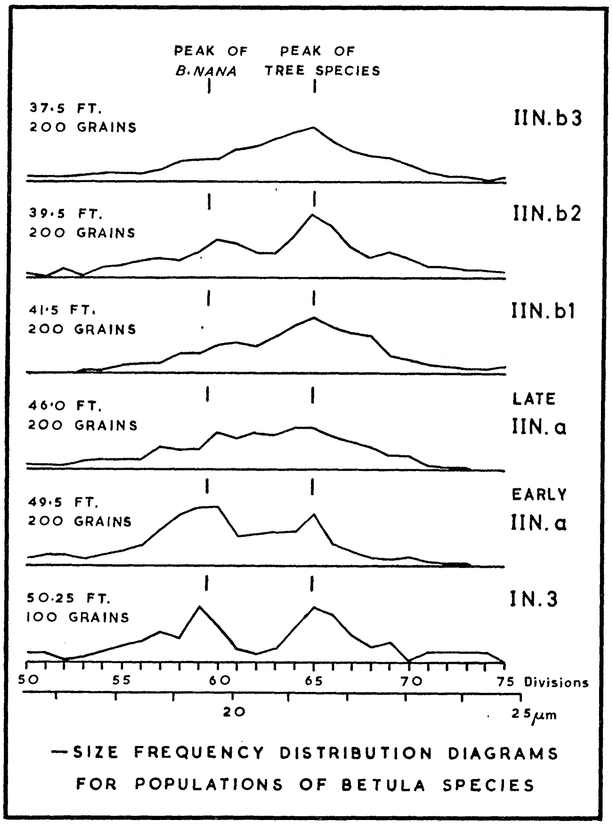

FIGURE 19. Size-frequency distribution diagrams for populations of *Betula* species.

TABLE 3

	B. nana	*B. verrucosa*	*B. pubescens*
fresh (1)	21·7	24·3	27·5
boiled with KOH (1)	18·4	21·5	23·8
boiled with KOH (2)	19·4	22·1	25·0

(Sizes in μm, from (1) Jentys-Szaferowa (1928), (2) Eneroth (1951).)

TABLE 4

	from Walker (fossil-modern)	Nechells (25 measurements)
'tree' *Betula*	6·17–7·84	$7{\cdot}19 \pm 0{\cdot}43$ (*a*)
B. nana	9·95–11·5	$9{\cdot}99 \pm 0{\cdot}37$ (*b*)

(Group (*a*) from sample from IIN.*b*3 and (*b*) from IIN.*a* (early).)

The small size of the tree-birch pollen suggests that *B. verrucosa* was predominant, though this is contrary to the evidence of the macro-remains. However, *B. pubescens* has a greater tolerance of wet habitats than *B. verrucosa*, and would be the more likely to be represented by macro-remains within the lake deposits, whereas the pollen rain would be representative of the frequencies of the species from over a wider area.

On the evidence from the size-frequency curves and the macrofossil identifications the changes in the specific composition of the *Betula* populations can be followed.

Zone IN. 3. Tree-birch and *B. nana* pollen are about equally represented. The existence of the tree-birches this early within the late-glacial period is confirmed by the macro-fossils, with fruit of both *B. pubescens* and *B. verrucosa* from this period.

Early Zone IIN.a. *B. nana* and tree-birch pollen are both abundant, the latter more so than in Zone I. Fruit of *B. nana*, *B. pubescens* and *B. verrucosa*, and cone scales of *B. pubescens* occur.

Late Zone IIN.a. Tree-birch pollen predominates, but *B. nana* pollen is still present; tree-birch macrofossils are present.

Zone IIN.b 1. A nearly symmetrical unimodal curve shows tree-birch pollen to be almost exclusively present, but perhaps with rare *B. nana*; only macrofossils of tree-birches occur from this zone.

Zone IIN.b 2. A distinctly bimodal curve clearly indicates the presence of *B. nana* pollen, but with the tree-birch pollen predominant. The macro-remains include both fruit of *B. nana* and fruit and cone scales of *B. pubescens* and *B. verrucosa*.

Zone IIN.b 3. A unimodal curve shows that only tree-birch pollen is present.

The return of the sub-arctic species, *B. nana*, in Zone IIN.*b* 2 is consistent with the presence of some other open habitat plants in this sub-zone (p. 582).

Ceratophyllum demersum (figure 22, plate 9). The genus has small spines on the leaf margins formed of a single thickened cell, narrowly elongate and sharply pointed. These occur frequently in the pollen slides from the earlier zones at Nechells, enabling a distribution curve to be drawn for them (see pollen diagram). Generally only the single cell forming the spine (*ca.* 38 μm long) is preserved, bearing at its base the characteristic pattern of attachment 'scars' of the adjacent cells. Occasionally, however, a few of these remain attached. Twenty-one seeds of *C. demersum* indicate that this is the species represented by the 'spines'. Nineteen of these coincide with the 'spine curve' peak in Zone IIN.*c*.

This species is a submerged, normally free-floating aquatic requiring tranquil conditions, in lakes, etc., with oligotrophic to brackish waters, most often eutrophic. Its distribution is now known to extend to 67° N. in Scandinavia (Julin & Luther 1959) but is considerably restricted in the northern area from its former extent in the Post-glacial. Sammuelson (1934) considered this to be due to an impoverishment of the northern habitats but others (Godwin 1956) have cited it as an example of restriction due to climatic recession. At Nechells the conditions allowed it to immigrate at the end of the late-glacial (Zone IN); which is the stage at which it appeared in the Post-glacial in Britain (earliest Zone IV) and in the Eemian deposit at Bobbitshole (Zones *b*/*c* transition).

Chrysosplenium alternifolium (figure 25, plate 9). A single small seed was found from Zone IIIN.*a* which belonged to this species, 0·63 × 0·41 mm, with the characteristic rib along one side, and a shiny black surface with a regular reticulate pattern (*ca.* 0·03 mm). It differs from *C. oppositifolium*, which has small papillae on the surface. It is a plant of wet shaded habitats on stream banks and in woods, local in Britain today and absent from the extreme west. This is its first record as a fossil in Britain.

Eleocharis spp.

E. palustris. Seven fruits came from Zone I N. 1 and 2, biconvex, 'inverted pear-shaped', 1·35–1·55 × 1·0–1·05 mm, with a persistent style base *ca.* 0·4 mm wide. This species is widely distributed today and is frequent in parts of Scandinavia to the Arctic Circle, with scattered localities to 70° N. Its fossil occurrences include Weichselian Full- and Late-glacial records from Britain and it occurs during the late-glacial (Elster) at Nechells.

E. cf. *carniolica* (figures 31, 32, plate 9). Five fruits of a second species of *Eleocharis* do not belong to a British species; they are biconvex, 1·05 × 0·6 mm, much smaller than the biconvex *E. uniglumis* and *E. palustris*, with a prominent, narrow (0·125 mm) style base which protrudes from the top of the nut. Dr S. M. Walters has examined these, and agrees that they resemble *E. carniolica*, to which species he has earlier tentatively assigned material from this Interglacial at Kilbeg (Watts 1959*a*). This species has a south-east European distribution, extending to Austria and north Italy in the west but chiefly within the Balkan peninsula. At Nechells it occurs in Zone II N. *c* when the climate was warm and moist.

Euphorbia stricta (figure 28, plate 9). The seeds of *Euphorbia* are readily identifiable at a specific level. None of the species with smooth (finely pitted) seeds approaches the small size of *E. stricta*. The fossil, 1·5 × 1·05 × 0·7 mm, matches modern seeds of *E. stricta* in the detail of its size and shape except in its thickness. The face of the seed has been flattened and is without the slightly angled two contact facets of the modern, though the slight seam between these is faintly shown.

The present distribution of this plant is mainly in central and southern Europe and is restricted in Britain to limestone woods in Monmouthshire and Gloucestershire. Hegi (1906), however, describes an occurrence on the Continent in alluvial alder woods, which was probably more typical of its habitat at Nechells. It is interesting that its only previous record as a fossil is also from this Interglacial from Clacton (Reid & Chandler 1923).

Geum cf. *rivale* (figure 27, plate 9). A single half carpel was found belonging to this genus; 3·2 × 1·1 mm, and ellipsoidal, narrowed into the remaining fragment of the awn, containing an ellipsoidal seed 2·1 × 1·0 mm.

The fruit of the two British species, *G. urbanum* and *G. rivale*, are similar and fossil material is not usually specifically identified. However, though there exists a wide variation in size, *G. urbanum* (*ca.* 5 mm) appears to be consistently larger than *G. rivale* (*ca.* 4 mm) whilst the seeds of the former tend to have a more pronouncedly pointed base. On these characters the fossil agrees most closely with *G. rivale*, a species whose presence in Zone II N. *c* would not be unexpected, when extensive marsh and fen wood had developed in the vicinity. However, the fertile hybrid *G.* × *intermedium* also exists, with the characters intermediate between its parents, and the fossil may belong to this. The identification is, therefore, only tentative. The genus has not been recorded from this Interglacial.

Hydrocharis morsus-ranae. Nine fruits of this species occurred in II N. *c* biconvex elliptical, 1·15 × 1·8 mm, with characteristic coarse epidermal cells (0·1 mm), the spiral thickenings of which become loosened to give a tangled hairy surface to the fruit. This free, 'floating leaf' limnophyte has a scattered distribution, and is absent from Scotland, western Ireland and north and west Scandinavia. Its only previous fossil occurrences are from the Eemian deposits at Bobbitshole (West 1957) and Selsey (West & Sparks 1960). At both of these it occurs during the period of optimum climate, as it apparently does at Nechells.

Hymenophyllum tunbrigense. Spores of *H. tunbrigense* were found to be distinguishable from those of *Trichomanes speciosum* using the criteria described by Watts (1959*a*), and were identified from the upper zones at Nechells and Cardigan Street. At the latter they were especially abundant, to 12% *AP* in III N. *c*. Its present distribution is distinctly western, extending northwards to Skye in Britain but only to northern France on the Continent. Watts (1959*a*) has described it from Kilbeg and Jessen *et al.* (1959) record *H. tunbrigense* vel *T. speciosum* from Gort. These records and its abundance at Nechells must imply that *H. tunbrigense* was a common fern in the damp largely coniferous forests of the latter part of the Interglacial.

Linum catharticum. Seeds of *L. catharticum* occurred in the early late-glacial of earliest Zone I N., 1·3 × 0·7 mm, with the characteristic shape and surface cell pattern of this species. It is a plant of open habitats, grasslands and dunes. In Scandinavia it does not have a pronouncedly northern distribution, only reaching the Arctic Circle in the extreme west, where there are disjunct localities to 69° N., whilst it is frequent only to 61° N. in the east. However, it reaches over 1000 m in S. Norway. Jessen *et al.* (1959) also recorded this species from the late-glacial of this Interglacial and, from a later stage also, from the limestone region at Gort. It has been found in Late-glacial (Weichsel) deposits in Scotland and Ireland.

Lycopodium annotinum. This was the only species of *Lycopodium* found at Nechells where it occurred in the late-glacial, Zone I N. and at the end of the Interglacial in III N. *c*. It is a typically arctic-montane species, with only a local distribution today in Britain, on hills and mountains north of Yorkshire, and its presence as a fossil is characteristically associated with late-glacial conditions. Godwin (1959) and Seddon (1962) have recorded it from the Weichsel Late-glacial in Britain from localities outside its present range. Similarly, for this Interglacial (Holstein) it is recorded from the early zones at Gort (Jessen *et al.* 1959) and from Kirmington (Watts 1959*b*).

Matricaria chamomilla (figure 29, plate 9). Two elongate achenes, 1·10 × 0·85 mm, obliquely truncated at the apex, with four narrow longitudinal ribs located on the inside of the achene, the central ribs not distinctly separated, and a surface with a rectangular epidermal cell pattern, agree in detail with modern achenes of *M. chamomilla*.

At the present day *M. chamomilla* is a weed, especially of lighter arable soils with a wide European distribution but it is considered to be introduced over much of its northern range where it is frequent only to 60° N., with isolated localities to 70° N. It has not previously been recorded as a fossil. At Nechells it occurs during an early phase of open birch woods and it is another addition to the list of species which are now ruderals or weeds but which were members of the natural vegetation in the 'late-' and earliest 'post-glacial' periods.

Mercurialis perennis. A small fragment of a seed (1·2 mm) from Zone III N. *c* has the distinctive ornament of this species; with deep and irregular depressions, *ca.* 0·3 mm across, and a finely (*ca.* 0·02 mm) reticulate surface pattern. *M. annua* has less well-defined and more irregular depressions.

M. perennis is a woodland herb with a wide distribution in Europe extending to central

Spain, the Caucasus and Iran in the south, but has only scattered localities (to 66° on the west coast) north of 57° in Scandinavia. This is its first record from this Interglacial.

Najas marina. The characteristic bivalve fruits of this species were obtained from Zone II N.*c*. This submerged aquatic is most frequently found in brackish water, as in its British localities in the Norfolk Broads, but has been repeatedly found fossil in freshwater deposits. Notably from the Post-glacial, these records occur far outside its present distribution in this country and in Scandinavia (Godwin 1956; Backman 1941). It requires a high concentration of electrolytes in the surrounding water (B. & C. Forsberg 1961), a character which Sammuelson (1934) used to explain its restriction of range within Scandinavia, by the impoverishment of the lakes. As with *Ceratophyllum demersum*, for which this reasoning was also cited, Godwin (1956) considered the controlling factor to be probably climatic, since its maximum extension coincided with the Post-glacial optimum. This is also the case for its records from the Eemian Interglacial. At Nechells, too, it seems to have been present about the optimal climatic period but its disappearance here was probably due to the restriction of open water in the lake. *N. marina* has also been recorded from this Interglacial from Clacton (Reid & Chandler 1923).

Nuphar pumila. Pollen of this species was identified from the higher zones. Its echinate, monocolpate pollen is distinguished from *N. lutea* by its more abundant echini which are shorter and broader than the more sparse and slender echini of *N. lutea*. It is a member of the floating leaf community in sheltered lakes with a northern distribution. Watts (1959*a*) recorded it from this Interglacial at Kilbeg.

Pimpinella saxifraga (figure 30, plate 9). One carpel, from Zone II N.*c*, of 2·15 × 1·45 mm, oval in outline and somewhat compressed, with a broad commissural face and bearing traces of five slight ridges, is identified as this species. It is a plant of dry grassy places and is considered to be a calcicole. However, it has a wide distribution in Britain though rare in north Scotland and Ireland, and is also widespread in the southern half of Scandinavia. This occurrence is its first record as a fossil in Britain.

Potamogeton spp. Seven species were identified from the numerous fruits found, according to the key of Jessen (1955) and modern material. Amongst those recorded were two of particular interest. *P. filiformis* was the earliest aquatic plant, recorded from the late-glacial lake deposits. Today it has a distinctly northern distribution, extending to the extreme north of Scandinavia and limited to Scotland, Anglesey and northern Ireland in Britain; and Sammuelson (1934) includes it as typical of the Swedish alpine zone. The other fossil records, consistent with this, are dominantly Weichselian Full- or Late-glacial.

P. pectinatus which appears shortly after *P. filiformis* has a much more southerly distribution, mainly south of 64° N. in Scandinavia. It is however strongly basiphilous and would be favoured by the eutrophic condition of the late-glacial lake at Nechells.

Sambucus nigra (figures 20, 21, plate 9). Large quantities of the characteristic seeds of *S. nigra* came from the upper part of the core. Seeds of this species have been frequently recorded from Pleistocene deposits of all ages, often in quantity, but there is only one previous reference to its pollen in Britain (Franks & Pennington 1961). The pollen of *S. nigra* is ellipsoidal—prolate to subspheroidal, 18·4–19·6 × 14·7–16·8 μm; tricolpate with an equatorial bridge or marked equatorial constriction, the colpi broad and shallow; polar area very small, the colpi often coalescing in treated material; exine distinctly two-layered, endexine *ca.* 0·45 μm, ectexine *ca.* (0·66–) 0·8 μm (–1·32); uniformly reticulate, luminae *ca.* 0·6 μm, with columellae projecting very slightly at the corners of the reticulum. *S. racemosa* pollen is apparently indistinguishable from this. *S. ebulus*, however, has much coarser reticulum, 1·3 μm, and thicker exine. Pollen of this type was found in small numbers throughout Zone II N. *d* and III N.

Stachys sp. Twenty nuts belonging to the genus *Stachys* were distorted and difficult to assign to a modern species, resembling both *S. arvensis* and *S. sylvatica* but too small for *S. palustris*. Statistical measurement of modern nuts showed that their breadth/length ratios, measured on the back of the nut, were consistently different, 1·2 for *S. sylvatica* and 1·3 for *S. arvensis*. Eighteen of the fossil seeds agreed with *S. arvensis* but two mature nuts had the ratio of *S. sylvatica* and are tentatively assigned to this species. *S. arvensis* today is a weed plant with a Sub-Atlantic distribution, less common in eastern Britain than in the west and common in Scandinavia only to 56° N. *S. sylvatica* is a woodland herb of wide distribution.

Stellaria graminea (figure 24, plate 9). A single seed of this species was found, 1·05 mm in diameter, decorated with narrow undulose divided ridges with interlocking spurs. *S. palustris* is larger and has shorter ridges. This is a common plant of woods or grasslands especially on light siliceous soils and has a wide distribution, extending to northernmost Scandinavia. It has not been recorded from this Interglacial and there is only one tentative record, from the Late-glacial, which is older than Roman.

Stellaria media. A single seed from Zone II N. *a*, 0·95 mm, with elongated but blunt tubercles, was identified as this species. This is a common plant of open habitats, and now a ruderal with a wide distribution.

Stellaria neglecta (figure 23, plate 9). One seed belonging to this species was found, of 1·5 mm diameter, subcircular, with rows of coarse tubercles without 'fingered' bases. These are mostly worn and broken but the complete ones are long (0·15 mm) and acutely pointed. Of the British species it agrees well with *S. neglecta*, differing from *S. media*, which has blunt tubercles and from *S. holostea* in which the tubercles are somewhat larger (0·15 to 0·2 mm) and more obtusely pointed. It is a plant of shaded habitats in wood margins, stream banks, etc., with a Sub-Atlantic distribution extending only into southernmost Scandinavia, whilst in Britain it is commonest in the west. Its occurrence therefore in the mild and oceanic Zone II N. *c* is consistent with this. *S. neglecta* has only one previous fossil record, from the Eemain deposits at Selsey (West & Sparks 1960).

Taxus baccata. Eight seeds of *T. baccata* came from Zone III N. *a* and upper II N. *d*. *Taxus* pollen is common at Nechells, as it is in the Irish Hoxnian interglacial deposits, and as it has been found to be, upon re-investigation, at Hoxne (West 1962). The pollen is characteristic (Andersen in Jessen *et al.* 1959) but difficult to identify when badly preserved, which it was in the brushwood peats of II N. *d*. (For initial aid in the identification of this pollen I am indebted to Dr W. Watts, of Dublin). The ecology and distribution of *Taxus* are discussed in Jessen *et al.* (1959) and Watts (1959 *a*).

Derived pollen and spores. Large numbers of microspores were found in the pollen slides, and compressed megaspores were common at several horizons in the macrofossil samples. These are similar to Carboniferous types, probably derived from the Coal Measures, which outcrop in the area drained by the proto-Tame, a content of coal detritus itself being a common feature of the drifts.

A curve for the frequency of the microspores shows a close relation to the content of allochthonous mineral detritus in the sediments (figure 5), as Andersen (1961) found for rebedded pollen in sediments of the Weichsel Glaciation. The significant features of both curves are: a large decrease at the opening of the Interglacial, a further decrease at the beginning of the period of closed forest vegetation, a short period of increased frequencies during the oscillation of II N. *b* 2, and increased amounts in the upper part where the sediments have a more fluviatile character.

The Carboniferous microspores are readily recognizable as secondary material and, therefore, do not confuse the interpretation of the pollen evidence, but secondary pollen of a more recent aspect, which will affect this, does occur, derived from Early Pleistocene or Tertiary deposits. It is apparent in the late-glacial period where it is responsible for the thermophilous tree component in the pollen assemblage. This, however, makes up $< 3\%$ of the pollen total and since presumably the frequency of this secondary pollen will follow the trend for the derived microspores curve, its effect will be insignificant during later periods. However, it may still be the explanation of solitary grains of unusual types, e.g. *Ephedra* in Zone II N. *b* 2.

4. The vegetation and environment of Nechells during the Interglacial

From the evidence of the palaeobotany and stratigraphy of the interglacial beds an attempt can be made to reconstruct the succession of the vegetation at Nechells, and to associate this with changing local edaphic and regional climatic conditions.

(*a*) *Zone I N*

This is the late-glacial period of the Elster glaciation, and its sediments clearly reflect its glacial character. Mostly they belong to an extensive glacial lake which was filling the valleys up to a level of at least 370 ft. O.D.; + 75 ft. deep at Nechells. Though the lake's existence required the north-eastern ice to be in the vicinity, the ice front could have been at least 12 miles away down-valley whilst maintaining this level (based on the present Solid topography).

I N. 1

The vegetation of this earliest part of the zone is known from a few macrofossils only, some or all of which may have been introduced by streams flowing into the lake. They indicate an early colonization of waters in the area by *Potomogeton* spp. and Characeae. Initially this was only by the northern species *P. filiformis*, but it was later accompanied by the basiphilous *P. pectinatus*, both of these and *Chara* indicating the eutrophic nature of the lake.

The terrestrial vegetation, pioneering on the bare drift surfaces above the level of the glacial lake, is only sparsely represented by fossils, but included at least *Sonchus arvensis*, *Arenaria serpyllifolia* and *Linum catharticum*. However, the ground probably largely remained bare until the spread of *Hippophaë rhamnoides*.

IN. 2

The glacial lake is thought to have been drained by the beginning of this sub-zone exposing the valley floor and lower hill-slopes, but leaving a remnant lake at Nechells of *ca.* 30 ft. in depth.

The lowest pollen sample suggests that a pioneer community dominated by *Hippophaë* had spread over the land surface as a whole (as West suggested for Hoxne) and was not restricted to the lake side as its present habitats might suggest. Pearson & Rogers (1962) give these as: river gravel and sand banks especially where calcareous, lateral moraine in alpine regions and coastal sand dunes. These indicate its ability to colonize an unweathered arenaceous substratum, such as was widespread at Nechells, when not overshadowed by other vegetation.

Grasses and sedges were at first less frequent than later and the other dwarf shrubs, including *Betula* (probably largely *B. nana*), were rare and the vegetation cover probably remained incomplete. This habitat suited the members of the Compositae (their pollen exceeds the total of all other plants) and amongst them were *Sonchus arvensis*, *Cirsium arvense* and *Matricaria chamomilla*.

IN. 3

The *Hippophaë* scrub declined rapidly, probably as a result of increasing competition as the vegetation cover closed; at first chiefly a greater abundance of herbs but with the dwarf shrub heath of *Juniperus communis*, *Salix* sp. and *Betula nana* becoming increasingly widespread.

The tree-birches (both *B. verrucosa* and *B. pubescens*) seem to have been present, as early as middle IN. 3, contributing equally with *B. nana* to the pollen rain, but would have occupied different habitats, presumably similar to those seen in S. Greenland. There tree-birches (*B. pubescens* agg.), though rarely morphologically trees, form dense scrub in favourable sheltered localities in valley bottoms at low altitudes, to within 2 miles of the Inland ice whilst elsewhere there is extensive *B. nana–Juniperus* heath. In Scandinavia also, *B. pubescens* var. *tortuosa* is characteristic of the sub-arctic zone.

The fossils suggest that in this zone the heliophytic plants had become more diverse and abundant, e.g. *Artemisia* sp., *Armeria maritima*, *Filipendula ulmaria*, *Plantago media*, *Galium* sp., *Thalictrum* sp., *Rumex* sp., *Valeriana officinalis*, *Botrychium lunaria*, *Ophioglossum vulgatum*, *Lycopodium annotinum*, and members of the Caryophyllaceae, Chenopodiaceae and Rosaceae.

In the lake the species present indicate a continuance of eutrophic conditions, e.g. *Chara*, *Myriophyllum verticillatum*, *Hippuris vulgaris*, *Potamogeton pectinatus*. Fringing it were reed swamps in which *Typha latifolia* may have been the major component since it can pioneer in this habitat, favoured by an inorganic substratum (van der Voo & Westhoff, 1961).

The vegetation of this period repeats the picture elaborated for the better known Weichsel Late-glacial, with pioneer communities of heliophilous and calcicolous plants colonizing the raw mineral soils, and basiphilous hydrophytes colonizing the richly eutrophic waters. It also conforms with the conclusion, that the flora of these periods had a unique character without comparison in the modern arctic and sub-arctic environments; namely the early appearance of relatively thermophilous plants, e.g. *Hippophaë*, *Valeriana officianalis*, *Typha latifolia* and the tree-birches. This presumably is an effect of

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latitude, with greater quantities of solar energy available at the lower latitudes (Thomassen 1956), perhaps allied to an initially rapid amelioration of the climate.

The succession of vegetation within the sub-zones illustrates the gradual colonization of the fresh fluvioglacial sediments: *Hippophaë* scrub and herbs of bare ground—grass/herb communities and *Juniperus–B. nana* heath—tree birch/*Salix* scrub with grass/herb and heath communities. It is largely a seral succession and need not be a direct result of continued climatic change; though perhaps modified by the delayed immigration of *Betula*. It is interesting that the appearance of tree birches is more or less contemporaneous with that of *B. nana*.

The climate of the Weichsel Late-glacial has been frequently discussed (Iversen 1954; Godwin 1956; and others), and the presence of various plants, which are also typical of the Elster late-glacial at Nechells, cited as indicative of relatively warm summer temperatures. Iversen has suggested that *B. pubescens* with *Hippophaë* meant a mean July temperature in excess of 10° C, and *T. latifolia* and *Filipendula ulmaria* a mean July temperature +14° C. The climate of this period at Nechells can perhaps be described as sub-arctic with warm summers.

(*b*) *Zone II N.a*

After the draining of the glacial lake, the local landscape was one of low relief with shallow, deeply infilled valleys with wide flat floors, surrounded by low (*ca.* 150 ft. high) flat-topped hills. This would provide a wide expanse of poorly drained habitats in the valley bottoms over much of which the vegetation described for the vicinity of the lake at Nechells would be typical. Better drained habitats would exist on the hill-slopes and valley-sides, whilst the hill tops probably constituted a third region, with less well-drained soils. Each would support different plant communities and the presence of these can be discerned throughout the Interglacial.

In the vegetation of this zone the tree-birches probably only formed closed stands in favourable areas and the vegetation had the open character of a forest tundra (lyesotundra, *sensu* Hustich 1953). In the stands of woodland, *Pinus* was associated with *Betula* and, apparently, also occasional *Quercus* and *Ulmus*. *Salix* was probably important on the wetter sites, perhaps with *B. pubescens*. Towards the end of the zone the woodland had expanded probably becoming for a while closed birch forest, before *Betula* was shaded out by the continuing expansion of *Quercus* which resulted in the oak woods of the next zone.

However, large areas remained open on the hills and exposed slopes until the final closing of the forest, supporting *B. nana–Juniperus* heath and a rich grass and herb flora. Notably heliophilous species amongst the herbs were: *Anagallis arvensis*, *Aphanes microcarpa*, *Arenaria serpyllifolia*, *Armeria maritima*, *Artemisia* spp., *Centaurea* sp., *Chenopodium rubrum*, *Leontodon autumnalis*, *Pastinaca sativa*, *Plantago media*, *Potentilla anserina*, *Prunella vulgaris*, *Scabiosa* sp. *Hippophaë* was also able to persist locally.

The lake continued to be eutrophic, and sufficiently calcareous to support *Chara* until the end of the zone. The species present earlier in the late-glacial were less abundant, perhaps as the lake was gradually impoverished as the production of organic detritus increased, though *Ceratophyllum demersum* and *Zannichellia palustris* had become frequent.

Extensive zones of vegetation had apparently already developed around the lake. In the littoral zones were *Sagittaria sagittifolia*, *Alisma plantago-aquatica*, *Schoenoplectus lacustris*, *Typha latifolia*, *Sparganium simplex*, *S. ramosum*, *Rumex maritimus* and *Ranunculus hederaceus*. In the marsh behind, spreading as the lake silted up, were *Apium graveolens*, *A. nodiflorum*, *Eupatorium cannabinum*, *Filipendula ulmaria*, *Galium* sp., *Hydrocotyle vulgaris*, *Lycopus europaeus*, *Mentha aquatica*, *Potentilla palustris*, *Ranunculus flammula*, *R. sceleratus*.

The basic changes in the vegetation: park tundra–birch forest–mixed oak forest continue the seral succession but the long continuance of open habitats indicated by the persistence of the late-glacial species implies the operation of some delaying factor, presumably climatic. However, temperatures had become sufficiently high to allow the presence of several plants of relatively southern distribution; *Aphanes microcarpa*, *Apium graveolens*, *A. nodiflorum* (the northern limits in Scandinavia of these and *Quercus* are very similar), and the probable presence of scattered *Quercus* and *Ulmus*. Moreover, this feature appears to be local since the forests of this period at Hoxne were closed (low *NAP*).

(*c*) *Zone II N.b*

The oak forest which gradually replaced the birch forest was composed of *Quercus*, *Fraxinus* and *Betula*, with *Pinus* and *Ulmus*. *Alnus*, *Corylus* and *Hedera* were also sporadically present. Of these *Fraxinus* would have been frequent in the wetter wooded habitats, before the spread of *Alnus*. In this closed forest, habitats for heliophilous plants were greatly reduced, but several species were able to persist into this period, e.g. *Aphanes*, *Armeria*, *Centaurea*, *Plantago*, *Pastinaca*. Graminae, however, remained exceptionally abundant, perhaps important in the field layer of the mixed-oakwoods as well as in the marshes.

Chara, *Myriophyllum* and *Hippuris* had evidently disappeared from the lake, which may have become mesotrophic as more humic matter was washed in and less mineral salts were available from the densely vegetated soils. The remaining limnophytes were joined by the free-floating *Azolla filiculoides*, which became common.

The continuing improvement of the climate enabled the appearance of *Alnus*, *Corylus* and *Hedera* in sub-Zone II N.*b* 1. The classic work of Iversen (1944) on *Hedera* suggests that the climate then exceeded the critical temperatures of +13·5° C summer and −1·5° C winter, the latter probably being the significant one in this case.

In the next sub-zone (II N.*b* 2) there is an apparent reversal of the trends of the preceding period, with the frequency of the remains of *Quercus* and *Fraxinus* reduced relative to those of *Betula*. Also there is a reappearance or increase of remains of *Juniperus*, *B. nana*, *Salix*, grasses and herbs, including the heliophytes *Armeria maritima*, *Cerastium vulgatum* and *Sonchus arvensis*, which suggests the creation of open habitats.

However at this time the level of the lake fell exposing the deposits in the shallow marginal areas to erosion, one result of which could be the secondary deposition of detritus, from the margins, in the remaining deeper parts of the lake, and therefore the occurrence of late-glacial plants at this horizon might be due to this alone. *Hippophaë* however is not found in this sub-zone which may be evidence against the reworking of late-glacial sediment. Apparently conflicting evidence is given by cold sensitive species; *Hedera* remains unaffected and there are traces of *Ilex*, whereas *Azolla* is very greatly reduced.

This oscillation also exists at Hoxne at this horizon where it can be explained equally by erosion of earlier sediments following a fall in lake level, or a cold oscillation.

The simplest explanation is that the observed lowering of the water table at Nechells represented a period of drier climate just possibly accompanied by colder conditions.

During II N.*b* 3 the conditions improved and the vegetation was again dominated by mixed oak forests but now with *Alnus* becoming increasingly abundant. In other respects the vegetation was similar to that of II N.*b* 1.

(*d*) *Zone II N.c*

Alnus soon dominated the local vegetation in this zone, probably having a twofold role: as a member of the general forest in a 'wet oakwood with ash and alder' type of community (Tansley 1939) on the wide valley floors, and secondly as alder fen-carr around the lake and in wetter areas elsewhere. Oakwoods continued to occupy the drier sites on the surrounding slopes and hills, with *Ulmus*, *Pinus*, *Fraxinus* and later *Tilia* as minor components. *Ilex* was present also, as a member of the second tree layer, *Corylus* as an undershrub and *Hedera* and *Lonicera* as woody climbers.

Taxus appeared a little later than *Alnus* but must have become very common. It is generally thought (Watts 1959*a*, and others) to have formed a second tree layer within the forests, and judging from Post-glacial occurrences it may have been common around the margins of the fen-woods (Professor H. Godwin, personal communication), leading to its abundance at Nechells.

The level of the lake had recovered within the preceding sub-zone and early part of this, but again dropped in the middle of the zone, apparently by about 10 ft., the lake thereafter remaining shallow. During this time the limnophytes flourished, including the eutrophic species, *Ceratophyllum demersum*, *Hippuris vulgaris*, *Najas marina* and *Potamogeton pectinatus*, which may have been due to an increase in the base status of the water as the erosion of the margins could supply mineral rich sediment. At the end of the period when only shallow pools persisted and alder fen-carr had become widespread these limnophytes had disappeared and only *Azolla* and *Nymphaea alba* were present.

The gradual decrease in abundance of the grasses, sedges and herbs records the encroachment of the carr over the open marsh. However, the shade-tolerant species typically associated with fen-carr were present or abundant: *Rubus fruticosus*, *Solanum dulcamara*, *Urtica dioica*, *Lycopus europaeus*, *Mentha aquatica*, *Ranunculus repens*, *Thalictrum flavum*, *Geum rivale*, *Sparganium ramosum*, *Carex riparia*. Other new marsh plants were *Bidens tripartitus*, *Valeriana dioica* and *Eleocharis* cf. *carniolica*.

Natural clearings, especially river and stream banks, provided open habitats for communities including such species as *Chenopodium rubrum*, *Lapsana communis*, *Pimpinella saxifraga*, *Stellaria neglecta* and *Viola* sp.

The rapid spread of *Alnus* after a long period of low frequencies would seem to be climatically determined (see next chapter) most likely due to an increase in the precipitation–evaporation ratio. Significantly its expansion coincided with the rising of the water-table which had resulted in renewed sedimentation in the marginal areas of the lake, independently suggesting an increase in precipitation. McVean (1953) considers that the eastern boundary of the present distribution of *Alnus glutinosa* correlates with the 20 in isohyet, though its northern boundary is probably temperature controlled (6 months less than 0 °C). A figure approaching this value might have represented the precipitation of the preceding period. However, over most of Zone II N. *c* it must have been greatly in excess of this as *Taxus baccata* today has a sub-oceanic distribution and Jessen *et al.* (1959) concluded that its presence at Gort was compatible with a climate similar to that of present-day Ireland—mild and wet, winter and summer.

The continuous presence of *Ilex* at Nechells suggests that minimum mean January temperatures were greater than 0·5 °C (Iversen 1944). If the appearance of *Hedera* and *Ilex* were climatically controlled then they indicate an increase in winter temperatures of *ca.* 1 °C between early II N. *b* and early II N. *c*. At Hoxne, *Tilia* is commonest in this zone and West, by analogy with the Post-glacial, considered that it was the period of optimum climate. This is not the case at Nechells where *Tilia* is more characteristic of the next zone.

On these criteria, it seems that the climate for II N. *c* was mild and warm, though not necessarily the period of maximum temperatures, and wet.

(*e*) *Zone II N. d*

Within this period the vegetation remained dominated by alder carr and mixed oakwoods, with *Taxus* less abundant than previously but with *Corylus* and *Tilia* at their most frequent. The conifers were also gradually becoming more frequent, mostly *Pinus*, but with *Picea* also definitely present.

At this time the site of the lake was probably a hollow within the alluvial *Alnus* woods of the valley, occupied by fen-carr and remnant pools of open water which were periodically receiving fluviatile sediments. The flora of the fen-carr is well represented; to the list of the previous zone can be added *Sambucus nigra*, *Euphorbia stricta*, *Lychnis flos-cuculi* and *Thelypteris palustris*, the latter characteristically abundant. The nitrophilous *Sambubus nigra* was frequent and may have been a colonist on areas of drying-out carr (Tansley 1939), suggesting a fluctuating water-table. The more or less restricted pools contained *Potamogeton coloratus*, typical of fen pools, and an abundant floating community of *Azolla*, *Nymphaea alba* and *Nuphar pumila* with *Alisma* and *Sagittaria*; and a reed swamp apparently exclusively of *Sparganium* spp.

Woodland herbs included *Moehringia trinervia*, *Ajuga reptans*, *Stachys sylvatica*, *Viola* sp., *Scirpus sylvaticus* and *Polypodium vulgare*, and herbs of river banks and marsh were *Ranunculus acris*, *Stachys arvensis*, *Rumex acetosella*, *Lychnis flos-cuculi*, and *Filipendula*.

By the end of this period the poorer soils would have become leached; the conifers *Picea* and *Pinus* were increasingly abundant and the presence of ericaceous plants and *Sphagnum* indicate that heath was beginning to develop.

As mentioned *Tilia* is commonest in this zone at Nechells, as it is at the Nar Valley Holsteinian site (Stevens 1960), implying that it was the warmest; though this is not the case at Hoxne. At all sites *Corylus* is most frequent during this period, at Nechells perhaps partly replacing *Taxus* in the oakwoods. It is probable that the zone continued to be warm and moist.

(*f*) *Zone III N. a*

The coniferous forest spread rapidly at the beginning of the period, reducing the oakwoods to local occurrences only, *Alnus* however continued to be common on the wetter sites. Initially *Picea* dominated a forest which included *Pinus*, the remnants of the oakwoods of *Quercus*, *Corylus*, *Taxus* and the newcomers *Acer* and *Carpinus*.

The ground layer of these woods contained species characteristic of damp habitats, notably *Chrysosplenium alternifolium*, *Hymenophyllum tunbrigense* and frequent *Polypodium vulgare*. In the alder carr the typical herb communities persisted whilst the remaining open water supported the northern *Nuphar pumila* and occasional *Azolla*. Heath was gradually becoming more extensive, probably on the hill-tops, but the forest in general remained closed.

The sudden expansion of the coniferous forest is suggestive of a climatic deterioration and West thought that for Hoxne this may have been a decrease in winter temperatures. Temperatures, especially winter ones, might be deducible from the presence of *Picea*, for Jeffree (1955) considered that its present distribution suggests the temperature limits of: winter, −17 °C minimum to −1 °C maximum; and summer, 12 to 21 °C. However, Jessen *et al.* (1959) believe that its western limit, beyond which winter temperatures were thought to be too warm to allow a normal resting period, may not be so clearly controlled since *Picea* propagates freely in plantations in Scandinavia where winter temperatures are up to 1 °C. Furthermore, with *Hedra* and *Ilex* almost as frequent as earlier, winter temperatures would seem to have been above 1 °C.

Several plants of relatively southern modern distribution suggest that summers continued to be warm; *Tilia*, *Carpinus*, *Carex riparia* and *C. pseudocyperus*; the present northern limit of the latter indicating a July mean +15 to 16 °C.

The humidity can also be considered to have been high especially from the presence of *Hymenophyllum tunbrigense*. Recent work (G. B. Brown unpublished) suggests also that this species requires a minimum annual precipitation of 30 in.

The climate therefore appears to have remained dominantly oceanic, mild and warm.

It is probable that it was edaphic factors which allowed the replacement, by *Picea*, of the mixed oak forest by the development of acidic podzols, the oceanic climate of the preceding zones leading to the leaching and increasing acidity of the soils. Allied to this was the spread of heath on ill-drained uplands. This explanation also allows for the different behaviour of *Picea* at Hoxne and on the Continent.

(*g*) *Zone III N.b*

Abies became the dominant conifer, soon after its appearance, in a forest largely of *Abies*, *Picea* and *Pinus* with more occasional *Betula*, *Quercus* and *Taxus*; *Alnus* still occupying the wetter sites. The vegetation was otherwise similar to that of III N.*a* but with a virtual absence of hydrophytes.

In the mountains of central Europe today *Abies* (with *Fagus*, cf. the Holsteinian) forms the vegetation zone below that of *Picea*. Therefore the successful competition of *Abies* with *Picea* during the Interglacial may have been allowed by an increase in summer temperatures. Furthermore, it is the period of *Abies*-dominated conifer forest which is considered to be the time of optimum temperatures, in central and eastern Europe (see below).

There also remains the possibility that its expansion marks only its immigration into an area, as has been shown for the Post-glacial. However, *Abies* pollen is known not to be transported far and there is some evidence that the tree was in the vicinity of Nechells somewhat earlier than the pollen suggests. This is the presence of a beetle which today specifically feeds on *Abies alba* (*Platypus oxyurus*), at two levels within II N.*d* (work in progress by F. W. Shotton & P. J. Osborne).

However if delayed immigration was the underlying cause *Abies* may have arrived, like *Taxus*, from Ireland where its appearance is perhaps much earlier.

Both *Abies* and *Hymenophyllum* require high humidities and the climate obviously continued to be dominantly oceanic.

Alluvial sediments are characteristic of these periods and the lake-site was most likely incorporated by then in the general flood plain. In consequence this zone is probably greatly condensed and the period it represents is likely to be much longer than the thickness of sediment present suggests. This also applies to the other upper zones.

(*h*) *Zone III N.c*

Pinus forest now became widespread with *Picea* and *Abies* as minor constituents only, but with *Betula* and *Salix* becoming more frequent. *Alnus* continued to dominate the low-lying wetter sites such as Nechells but was virtually absent from the higher surrounding areas, e.g. Cardigan Street. In the damp forest *Polypodium vulgare* and *Hymenophyllum tunbrigense* were locally abundant and *Mercurialis perennis* and *Hypericum hirsutum* were present.

The forest was now much more open and heathland was probably extensive, with communities of *Calluna vulgaris*, *Empetrum nigrum*, *Erica* sp., *Lycopodium annotinum* and *Sphagnum*. More significant was the development of open grassland communities with the reappearance of heliophilous plants that were common in the late-glacial, *Juniperus*, *Artemisia*, *Centaurea* and other members of the Compositae, *Helianthemum*, *Rumex acetosella* and *Selaginella selaginoides*.

The replacement by *Pinus* of the other conifers suggests a deterioration of the climate (the first major one), perhaps notably a drop in summer temperatures. The thermophilous trees, including *Taxus*, were virtually absent whilst the increase in open habitats with their characteristic flora signifies the proximity of the early glacial conditions preceding the next glaciation. An area in which the flora of this zone is found today would be in west-central Scotland (delineated especially by the present distributions of *Lycopodium annotinum*, *Mercurialis perennis* and *Hymenophyllum tunbrigense*) and its climate may resemble that of Zone III N.*c*.

The development of the vegetation and environment at Nechells which has been described follows a general pattern that is beginning to be discerned in all the Interglacial periods, though with varying form (Firbas 1949; Iversen 1961; Andersen 1964). At Nechells this can be summarized as:

(1) Ameliorating climate, open vegetation of light-demanding plants on unleached calcareous soils (I N and II N.*a*).

(2) Closed broad-leaved forest, the climax vegetation on forest brown soils (II N.*b* to *d*).

(3) Largely closed coniferous forest, some open heath, the climax vegetation on acid podsols (III N.*a* to *b*).

(4) Deteriorating climate, change of coniferous forest components, forest increasingly open, with heath and grassland (III N.*c*).

(1–3) correspond to the Protocratic, Mesocratic and Oligocratic stages of Andersen, whilst (4), defined on the temperature decline, in part corresponds with the Telocratic of Iversen.

Andersen has described these stages for an Eemian and a possibly Cromerian site in Denmark and Nechells (and Hoxne) are similar to these in possessing a well-developed Mesocratic stage. It is interesting that in many of the Holsteinian sites from the Continent, however, this stage is virtually suppressed.

5. Correlation with other areas

(*a*) *Interglacial Series*

On stratigraphical evidence the interglacial beds at Nechells are with certainty pre-Saale and most likely post-Elster, and Duigan has already concluded that the pollen sequence dates them to the Holsteinian (Hoxnian) Interglacial. A detailed comparison of the pollen diagrams from Nechells has already been made with those from Hoxne, which is stratigraphically pre-Saale and archaeologically 'Great Interglacial' (Holsteinian). Despite certain differences, the two are obviously similar and could only belong to the same Interglacial. This degree of similarity extends also to the other English Hoxnian sites if allowance is made for the non-recognition of *Taxus*. Saints Cross, South Elmham (West 1961 *b*) covers Zones II.*a* to II.*d* and closely parallels Hoxne. Clacton (Pike & Godwin 1953) is more restricted and covers only the period of deciduous forest and its replacement by *Abies* dominated coniferous forest. In the latter it resembles Zone III N.*b* of Nechells, but differs in the preceding phase as it has very low values of *Picea*. Several spectra from deposits of this age at Kirmington (Watts 1959 *b*) have essentially similar characteristics to this period with low *Picea* at Clacton. The upper marine sediments of the Nar Valley interglacial beds (Stevens 1961) comprise Zone III and are also similar to Clacton whilst the older freshwater deposits cover Zones I to II. *d*. Whilst the character of the latter are to some degree comparable to other English sites they differ markedly in lacking the development of oak forests and having *Pinus* dominating the general vegetation.

Correlation with the Holsteinian sites on the Continent, and in Ireland is however initially less obvious. Many deposits of this Interglacial have been described but relatively few cover a major part of it in any detail. Amongst those which do are diagrams from Ireland, Kilbeg (Watts 1959 *a*) and Gort (Jessen *et al.* 1959); Netherlands, Bantega (Brouwer 1949) and Rosmalen (Ridder & Zagwijn 1962); Germany, Hummelsbüttel and Weichel (Hallik 1960); Denmark, Tornskov (Andersen 1963); Czechoslovakia, Stonava (Vodickova-Kneblova 1961); and many from Poland (in Szafer 1953; Sobolewska 1956; Srodon 1957).

As previous authors have remarked these differ from most English sites in their lack of the development of a phase of *Quercetum mixtum* forest. In its stead *Pinus* with *Betula* and later joined by *Picea*, forms the regional forest for most of the Interglacial. However, this distinction is made less marked by the existence of a cline in the forest composition, within England and extending to the Continent. Approximate figures for the percentages of *Quercus* during the period prior to the *Alnus* maximum (Zone II N.*b*) are: Nechells, 60%; Hoxne, 40%; South Elmham, 25%; Rosmalen, 20%; Bantega, 15%; Hummelsbüttel, 5%. Nechells is at one extreme with the greatest development of oakwoods. Eastern Europe is at the other since *Quercus* is scarcely present until much later. Contrary to the direction of this gradation, Ireland (Kilbeg) and also the Nar Valley, show most affinity to the Continent (10%).

Apparently the two basic forest types had the same role in the vegetation during the same period. This may be due to edaphic differences on a regional scale such that coniferous forest developed on widespread thin or rapidly leached soils and oakwoods on the more fertile (Watts 1959*a*), but it is more probably conditioned by a complex of factors.

When finally the soils deteriorated in England the forest composition became more orthodox, with conifers, though mainly *Picea*, replacing the oak forest.

Apart from this, one of the features of this Interglacial is the uniformity of the vegetation and its development.

The late-glacial and early Interglacial phases are naturally similar everywhere. Where the diagrams extend low enough they begin with a sub-arctic vegetation in which *Hippophaë* is characteristically important (Nechells, Hoxne, Baggotstown, Ireland (Watts, in the press) and suggested by the bottom sample of Hummelsbüttel).

This is later succeeded by a phase of *Betula* with *Pinus* forest, to be followed either by the *Pinus* or *Quercetum mixtum* forest.

In all the diagrams the behaviour of *Alnus* is strikingly similar, showing a rapid and great expansion after a relatively long period of low but continuous values. This suggests that its rapid expansion was a response to a climatic change, prior to which it had a wide distribution but a much more restricted occurrence. This parallels its behaviour in the Post-glacial when it increased abruptly at the Zones VI/VII transition; for which a change in climate is invoked. The nature of this change has been considered to be either an increase in summer temperatures (Firbas 1949) or an increase in precipitation (Godwin 1956; and others). In the Holsteinian at Nechells it was accompanied by a rise in the water table which, since the area is beyond the influence of eustatic rise in sea-level, infers that the latter change was the case. If it is so climatically determined the expansion of *Alnus* will provide a useful datum for correlation.

It now appears that in the *Pinus–Picea–Alnus* or *Quercetum mixtum–Picea–Alnus* forests *Taxus* was a typical component of the vegetation at one period. It had a wider geographical distribution than at present, having been recorded in pollen diagrams from Ireland (Gort and Kilbeg), England (Nechells and Hoxne), Denmark (Tornskov) and Poland (Gosciecin) and from other sites as macrofossils (see Jessen *et al.* 1959), which suggests that its pollen may exist unrecognized at these. Its first appearance was usually after the expansion of *Alnus* (after the rise in humidity) and its main occurrence was before the expansion of *Abies* (England, Denmark and Poland). However, in Ireland it appeared earlier, at the *Alnus* expansion, and was associated with *Pinus*, *Picea*, *Abies* and *Rhododendron*.

This unique flora is indicative of more oceanic conditions than is represented by the floras elsewhere. Though the climate of the Interglacial was apparently more uniform in some respects than today, there yet existed some geographical variation.

The subsequent phase of vegetation is characterized by the expansion of *Carpinus* and then *Abies* and, at least in Poland and probably elsewhere, it represented the climax vegetation of the Interglacial optimum, on leached soils. Their frequency in the forests varied, *Abies alba* being most frequent to dominance in England and Poland whilst much less so in northern Europe. *Carpinus* is scarce in England, but a major constituent in central and eastern Europe, which reflects the easterly trend to increasing continentality.

Buxus is another southern plant typical of this Interglacial with a distribution well beyond its present limits. In Poland and Czechoslovakia it occurred during the *Abies* phase but elsewhere it was also present earlier (Gort, Kilbeg, Nechells, Tornskov).

In Poland exotic thermophilous water plants are found in the levels of the *Abies* phase, pointing to its relationship with the climatic optimum—*Trapa* and *Aldrovanda* at Nowiny Zukowskie and also *Azolla* in Poland (Sobolewska 1956); whilst *Aldrovanda* also occurs in Czechoslovakia (Stonava). Elsewhere *Azolla* is found in earlier vegetation phases and is almost ubiquitous in northern Europe (van der Vlerk & Florschutz 1953; Tralau 1959) though perhaps not uniquely characteristic of this Interglacial (p. 571).

The vegetation of the middle stages of the Interglacial indicates that a warm and humid climate was widespread (over Europe) and as Watts (1961) has emphasized extending even into eastern Europe.

Everywhere the temperature decline at the end of the Interglacial is marked by the extension of *Pinus* and *Betula* forests with the increasing formation of open heaths and grasslands as the next glaciation approached.

Thus it can be seen that the vegetational history at Nechells fits into the general pattern for the Holsteinian Interglacial, with its distinctive characters part of regional variations due to climatic and perhaps edaphic differences.

(*b*) *Glacial Series*

The demonstration of the Holsteinian age of the Nechells Interglacial dates the deposits of the First and Second Glaciation to the Elster and Saale respectively, as Duigan had previously established.

The succession has already been compared with that given by Pickering for south Birmingham. Almost all the deposits of both areas relate to the history of the north-western ice sheets but they can be correlated with that of north-eastern ice through the succession for the south Midlands (Shotton 1953). This also correlates them with the standard successions for other regions of Britain (see Shotton 1953, p. 238).

The Elster glaciation is represented there by the 'Bubbenhall Clay' which includes lake deposits, and possibly also tills, and is thus genetically equivalent to the varved clays (N. 2) of Nechells. The two may even be the products of the same ice sheet since the lake at Nechells implies damming by ice from the north-east.

In the south Midlands, as in Birmingham, the Interglacial was mainly a period of erosion, and so far no locally preserved deposits belonging to it have been found.

Just as at Birmingham the topography allowed the formation of the glacial lakes in both Elster and Saale times. In the south the deposits of the Saale Glaciation are dominated by the 'Wolston Clays' of glacial Lake Harrison, the surface of which was at about 435 ft. O.D. (Bishop 1958), and Pickering correlated his lake at 431 ft. O.D. (Lower Still Water Deposits N 4. *c*), with it. Tills of the same glaciation have now been shown to exist below the lake deposits in Birmingham, but this need not invalidate the correlation. The deposits of this lake are more extensive than those associated with lakes formed by local ice advances and retreats and are not restricted to the southern tributary valleys, and moreover it would require ice from the north-east to dam up the lower reaches of the main valley. The ice advancing from the north-east, damming up Lake Harrison, would provide this.

Presumably the lake at 431 ft. O.D. would correlate with the latest stage of Lake Harrison and therefore its deposits with the topmost 'Upper Wolston Clay'. This means that the three oscillations of the ice front prior to this, which Shotton records, predates this stage at Birmingham. If the north-western ice behaved similarly to the north-eastern, these oscillations are not all recorded at Birmingham.

Thus at Birmingham the north-western ice, not unexpectedly, was present in the area before the influence of the north-eastern ice was felt.

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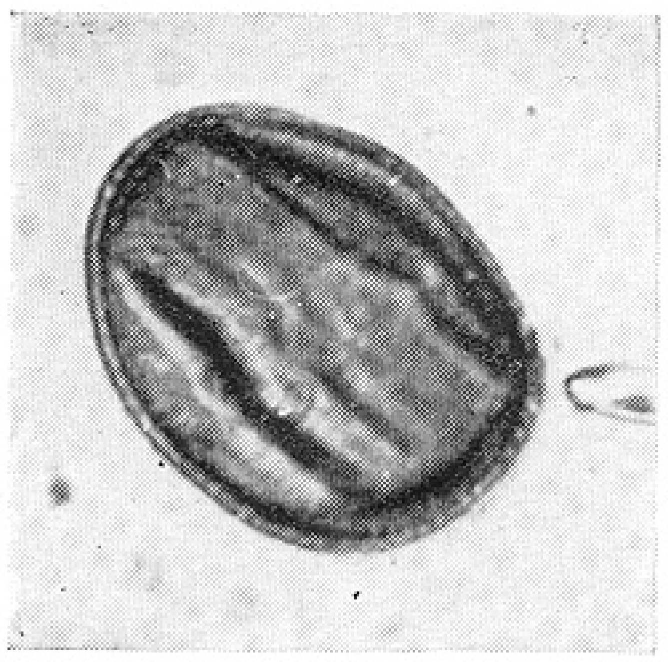

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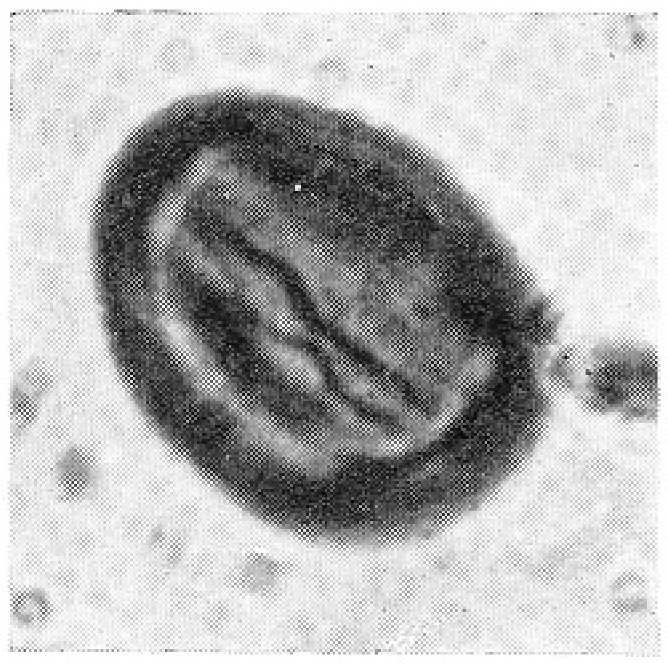

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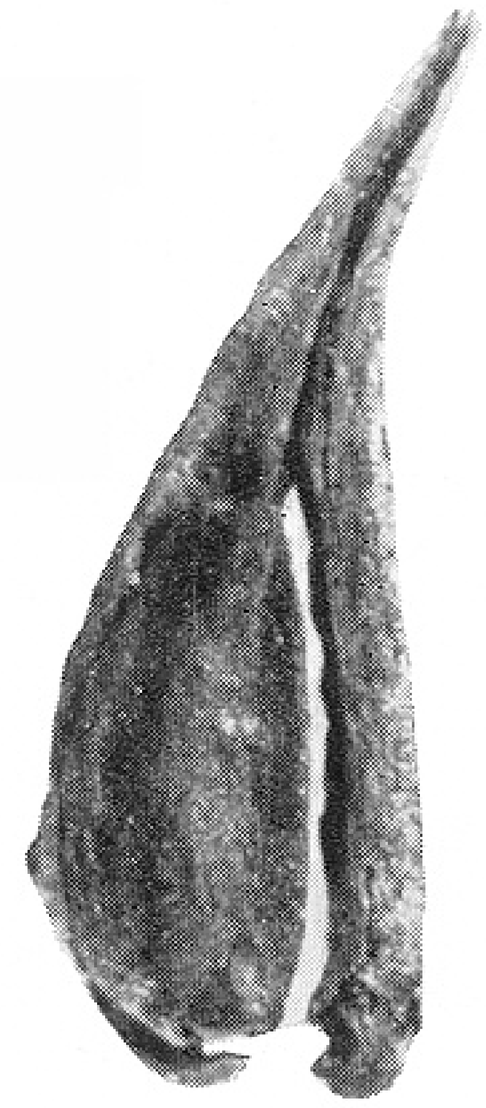

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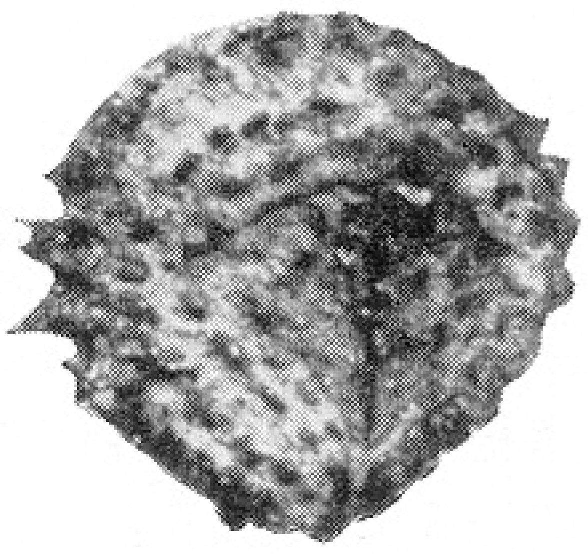

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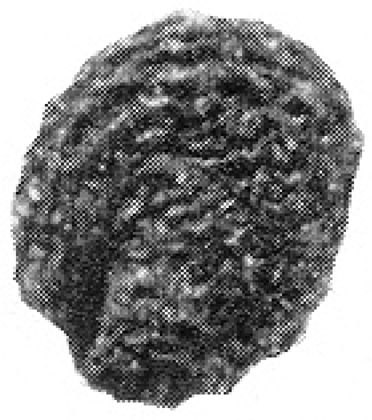

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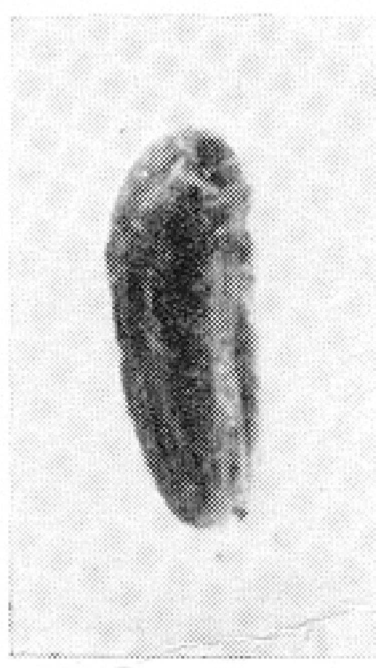

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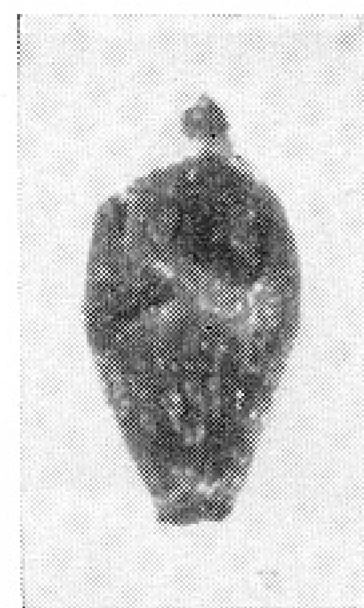

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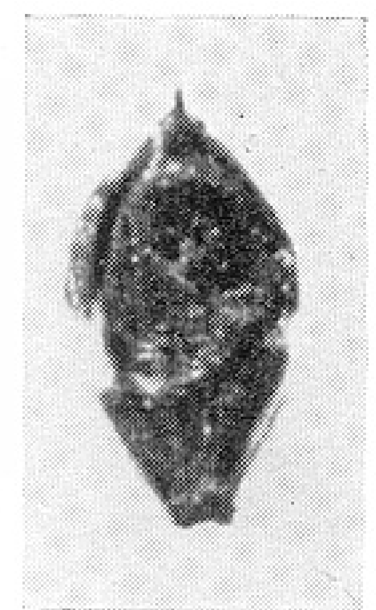

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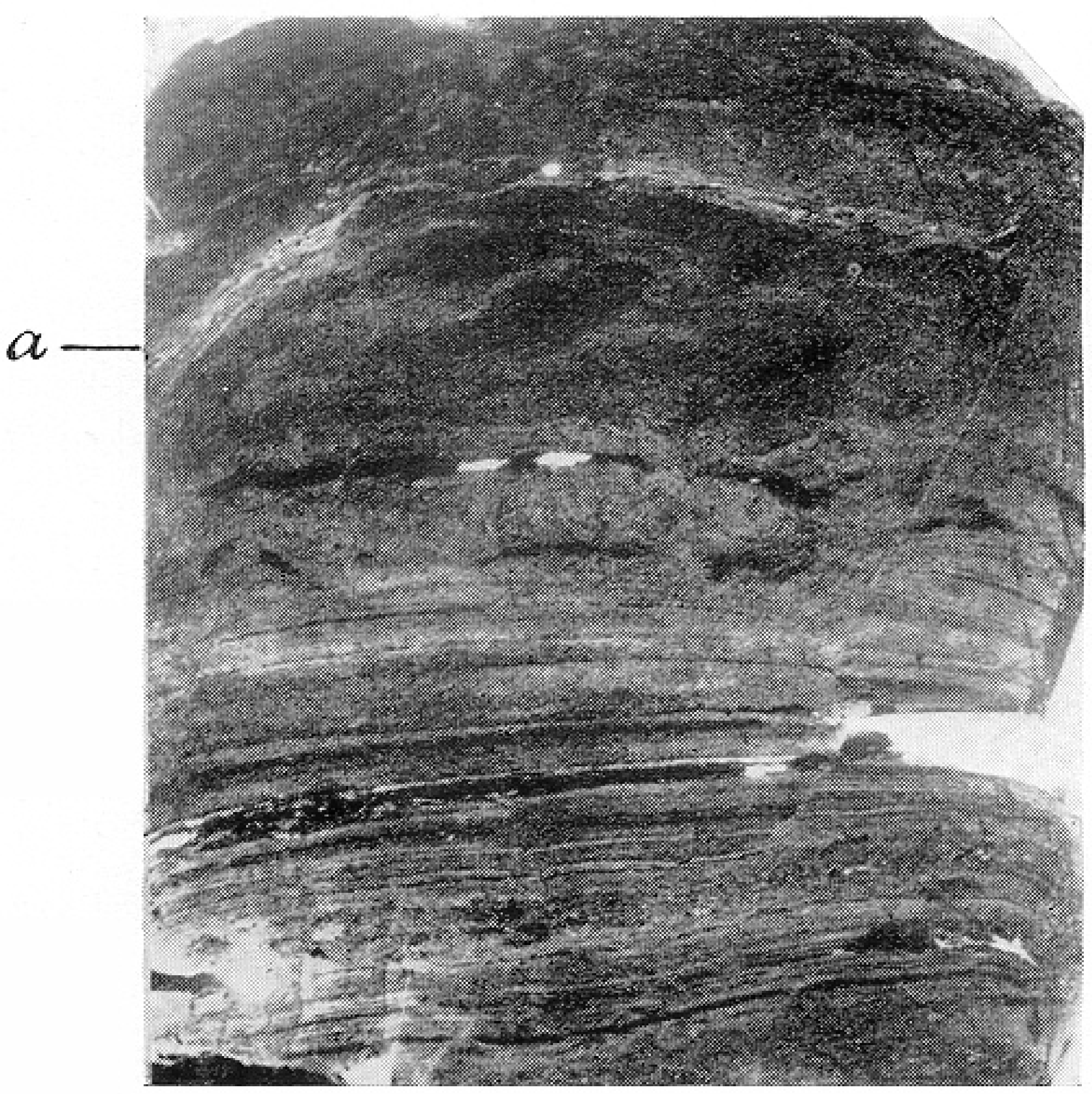

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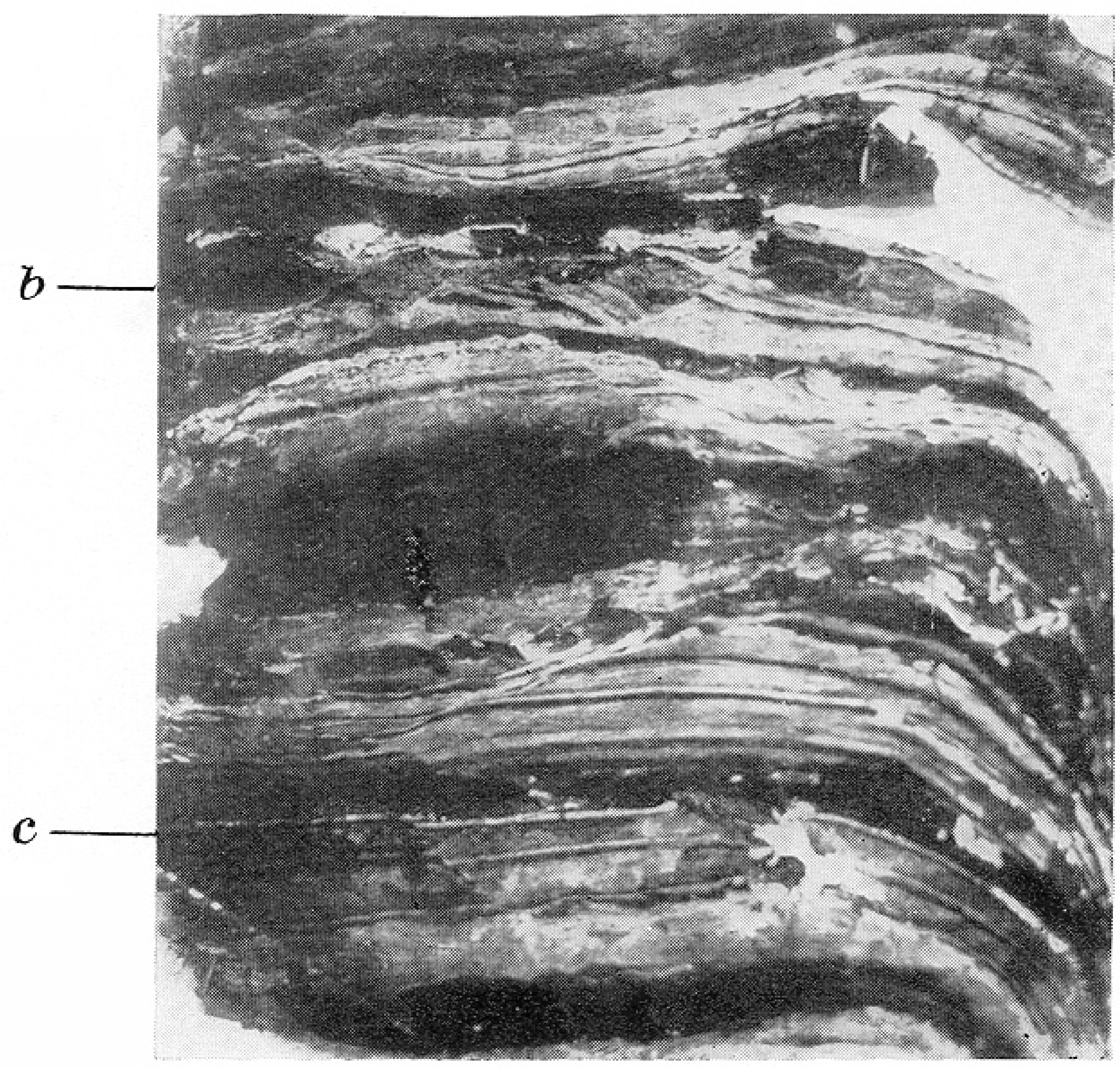

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