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R. G. West

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INTERGLACIAL DEPOSITS AT BOBBITSHOLE, IPSWICH

By R. G. WEST

Sub-department of Quaternary Research, University of Cambridge

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[Plates 1 and 2]

CONTENTS

The stratigraphy and palaeobotany of fresh-water interglacial deposits at Bobbitshole, Ipswich, Suffolk, have been investigated. The interglacial deposits are shown to occupy a lake basin in a valley cut in the local plateau, which is partly formed by a chalky boulder clay assigned to the Gipping ice advance. In this basin was deposited a series of lacustrine sediments, first silt (probably of aeolian origin), then clay-mud and finally clay. These interglacial sediments are sealed unconformably by sandy gravel, probably deposited under cold conditions.

Pollen diagrams and macroscopic plant remains from the interglacial deposits are described. They give evidence of the vegetational and climatic history during the first half of an interglacial period. The succession of pollen zones found is similar to that described from the Eemian (Last) Interglacial in north-west Europe, with which the interglacial is correlated. The Eemian pollen zones *b*, *c*, *d*, *e* and *f*, which show the succession from birch- to pine- to oak-dominated forest, are all present. An analysis of the very abundant macroscopic plant remains, together with the pollen results, suggests a rapid amelioration of the climate at the beginning of the interglacial period, and in zone *f*, the final zone represented, there are indications of a summer warmth exceeding that of the present day in the area. The interglacial flora is particularly rich in aquatic plants, and an analysis of the abundance of each species indicates a vegetational succession, as the lake filled with sediment, from open-water to reed-swamp to marsh vegetation.

The palaeobotany of the deposits is briefly compared with that of other interglacial deposits in Britain and on the continent.

The correlation of the interglacial deposits with the continental Eemian (Last) Interglacial provides confirmation of the correlation of the Gipping ice advance with the Saale Glaciation of northern Germany, and indicates that the covering gravels are of Last Glaciation age.

The interglacial deposits are partly below sea-level, and close to the tidal Orwell estuary. The significance of this for local relative land- and sea-level changes in and after the interglacial is discussed.

1. Introduction

Deposits of very fossiliferous lacustrine clay-mud covered by gravel were discovered at Bobbitshole, near Ipswich, Suffolk, by Mr H. E. P. Spencer in 1952 (Spencer 1953). The site of Bobbitshole (a small neighbouring property, National Grid Reference TM 148414, O.S. 1 in. Sheet no. 150) lies in the valley of the Belstead Brook, about a mile south of Ipswich (figure 1). The Belstead Brook joins the estuarine River Orwell less than a mile to the east, the tides being excluded from the flood-plain of the Brook by a sea wall.

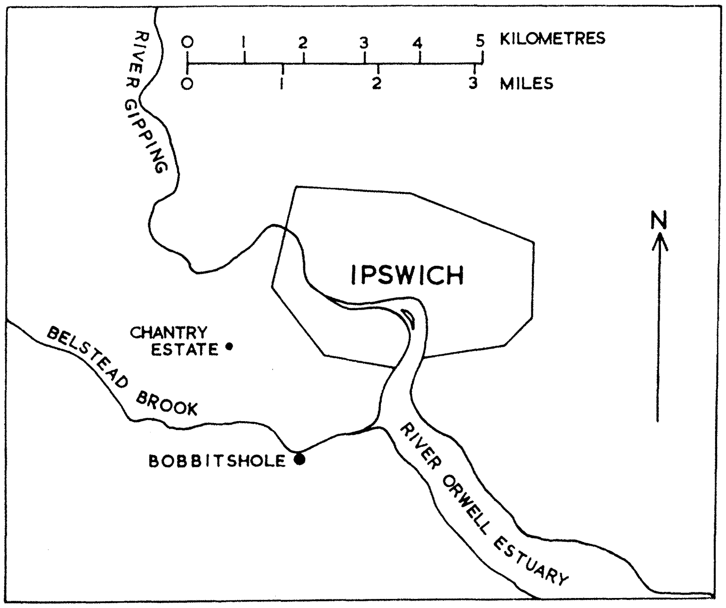

Figure 1. The location of Bobbitshole, Ipswich.

The organic deposits were exposed during the construction of a sewerage works by the Ipswich Corporation in the valley of the Belstead Brook. During these excavations several sections were recorded and samples for pollen analysis taken from them. The pollen analyses from these preliminary samples showed that the organic deposits were formed under interglacial climatic conditions. Clear indications were also present in the vegetational succession shown by the analyses that the organic deposits were laid down in the first half of the Eemian (Last) Interglacial. A sequence of organic deposits of such an age has not been reported from Britain previously, and in order to obtain a more complete succession of the deposits a borehole taking continuous 4 in. cores was made.

The samples from these cores and those taken previously contained abundant fruits, seeds and non-marine Mollusca, as well as pollen. The plant remains and stratigraphy are described here. The non-marine Mollusca and their relation to the vegetational and climatic succession given here are described by Sparks in the following paper, p. 33.

2. Stratigraphy

(a) *Local geology*

The geology and relief of the area are described in the *Geological Survey Memoir* explaining the New Series Sheet 207 (Boswell 1927). The geological map shows that the surrounding heights are covered by drift deposits, chiefly boulder clay to the north and west and

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glacial sand and gravel to the south and east, so that the south-east margin of the boulder clay appears to be in this region. The valleys in the area are, in general, cut through the boulder clay and glacial sand and gravel of the plateau into the Crags and Tertiary clays lying beneath them, though Boswell (1927) has described glacial drift occurring in places in buried channels in the present valleys. At Bobbitshole the alluvium of the Belstead

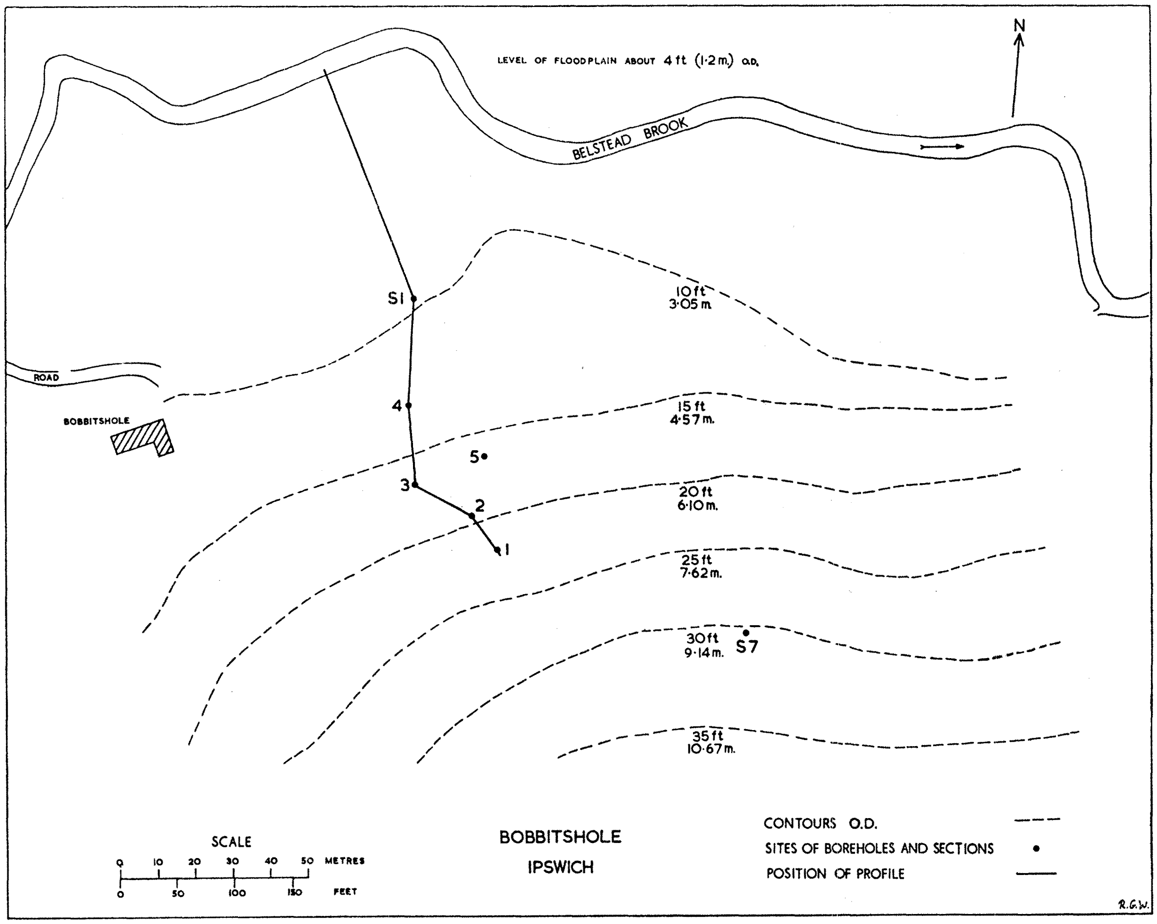


Figure 2. Map of Bobbitshole, with positions of sites of boreholes and sections and of the profile, figure 4.

Brook is shown on the geological map to lie on London Clay and Oldhaven Beds, with Red Crag outcropping at the valley sides, and glacial sand and gravel lying on the Crag on the heights around.

(*b*) *The interglacial and related deposits*

The records of sections exposed during the excavations and of boreholes are given in the appendix. These records make it possible to describe in outline the stratigraphy of the interglacial and related deposits. A more detailed stratigraphical investigation was prevented by the thick covering gravel.

The positions of the sections and boreholes, including two trial boreholes, S1 and S7, made by Ipswich Corporation, are shown in figure 2. The stratigraphical results are embodied in the profile (figure 4), the position of which is shown in figure 2. The sediment symbols used in the profile and in the pollen diagrams are explained in figure 3.

The following strata are distinguished:

A. Red and grey roughly sorted sandy gravel, with sand and clay layers, non-calcareous.
B. Mottled red, grey and yellow shelly clay, calcareous.
C. Brown shelly clay-mud, slightly sandy, calcareous.
D. Grey silt, calcareous.
E. Brown sandy clay and sand, with inclusions of brown chalky boulder clay, calcareous.

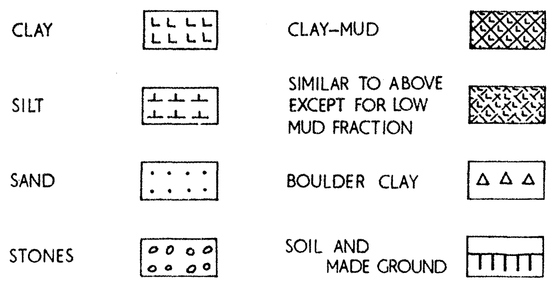


Figure 3. Sediment symbols used in the profile and the pollen diagrams.

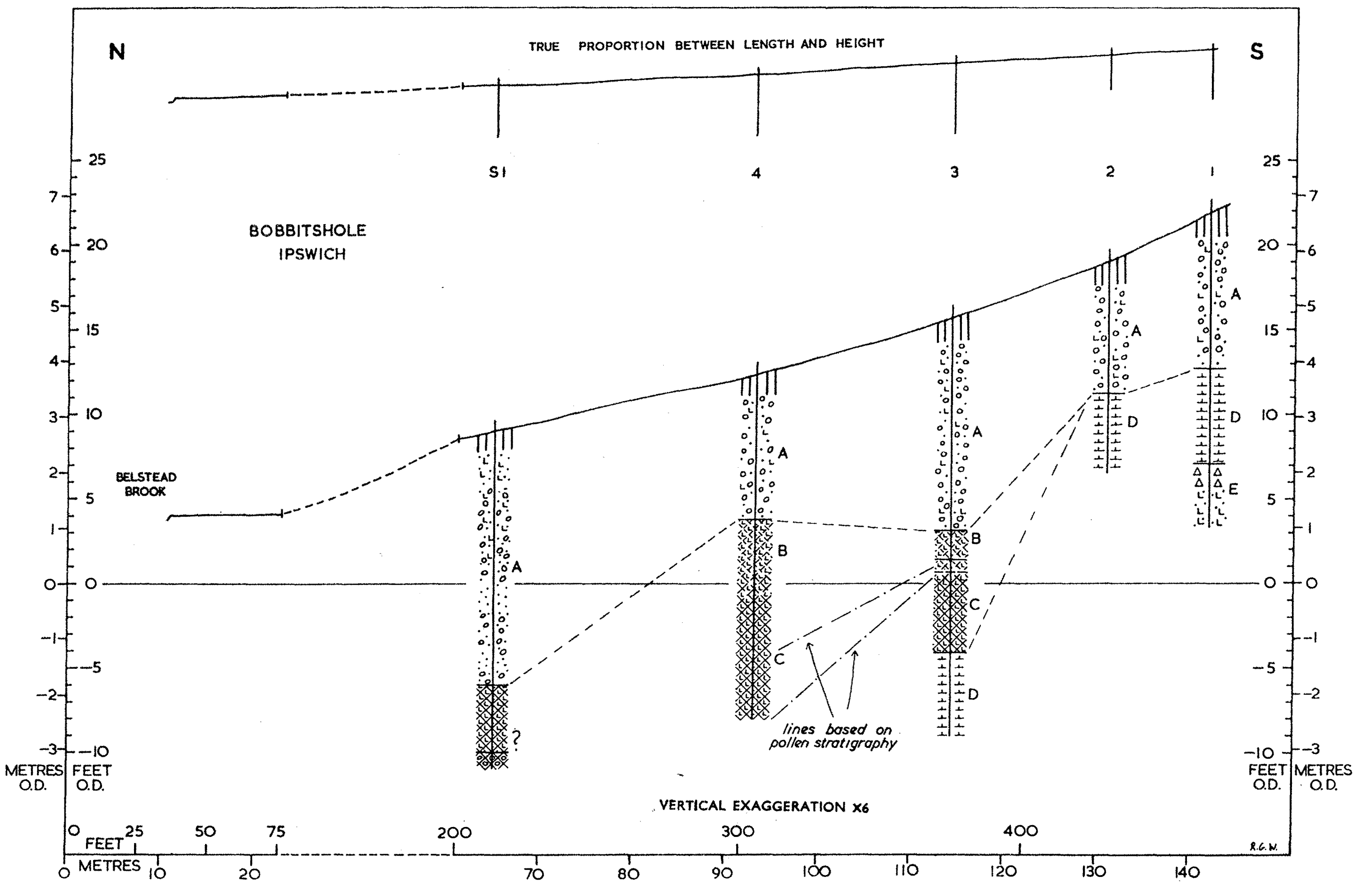


Figure 4. North-south profile through the deposits.

(i) *Stratum E*

Stratum E was only seen near the base of the section at site no. 1. Here a brown sandy clay with sand inclusions lay beneath a fragment of brown chalky boulder clay. This layer of boulder clay appeared to be a raft in the sandy clay, for in auger holes put down a few feet away it was missing.

The origin of the stratum is not clear from the small exposure. The boulder-clay fragment was identical in appearance with the uppermost of the two kinds of boulder clay known in the Ipswich area, that is, with the Gipping Boulder Clay of Baden-Powell (1948). The older boulder clay, Baden-Powell's Lowestoft Boulder Clay, is, in contrast to the brown Gipping Boulder Clay, dark blue in colour in the Ipswich area. The nearest exposure of boulder clay to Bobbitshole was seen in sections excavated during the construction of the Chantry Estate, on the plateau about a mile and a half to the north-west of Bobbitshole. The position of the Chantry Estate is shown in figure 1. Here the sections showed 2 m of brown chalky boulder clay of Gipping type lying on Red Crag. Stone orientation measurements of this till by West & Donner (1956) gave an orientation conformable with the direction of the Gipping ice advance in this area. It therefore seems probable that this local plateau boulder clay is of Gipping age. Thus both the boulder-clay fragment at Bobbitshole and the local plateau boulder clay appear to be of Gipping age. The relation between the two exposures is not clear. The fragmentary nature of the Bobbitshole boulder clay suggests that it was derived from the plateau during the erosion of the valley of the Belstead Brook, rather than that it was laid down by a valley lobe of the Gipping ice after the deposition of the plateau boulder clay. The geological map certainly suggests that erosion of the valleys took place after the deposition of boulder clay on the local plateau, indicating a phase of erosion between its deposition and that of the boulder clay in the valley at Bobbitshole.

(ii) *Stratum D*

In the section at site no. 1 grey calcareous silt was seen to be overlying stratum E. The silt is shown in the photograph (figure 8, plate 1). The junction between the silt and the lower stratum was irregular, but not obviously unconformable. The silt dipped steeply northwards, where it was seen in the section at site no. 3 to be covered conformably by the clay-mud of stratum C. The maximum depth of the silt seen was 1·3 m; Spencer (1953) reported that he found a thickness of 16 ft. (4·9 m).

Sedimentary analyses of the silt were made by Dr I. W. Cornwall of the University of London Institute of Archaeology, and he has kindly allowed his results to be given here in table 1*A*. The analyses show the preponderance of the silt fraction, and they have the proportions characteristic of loess; an aeolian origin of the silt is suggested. Laminations seen in the silt indicate that it was water-lain, and, remembering the uniform nature of the stratum, it may be concluded that wind-blown material was deposited in quiet water.

(iii) *Stratum C*

In the section at site no. 3 the top of the grey silt of stratum D passed upwards through a transitional layer to the darker clay-mud of stratum C. The maximum depth of the stratum found was 2·2 m in the borehole at site no. 4. Sediment analyses from the deposit are given in table 1*B*.* They show an increase in the inorganic fraction and a decrease in the organic fraction towards the top of the stratum, a change which corresponds to the change in colour at the level of core 4 (borehole at site no. 4) from brown to grey.

* The author is indebted to Mr H. H. Nicholson, Reader in Soil Science in the University of Cambridge, for having the samples from strata B and C analyzed.

The clay-mud had a coarse-textured mud fraction and contained frequent fragments of squashed wood and also abundant fresh-water Mollusca. Evidently it is a deposit of shallow fresh water.

The deposition of the clay-mud followed conformably the deposition of the underlying silt, a transition occurring between them which showed a gradual increase in the organic content of the silt.

TABLE 1. SEDIMENT ANALYSES

(The particle-size scales in *A* and *B* differ)

A. From stratum D; percentages of total inorganic sediment

sample	particle sizes (mm): <0·002 clay	0·002 to 0·006 silt	0·006 to 0·02 silt	0·02 to 0·06 silt	0·06 to 0·2 sand	0·2 to 0·6 sand
1. 2 m below the transition from stratum C to stratum D, near the section at site no. 3	11	3	14	67	4	1
2. at south end of the profile (figure 4)	15	9	23	44	6	3

B. From strata B and C in the borehole at site no. 4; percentages by weight of air-dry sample

sample	particle sizes (mm): <0·002 clay	0·002 to 0·02 silt	0·02 to 0·2 fine sand	0·2 to 2 coarse sand	$CaCO_3$	loss on ignition	H_2O	organic carbon
stratum B:								
1. top of core 1	26·8	16·9	13·7	0·02	35·8	4·6	3·5	1·24
2. bottom of core 2	25·5	15·6	17·4	0·7	31·0	4·6	3·7	1·96
3. top of core 3	20·2	13·0	25·4	0·7	29·7	8·7	2·9	4·60
stratum C								
4. top of core 4	13·9	7·8	31·7	5·5	25·0	10·1	3·2	6·66
5. top of core 6	14·5	9·2	21·9	1·1	26·0	21·2	5·6	14·80

An unconformity within the stratum towards the edge of the lake at site no. 3 is indicated by the pollen-analytical results described later. The unconformity is shown in the profile (figure 4). A drop in lake water-level during the deposition of the stratum, with consequent erosion and/or non-deposition at the edge of the lake, is suggested.

In some of the excavations the brownish clay-mud of stratum C was irregularly bleached in its upper part (figure 9, plate 1). Such an effect was probably caused by post-depositional weathering.

(iv) *Stratum B*

This stratum of mottled red, grey and yellow sandy shelly clay, seen in figure 9, plate 1, appeared to lie conformably on stratum C in the borehole at site no. 4, but in the section at site no. 3 pollen-analytical results show that there is an unconformity between the two deposits. At the marginal part of the lake basin, by site no. 3, a period of non-deposition with or without erosion may have again occurred, as suggested by the profile (figure 4). Both erosion and non-deposition may have been caused by a drop in water-level, but not a sufficient drop to cause a cessation of deposition in the deeper part of the lake basin by site no. 4.

Sediment analyses from stratum B are given in table 1*B*. These show stratum B to differ from stratum C in having a greater amount of the finer mineral fractions, more calcium carbonate and less organic carbon (the organic carbon fraction may be considered proportional to the organic matter in the sample; a conventional multiplication factor of 1·724 is sometimes used to convert the organic carbon to the total organic matter). The lowering of the organic fraction may in part be caused by weathering processes, for decalcification, race and a purple iron-manganese accumulation layer were observed at the top of the stratum in various places. Pollen was present only in very small amounts in stratum B in the borehole at site no. 4, the only grains preserved being those known to be resistant to weathering. As described above, stratum C also appeared to be weathered paler in places to a colour similar to that of stratum B, and this made it difficult to make a real separation between the two strata. They are evidently both a part of a continuous period of sedimentation in the deeper parts of the lake basin, with the analyses showing at least a change in the rates of sedimentation of the mineral fractions. The continued abundance of the fresh-water Mollusca in stratum B (except where it is decalcified) show that shallow fresh-water conditions persisted throughout the deposition of the stratum, but beyond this it is not possible to say anything from the stratigraphy. Further evidence on the origin of the stratum was obtained from the plant remains and is discussed in §4(*g*).

(v) *Stratum A*

This stratum, mainly of red sandy gravel, overlies the older deposits (including London Clay in borehole S7) unconformably. The junction between it and the lower beds was irregular, the stratum appearing to cut into the underlying deposits, as shown in figure 8, plate 1.

The gravel was roughly stratified and sometimes sorted, and clay and sand layers were observed within it. Spencer (1953) described a raft of silt of stratum E lying in the gravel. He also described the lower part of the gravel as fluviatile, and the upper part as clayey and unsorted.

The origin of the stratum is difficult to interpret. The gravels must in part be water-lain, and it also seems probable from the lithology and from the distribution of the stratum that solifluxion played some part in their deposition. The rafting of the lower soft deposits suggests deposition under cold conditions when such rafts might be frozen. It thus appears that the gravel was deposited in a cold period at some time after the deposition of the interglacial deposits. The unconformable lower boundary of the stratum and the fact that the pollen-analytical results show the upper part of the interglacial to be missing suggest that the base-level was lowered and erosion followed by deposition of the gravel occurred. Such a sequence could be caused by the lowering of sea-level during the glaciation following the interglacial.

(*c*) *The relation of the deposits to the relief of the land*

A question remains as to whether the lake beds are part of the old valley deposits of the Belstead Brook valley or whether they occupy an isolated hollow in the older deposits now coincident with the present valley. The profile given in figure 4 appears to give evidence that the interglacial deposits are part of the valley system, but as we know of their extension only in a direction at right angles to the present valley and not parallel to it, such an indication is not conclusive. The fragmentary boulder clay below the interglacial deposits, as discussed above, suggests that after the Gipping ice advance a period of erosion occurred in which the valley was formed. If this is correct the interglacial deposits must be regarded as valley deposits.

This question of whether the interglacial deposits are part of the valley system or not is of importance when considering any relative land- and sea-level changes indicated by the presence of fresh-water interglacial deposits. At present the estuarine River Orwell is less than a mile down the valley to the east, and the Belstead Brook would be tidal were it not for a barrier near the estuary. It is seen in the profile (figure 4) that the fresh-water deposits extend to at least 2·5 m below O.D. If the fresh-water deposits were part of the valley system, then a connexion of the valley-level to the sea-level would be indicated. It would follow that throughout the first part of the interglacial either the level of the land relative to the sea would be higher than at the present time and/or that the sea was considerably more distant than it is at the present time. Only a complete isolation of the lake, and this is hardly possible in view of the nature of the fossil contents, might prevent such a conclusion. The matter of relative land- and sea-level changes in the interglacial is discussed further in §§4 (*g*) and 5 (*c*).

3. Pollen diagrams and plant remains

(*a*) *Introduction*

The main fossiliferous horizon of the interglacial deposits was found to be the clay-mud of stratum C. Both pollen and macroscopic plant remains were abundant in this layer. The grey silt of stratum D and the clay of stratum B contained little pollen and no macroscopic plant remains.

Bulk samples for washing for macroscopic remains were taken from the cores of the 4 in. borehole at site no. 4 and from various sections exposed in the excavations.

Samples for pollen analysis were taken from the cores of the borehole at site no. 4 and from the section at site no. 3. The samples from the borehole cores were taken down the centres of the cores after sawing them in half lengthways. Core 5 fell out of the coring tool during removal, and had to be taken out with an auger; the pollen samples at this level were taken from the auger sample. During the boring some sediment was lost between the cores, but the pollen diagrams from the cores show that there are no large gaps between them.

The results of the pollen analyses are expressed in the pollen diagrams (figures 5 and 6). The percentages are based on counts of 150 tree-pollen grains. *Corylus* and other shrubs are excluded from the tree-pollen total and from the tree pollen (*AP*)/non-tree pollen (*NAP*) ratio. The *NAP* total also excludes pollen of water plants and spores. The massulae of *Salvinia* are recorded in the non-tree pollen diagram not in numbers but as present or absent. The *Sparganium* curve includes all *Sparganium* and *Typha* pollen types except for the tetrads of *Typha latifolia*, which are recorded separately.

The tree-pollen frequency is expressed as the number of traverses required to count 150 tree-pollen grains, an approximate and relative method of measurement.

Figure 3 explains the sediment symbols used in the pollen diagrams.

The plant nomenclature is based on the *Flora* of Clapham, Tutin & Warburg (1950).

(*b*) *Pollen diagrams*

The tree- and non-tree pollen diagrams from the interglacial deposits are shown in figures 5 and 6 respectively. The diagrams from the section at site no. 3 and the borehole at site no. 4 are superimposed to give a composite diagram. It was hoped that the diagrams would overlap, but the borehole, which was made after the samples from the section had been analyzed, had to be abandoned after the ninth core had been taken. However, little seems missing between the diagrams (as indicated in the profile, figure 4), for the base of the upper diagram closely resembles the top part of the lower diagram, if we except the top pollen-rich sample of the lower diagram. The analysis from this sample differs much from the next lower analyses, but resembles analyses from core 7 in the upper diagram. Thus there appears to be an unconformity towards the top of the lake deposits in the section at site no. 3; this unconformity is marked by a dashed line across the stratigraphical column of the lower diagram.

The composite diagram can therefore be considered to represent a continuous period of vegetational history with the sequence shown by the upper diagram following on that of the lower diagram, with the exception that the differing distances of sites nos. 3 and 4 from the edge of the interglacial lake will mean that the influences of the local vegetation will differ. The difference does not affect the general zonation of the diagrams, which is made on the tree-pollen curves, themselves dependent on the regional rather than the local vegetation.

The composite pollen diagram closely resembles the diagrams from the Eemian (Last) Interglacial Period described by, amongst others, Jessen & Milthers (1928) and van der Vlerk & Florschütz (1950). We may therefore apply the scheme of zonation for this interglacial first put forward by Jessen & Milthers (1928). Zones *b*, *c*, *d*, *e* and *f* of Jessen & Milthers are distinguishable in the diagrams. The characteristics of these zones and their demarcation in the pollen diagram is as follows (the youngest zone at the top):

Zone *f*. Upper diagram: 3·5 to 5·2 m; lower diagram: sample at 4·5 m. Zone of *Quercus*, *Pinus* and *Corylus*. The base of the zone is where *Corylus* begins to rise to high values. *Quercus* culminates in this zone.

Zone *e*. Upper diagram: 5·2 to 6·2 m; lower diagram: 4·6 to 5·0 m. Zone of *Pinus* (dominant), *Betula*, *Quercus* and *Ulmus*. The base of the zone is where the *Quercus* curve starts to rise. *Pinus* and *Ulmus* culminate in this zone.

Zone *d*. Lower diagram: 5·0 to 5·3 m. Zone of *Betula* (dominant), *Pinus* and *Ulmus*. The base of the zone is where *Pinus* and *Ulmus* start to rise and *Betula* starts to decline.

Zone *c*. Lower diagram: 5·3 to 5·9 m. Zone of *Betula* (dominant) and *Pinus*. The base of the zone is where *Betula* and the tree-pollen frequency increase. *Betula* culminates in this zone.

Zone *b*. Lower diagram: 5·9 to 6·1 m. Zone with low tree-pollen frequency. *Betula* dominant. *Pinus*, *Juniperus* and abundant herbs present.

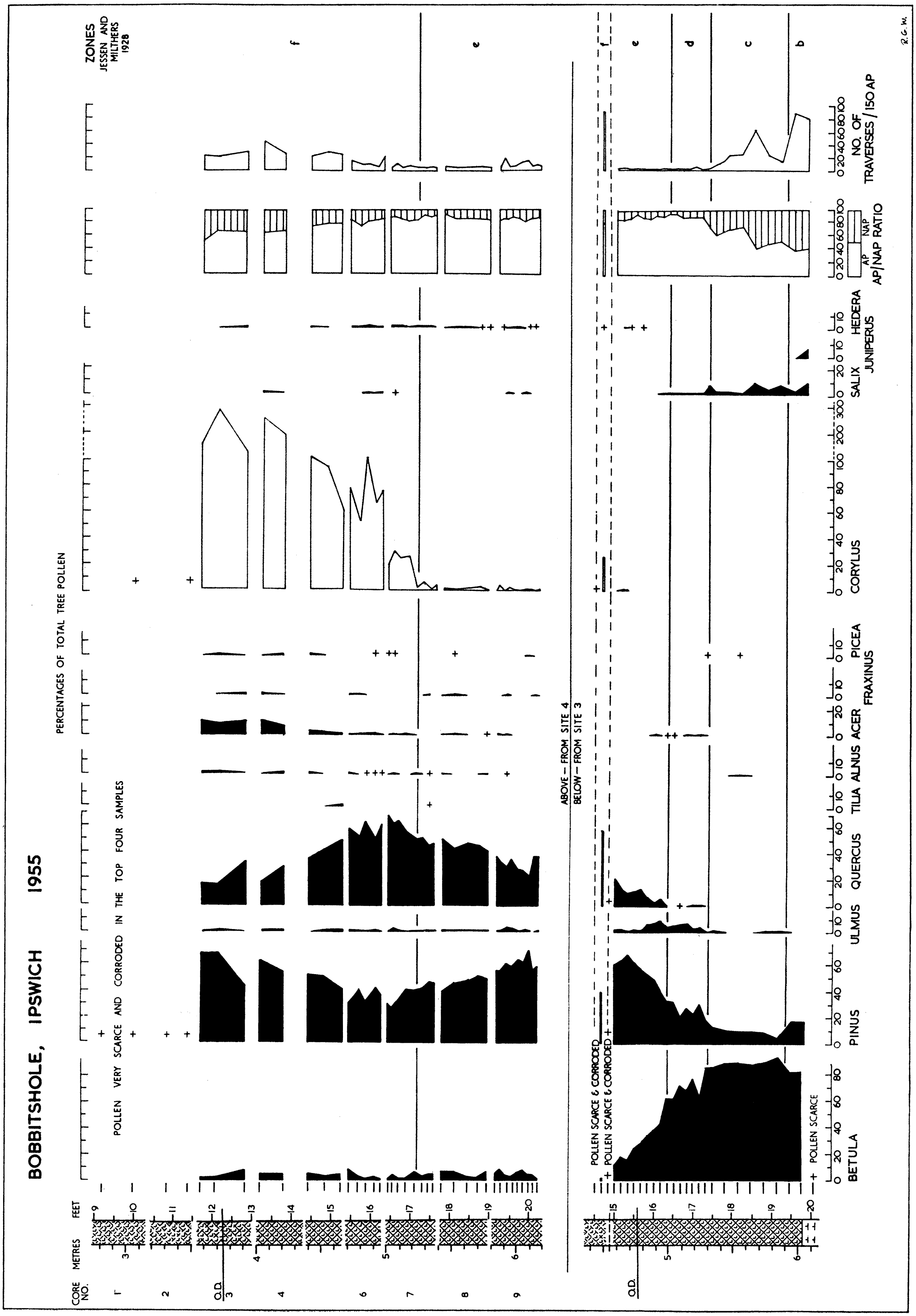


FIGURE 5. The tree-pollen diagram.

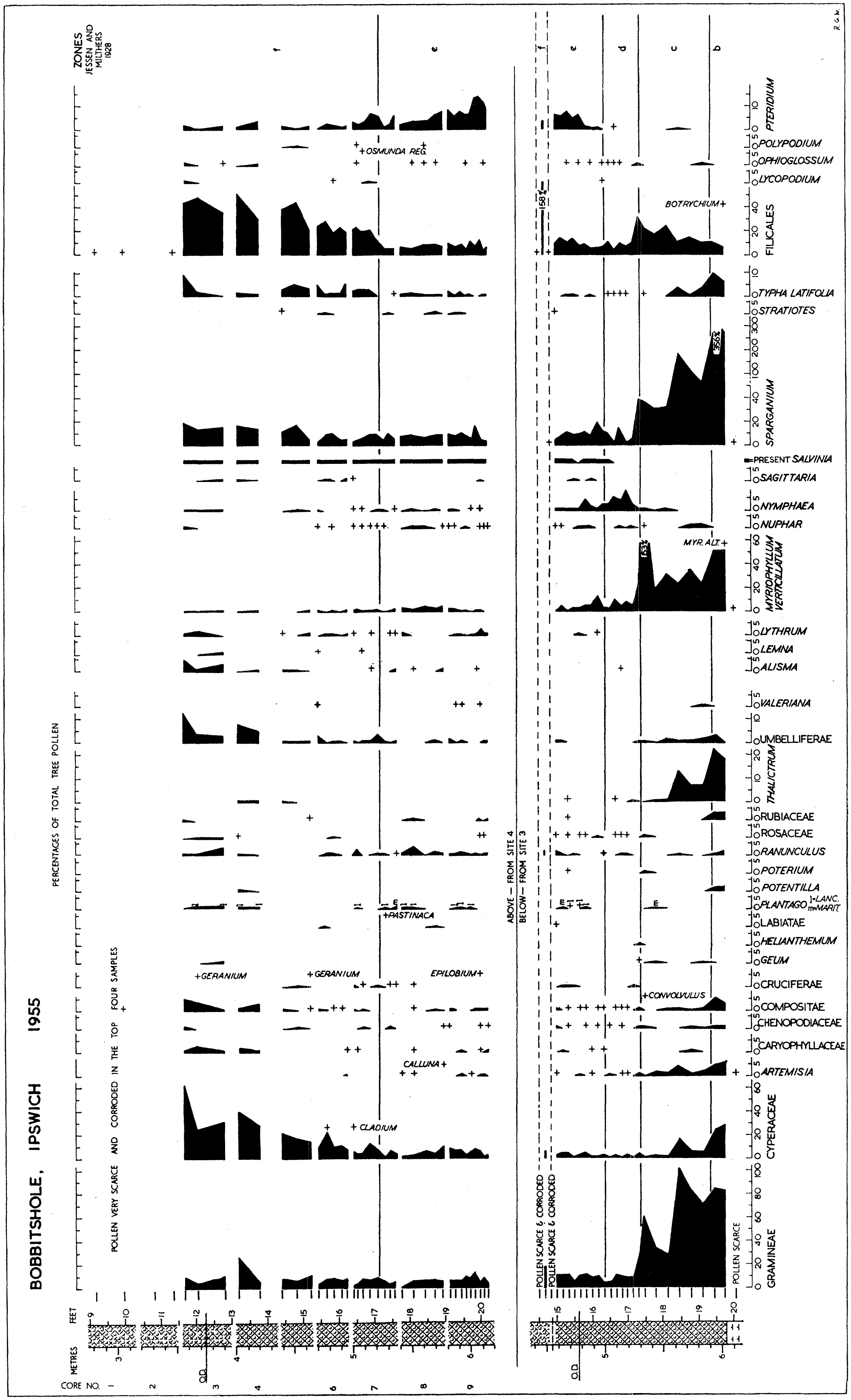


FIGURE 6. The non-tree pollen diagram.

(c) *Macroscopic plant remains*

Bulk samples of equal size from the top (affix *t*) and bottom (affix *b*) of the cores of the borehole at site no. 4 were washed for macroscopic plant remains. Cores 1 and 2 were sterile, the top half of core 3 (sample 3*t*) contained only few remains, and the bottom half of this core and the remaining cores were all highly fossiliferous. No bulk samples from core 5, lost during its extraction, were obtained. Samples from the section at site no. 3, samples A and B, from depths of 4·6 and 4·8 m respectively, were also washed.

The above samples are from known depths in the borehole at site no. 4 and the section at site no. 3, and their relation to the pollen stratigraphy is therefore known. The remaining samples washed include one from the section at site no. 5, sample E, and five small blocks of sediment, samples C, D, F, G and H, collected from the excavations by Mr H. E. P. Spencer. The positions of these six samples in the pollen stratigraphy were determined by pollen analyses of them. The tree-pollen analyses from these samples are given in table 2, together with the relation of the samples to the pollen stratigraphy shown by the composite pollen diagram.

The macroscopic plant remains from all these samples are listed in table 3 (see pp. 14–15).

Table 2. Pollen analyses from samples washed for macroscopic remains

	C	D	E	F	G	H
	(percentages of total tree pollen)					
Betula	34	45	52	69	90	94
Pinus	61	48	45	29	8	5
Ulmus	3	3	3	2	—	—
Quercus	2	4	—	—	1	1
Alnus	—	—	—	—	1	—
NAP total, excluding pollen of water plants and spores, expressed as percentage of total *AP* + *NAP*	9	6	15	9	53	59
approximate equivalent depth in lower pollen diagrams (m)	4·8	4·9	5·0	5·2	5·7	5·9
zone	*e*	*e*	end of *d*	*d*	*c*	*b-c* transition

During the washing of the samples for plant remains numerous small brown capsules (figure 22, plate 2) were isolated. I am indebted to Miss D. M. Burkill, of the Department of Zoology, University of Cambridge, for the following report on these objects:

'The specimens are smooth, dark brown, flattened spheres and ovoids from 0·5 to 1·0 mm in diameter. They are most probably the egg-capsules of *Turbellaria*. The lack of sculpturing and the negative reaction to the chitosan test for chitin precludes the possibility that they could be the remains of aquatic insect eggs. The relatively large size and the substantial wall suggests that the egg-capsules are of triclad origin rather than of other turbellarian orders. It is improbable that the capsules belong to parasitic platyhelminth orders since they have no spines and lack a cap. All the capsules show an uneven rupture, presumably caused by the emergence of the young.

'The genera to which the cocoons belong cannot be determined, since unstalked spherical or oval cocoons are laid by several genera living in the shallow water at the edge of lakes. Some genera could, however, be eliminated by the lack of a stalk on the cocoons.'

The numbers of these capsules found at the different levels of the borehole at site no. 4 are shown on the right of figure 7.

4. The vegetational and climatic history of the interglacial period

(*a*) *Introduction*

The pollen diagrams and macroscopic plant remains described in the preceding section may now be used in the reconstruction of the vegetational and climatic history of the interglacial period.

The present-day distributions of the various plants, of significance in considering the course of immigration of the flora and the climatic implications of the immigration, are taken chiefly from Hultén's (1950) *Atlas of the distribution of vascular plants in N.W. Europe*. Table 4 is an attempt to summarize the process of immigration of the flora, as shown by the list of macroscopic plant remains. Six categories of plant distribution type were made, which could be used in connexion with Hultén's atlas. The categories are

Table 4. Analysis of plant-geographical categories in the list of macroscopic plant remains

The figures give the number of species (or genera) in each category in each zone; figures in parentheses are the percentages of the zone totals in each category

	category						
zone	1	2	3	4	5	6	zone total
f	—	13 (25)	8 (15)	8 (15)	19 (37)	4 (8)	52
e	—	12 (32)	7 (18)	6 (16)	12 (32)	1 (3)	38
d	1 (5)	5 (25)	3 (15)	5 (25)	5 (25)	1 (5)	20
c	—	4 (50)	1 (13)	2 (25)	1 (13)	—	8
b-c transition	1 (14)	2 (28)	—	3 (42)	1 (14)	—	7

Definition of categories:

1. Arctic-alpine plants.
2. Plants distributed throughout Scandinavia.
3. Plants with northern limits in Scandinavia near the Arctic Circle.
4. Plants with northern limits in Scandinavia about midway between those in categories 3 and 5.
5. Plants with northern limits in the south of Scandinavia.
6. Plants with northern limits in north-west Europe south of Scandinavia.

defined in the table, and the placing of each species (or genus where this was possible) in its category is shown in table 3. Table 4 is constructed from the plant list in table 3, except that records of *Salvinia natans* are included. Pollen and spore identifications are excluded from the table because the significance of the frequency of these in relation to the local flora varies widely.

(*b*) *Zone b*

The earliest of Jessen & Milthers's zones seen in the pollen diagram is zone *b*. The low tree-pollen frequency, low *AP*/*NAP* ratio and abundance of herbs during zone *b* indicate an open aspect of the vegetation at that time, with only sparse tree cover. The one important tree represented in the zone is *Betula*. Only low values of *Pinus* are recorded;

TABLE 3. LIST OF MACROSCOPIC PLANT REMAINS

			zone	...	*f*						*e*								*d*		*c*	*b-c* transition
				core samples from borehole at site no. 4												samples from the section site no. 3		miscellaneous samples				
species (species illustrated are marked with an asterisk)	distribution category	type of remains	sample	... 3*t*	3*b*	4*t*	4*b*	6*t*	6*b*	7*t*	7*b*	8*t*	8*b*	9*t*	9*b*	A	B	C	D	E	F	G	H
			total specimens in sample ...	6	159	208	407	429	405	367	143	142	185	160	338	173	191	51	27	128	18	56	18
			(the figures give the number of specimens of each plant at each level)																				
Acer cf. *monspessulanum* L.	6	*fr*		.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ajuga cf. *reptans* L.	5	*n*		.	.	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Alisma plantago-aquatica L.	3	*fr*		.	22	15	84	9	2	3	3	4	2	2	10	.	.	2	1	.	1	.	.
Betula cf. *nana* L.	1	*fr*		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1
B. pubescens Ehrh. or *B. verrucosa* Ehrh.	2	*fr*+*cs*		.	.	.	.	.	.	.	.	.	1	.	1	3	85	11	2	7	7	2	.
Berula erecta (Huds.) Coville	5	*fr*		.	8	12	15	21	21	16	5	10	10	5	18	2	.	.	.	.	.	.	.
Bidens cernuus L.	4	*a*		.	.	3	2	5	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B. tripartitus L.	4	*a*		.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.
Carex sp.	.	*n*		1	3	30	63	72	73	56	19	17	14	16	18	14	6	2	1	3	1	4	3
C. acutiformis Ehrh.	5	*n*+*u*		.	.	.	.	17	9	16	7	12	5	6	9	10	.	1	.	5	2	10	2
C. riparia Curt.	5	*n*+*u*		.	.	.	.	.	4	7	1	.	1	.	2	2	1	.	.	.	.	.	.
C. rostrata Stokes	2	*n*+*u*		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.
Ceratophyllum demersum L.	4	*n*		.	3	2	3	13	13	43	37	15	32	33	41	13	24	8	3	9	1	18	4
Chenopodium album L.	2	*s*		.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
C. polyspermum L.	4	*s*		.	1	1	4	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cladium mariscus (L.) Pohl	5	*n*		.	.	.	.	6	5	7	1	1	1	1	.	3	.	1	.	.	.	.	.
Compositae sp.	.	*a*		.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cornus sanguinea L.	5	*st*		.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crataegus sp.	5	*th*		.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eupatorium cannabinum L.	5	*a*		.	1	1	.	2	1	.	2	.	1	1	2	.	.	.	.	.	.	.	.
Hippuris vulgaris L.	2	*st*		.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hydrocharis morsus-ranae L.*	4	*s*		.	.	.	2	9	6	4	1	1	.	.	.	.	.	.	.	.	.	.	.
Hypericum cf. *tetrapterum* Fr.*	5	*s*		.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Labiatae sp.	.	*n*		.	.	.	1	.	.	1	.	1	.	.	1	1	.	.	.	.	.	.	.
Lemna cf. *minor* L.*	3	*s*		.	.	.	.	3	8	4	.	.	.	2	.	.	.	.	.	.	.	.	.
Lycopus europaeus L.	4	*n*		.	6	7	9	45	21	16	10	1	6	12	29	.	.	.	.	1	.	.	1
Mentha aquatica L.	5	*n*		.	42	59	91	52	51	13	12	27	35	12	56	.	2	.	.	8	1	.	.
Moehringia trinervia (L.) Clairv.	2	*s*		.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Myosoton aquaticum (L.) Moench	4	*s*		.	1	.	4	1	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
Myriophyllum spicatum L. or *M. verticillatum* L.	2 or 3	*n*		.	.	.	.	2	4	2	7	11	12	19	58	25	22	2	3	14	.	.	1
Najas flexilis (Willd.) Rostk. & Schmidt*	5	*fr*		.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
N. marina L.*	4	*fr*		.	.	.	.	1	.	3	2	.	5	1	1	7	5	9	5	17	.	.	.
N. minor All.*	6	*fr*		.	8	8	10	2	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Nasturtium microphyllum (Boenn.) Rchb.*	5	*s*	.	4	6	12	8	2	.	1	.	2	2	.	.	.	.	.	.	.	.	.
Nuphar luteum (L.) Sm.	2	*s*	.	.	.	1	4	7	7	2	1	3	4	2	2	4	1	.	2	.	.	.
Nymphaea alba L.	3	*s*	.	.	.	.	2	2	3	3	7	9	6	1	10	31	4	5	27	1	.	.
Oenanthe aquatica (L.) Poir.	5	*fr*	.	2	1	1	19	26	24	4	3	13	18	35	.	1	.	.	1	1	.	.
Polygonum cf. *lapathifolium* L.	2	*n*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potamogeton sp.	.	*st*	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. acutifolius Link	5	*st*	.	.	.	.	4	1	1	2	.	.	.	.	.	.	.	.	.	.	.	.
P. berchtoldii Fieb.	2	*st*	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Potamogeton cf. *densus* L.	5	*st*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
P. natans L.	2	*st*	.	.	.	.	.	.	2	4	.	2	.	.	5	.	.	.	.	.	9	2
Potamogeton cf. *perfoliatus* L.	2	*st*	.	.	1	.	.	.	.	.	.	.	1	.	1	.	.	.	2	.	.	.
Potamogeton cf. *pusillus* L. sec. Dandy & Taylor	3	*st*	.	.	.	1	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.
P. trichoides Cham. & Schlecht.	5	*st*	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Prunus spinosa L.	5	*st*	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus sp.	.	*a*	.	1	.	1	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.
R. acris L.	2	*a*	.	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus cf. *lingua*	4	*a*	.	.	.	.	.	.	.	.	1	.	.	.	3	.	.	.	1	.	1	2
R. parviflorus L.*	6	*a*	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
R. repens L.	2	*a*	.	7	5	7	.	1	.	.	1	1	1	.	.	.	.	.	.	.	.	.
R. sceleratus L.	3	*a*	.	15	24	45	27	20	11	4	1	2	4	21	.	.	.	.	.	.	.	.
Ranunculus-Batrachium sp.	.	*a*	.	6	8	7	27	14	15	.	2	4	4	3	.	1	.	1	.	.	.	.
Rubus fruticosus L.	.	*st*	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.
Rumex sp.	.	*p*	.	3	2	1	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Rumex cf. *conglomeratus* Murr.	5	*n*+*p*	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
R. maritimus L.	5	*n*+*p*	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	8	1	.	.
Sagittaria sagittifolia L.*	3	*fr*	.	.	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Schoenoplectus lacustris (L.) Palla	2	*n*	5	5	1	3	10	26	41	5	11	18	1	8	52	5	7	4	10	1	9	2
Solanum dulcamara L.	4	*s*	.	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sparganium angustifolium Michx.	2	*st*	.	1	.	1	1	6	3	1	3	.	.	2	4	.	2	1	.	.	.	.
S. minimum (Hartm.) Fr.	2	*st*	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
S. ramosum Huds.	3	*st*	.	7	12	24	58	69	63	5	7	4	2	10	16	1	.	.	1	.	1	.
S. simplex Huds.	2	*st*	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stachys sp.	.	*n*	.	1	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Teucrium scordium L.	5	*n*	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Thalictrum flavum L.	2	*a*	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Urtica dioica L.	2	*fr*	.	3	1	7	3	2	2	2	4	1	6	6	.	.	1	.	7	.	.	.
Verbena officinalis L.	5	*n*	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Zannichellia palustris L.	3	*a*	.	2	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Characeae	.	*o*	found in all samples																			

Abbreviations: *a*, achene; *cs*, cone scale; *fr*, fruit; *n*, nut or nutlet; *o*, oospore; *p*, perianth; *s*, seed; *st*, fruit-stone; *th*, thorn; *u*, utricle of *Carex*.

this and the fall in *Pinus* at the end of the zone both suggest that the pollen of this tree was derived from some distance and not from the local vegetation. *Betula nana* pollen was not counted separately from the tree-birch pollen, but was recorded occasionally in pollen counts from the zone. One fruit of *Betula* cf. *nana* was found at the transition between zones *b* and *c* in the sample H (table 3). *B. nana* was evidently present in the open vegetation of this period, as well as the more abundant tree-birches. *Salix* and *Juniperus* are both well represented in the zone. The presence of *Juniperus* is another indication of open vegetational conditions.

The high values of pollen of herbaceous plants, both aquatic and land, testify to a rich herb vegetation in and around the interglacial lake. *Myriophyllum verticillatum*, *Sparganium* and *Typha latifolia* are all well represented. The variety of herbs includes Gramineae, Cyperaceae, *Artemisia*, Chenopodiaceae, Compositae, *Potentilla*, *Ranunculus*, Rubiaceae, *Thalictrum* and Umbelliferae. Some of this pollen probably belongs to local swamp species bordering the interglacial lake, but the subsequent general decrease of the high *NAP* values seen in zone *c* as the forest density increases may suggest that the sum is mostly derived from the herbaceous vegetation of the surrounding land.

Many of the herbaceous pollen types (and *Botrychium*, a single record of which comes from this zone) are also associated with the late-glacial conditions of open vegetation found at the close of the Last Glaciation in north-west Europe, as described, for example, by Iversen (1954) in Denmark and Godwin (1956) in Britain.

For the further assessment of vegetational conditions during zone *b* the conditions of deposition and the sediments formed in the interglacial lake at that time have some significance. The earliest sediment containing pollen is the top part of the silt of stratum D. This silt, whose aeolian origin was suggested in §2(*b*), was the first uniform sediment to be deposited in the lake basin. Its deposition has no direct climatic significance, and only indicates that there was an interval of time between the formation of the valley and the immigration of an abundant flora in which the scarcity of vegetation allowed the accumulation of aeolian deposits. The rare pollen found in the upper part of the silt, that of *Betula*, *Artemisia* and *Myriophyllum verticillatum*, indicates that these plants began to immigrate towards the end of the period of silt deposition. The development of the zone *b* vegetation outlined above caused the change of sediment from an inorganic silt to an organic clay-mud. The aquatic flora became rich enough to cause the deposition of clay-mud, while the land flora increased enough to produce relatively abundant pollen.

During zone *b*, then, we may envisage the interglacial lake, with a rich aquatic and swamp flora, and surrounded by open vegetation, probably of the park-tundra type, with abundant herbs and scattered tree-birches.

Apart from the general climatic amelioration suggested by the immigration of the flora at the transition from the silt to the clay-mud, there are few evidences of climatic conditions in the pollen spectra from zone *b*. The aspect of the vegetation and the presence of *Betula* cf. *nana* suggest rather severe conditions which prevented the rapid development of forest. On the other hand, *Typha latifolia* is considered by Iversen (1954) to be a distinctly thermophilous plant, as in Scandinavia it is not found beyond the 14° C July isotherm and in the Alps it rarely exceeds heights of 1000 m, considerably below the forest limit. The percentages of *T. latifolia* seen in zone *b* of the pollen diagram thus indicate a fairly temperate climate at that time. The high values of *Myriophyllum verticillatum* have only a doubtful climatic significance, for, though the northern Scandinavian limit of this plant resembles that of *Typha latifolia*, the fact that it is decidedly eutrophic in its requirements makes caution necessary in interpreting its present distribution solely in terms of climate. However, these high values may perhaps indicate, as with *T. latifolia*, a climate more temperate than sub-arctic.

(c) *Zone c*

The increase in the tree-pollen frequency at the beginning of this zone and the rise in the *AP/NAP* ratio throughout the zone indicate that the gradual closure of the forest took place at this time. *Betula* remained the dominant tree, its pollen values reaching as high as 95 % of the total tree pollen. Two fruits referable either to *B. pubescens* or *B. verrucosa* were found in the sample G from this zone. Again a few pollen grains of *B. nana* type were recorded in the zone. *Pinus* continued in zone *c* to have a low frequency which rose slowly towards the end of the zone. The values are hardly high enough to indicate that *Pinus* played any significant part in the local forest. The traces of *Ulmus* found in the zone are the first indication of the immigration of the thermophilous trees. *Picea* pollen first occurs in zone *c* and is found sporadically throughout the later zones. The percentages are always very low and there is no indication that the tree was present in the local forest.

Throughout zone *c* there is a gradual fall in the frequency of the non-tree pollen, both of aquatic and land plants. Only the Filicales increase their frequency. The decline of herbs is particularly noticeable in the curves for Cyperaceae, *Artemisia*, Compositae, Rubiaceae and *Thalictrum*. The pollen of *Plantago maritima* is an interesting record from this zone; the presence of the plant suggests a not-too-distant maritime environment. Of the aquatic and swamp plants *Sparganium* and *Typha latifolia* show the most marked decrease. The interpretation of the curves is made difficult by the imprecise identification of the pollen types. While the general development of the forest appears to have caused many of the decreases, it is also probable that changes in the local lake vegetation are a reflexion of changing lake conditions. Thus the decrease in the pollen of reed-swamp plants may have been caused by a rise in the water-level of the lake in zone *c*.

It will be noted that although during zone *c* the tree-pollen frequency in general increases, there is a fall in the middle of the zone, which is level with rises in the frequency of certain herbs. It seems that there were fluctuations in the vegetational changes described above, but no valid zonal subdivisions are possible in the pollen diagram.

Two samples washed for macroscopic remains may be considered here. They are sample H from the transition between zones *b* and *c* and sample G from zone *c*. All the species found in the two samples are aquatic or fen plants, except for the single fruit of *Betula* cf. *nana* in sample H and the two fruits of *B. pubescens* or *B. verrucosa* found in sample G. There are the aquatics *Ceratophyllum demersum*, *Myriophyllum verticillatum* or *M. spicatum* (probably the former in view of the pollen identification) and *Potamogeton natans*, and the reed-swamp or fen species *Carex acutiformis*, *C. rostrata*, *Lycopus europaeus*, *Ranunculus* cf. *lingua*, *Schoenoplectus lacustris* and *Sparganium ramosum*.

Thus at this early stage in the interglacial there was a rich lake flora. The geographical affinities of this flora are not noticeably northern, as seen in table 4. In particular, we may note the occurrences of *Carex acutiformis* and *Lycopus europaeus* (which occur in both the sample from the zone *b-c* transition and the zone *c* sample), the former being rare in Scandinavia north of 60° latitude and absent north of 63° latitude, the latter also having its northern Scandinavian limit at about 63° (Hultén 1950).

(*d*) *Zone d*

The immigration of the thermophilous trees, already begun in the preceding zone with the appearance of traces of *Ulmus* pollen, continued in this zone with the expansion of *Ulmus* and the appearance of pollen of *Quercus* and *Acer*. At the same time as this immigration was taking place the frequency of *Betula* declined as that of *Pinus* increased, although *Betula* remained dominant throughout the zone. Thus the three important forest trees of this zone are *Betula*, *Pinus* and *Ulmus*.

The values of the non-tree non-aquatic pollen are low in this zone, compared with those of the previous zone. By this time the closure of the forest appears to have been more or less complete. However, some open ground indicators, such as *Artemisia* and *Helianthemum*, are present.

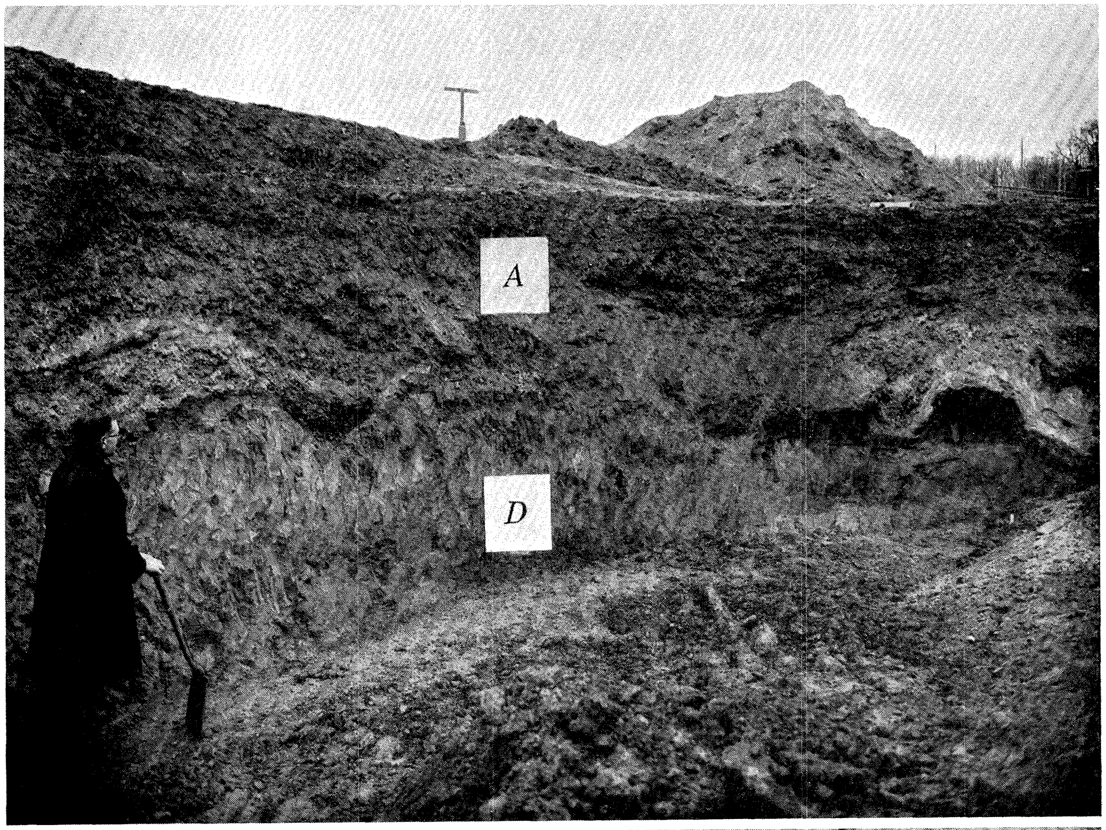
Aquatic, reed-swamp and fen plants are again the most frequent plants identified in the macroscopic samples from this zone (samples E and F). The only exceptions are the single fruit-stone of the aggregate species *Rubus fruticosus*, the fruits of the tree-birches, *Betula pubescens* or *B. verrucosa*, and the single fruit of *Betula* cf. *nana*. The last species evidently persisted into this zone, though the forest density was comparatively well developed.

The number of species recorded from the lake flora increases during zone *d*, and the plant list clearly points to the richly eutrophic character of the interglacial lake. The following plants of the lake flora occur for the first time in this zone: *Alisma plantago-aquatica*, **Mentha aquatica*, **Myosoton aquaticum*, **Najas marina*, *Nuphar lutea*, *Nymphaea alba* (pollen of which was abundant in this zone), **Oenanthe aquatica*, **Potamogeton* cf. *densus*, *Potamogeton* cf. *perfoliatus*, **Rumex maritimus*, **Salvinia natans*, megaspores and massulae (figures 20 and 21, plate 2) of which became frequent at the end of the zone and *Urtica dioica*.

The list of plants with a rather southerly distribution in Scandinavia or which do not reach as far north as Scandinavia increases in this zone, as seen in table 4. Such plants are marked with an asterisk in the list just given above. Thus the number of thermophilous plants found in zone *d* is quite considerable. The amelioration of the climate at the beginning of the interglacial must have proceeded rapidly, even though the dominant tree remained *Betula*.

(*e*) *Zone e*

During the period covered by this zone the composition of the forest altered rapidly. The frequency of *Betula* fell to low values at the beginning of the zone, and its place is taken by *Pinus* and *Quercus*. During the middle of the zone *Pinus* reaches its maximum value of 71 % of the total tree pollen. *Quercus* starts to rise at the beginning of the zone and reaches high values, over 50 % of the total tree pollen, at the end of the zone. *Ulmus*, however, after reaching a maximum of 9 % at the beginning of the zone declines to low values for the remainder of the zone. *Acer* continues to appear in low values throughout the zone, and *Fraxinus* begins to occur in the second half of the zone. *Picea*, *Alnus* and *Tilia* also appear infrequently.



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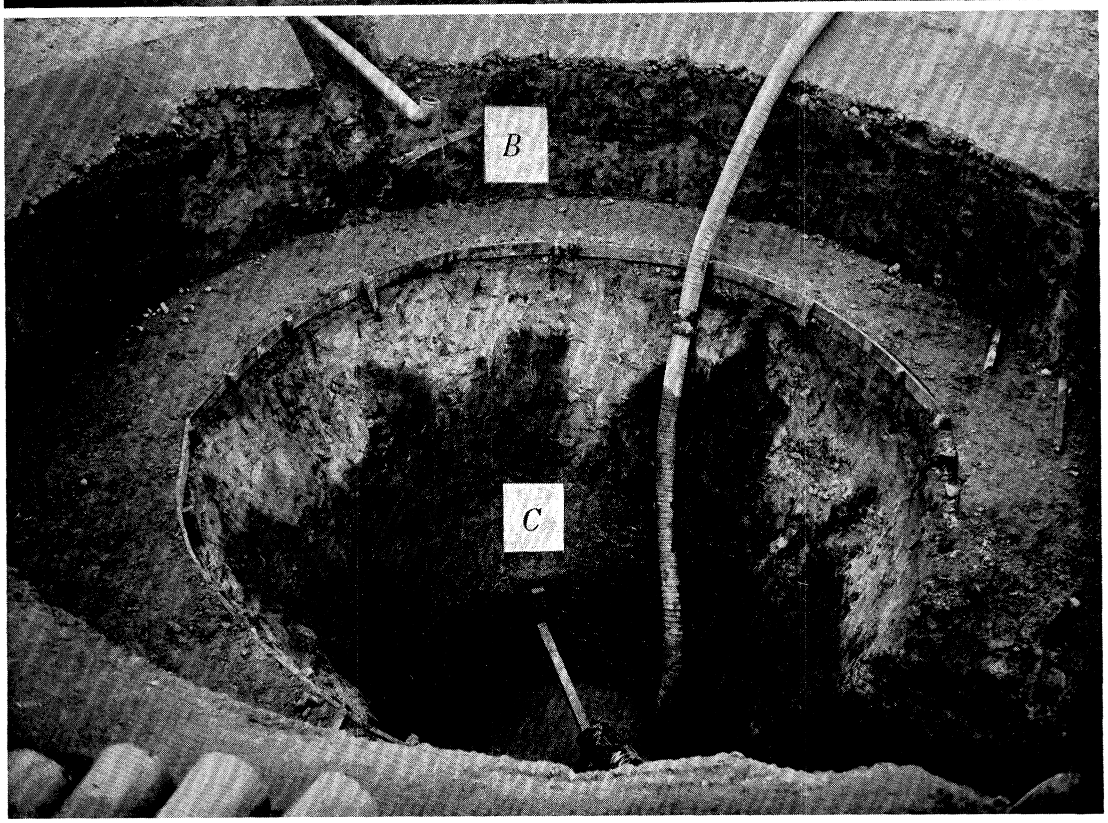

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FIGURE 8. Section at the south end of the profile, near site no. 1. The sandy gravel of stratum A is seen lying unconformably on and cutting into the silt of stratum D.

FIGURE 9. Section at site no. 5. The clay of stratum B lies on the clay-mud of stratum C, the top of which is irregularly weathered.

(*Facing p.* 18)

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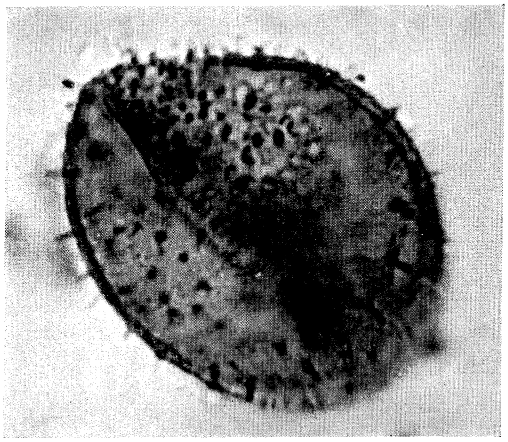

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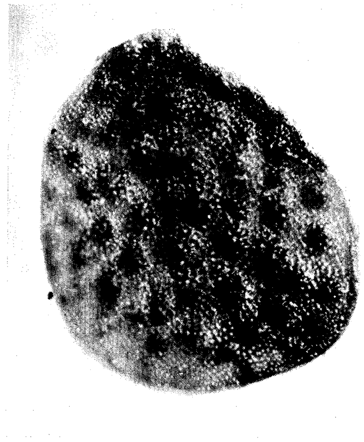

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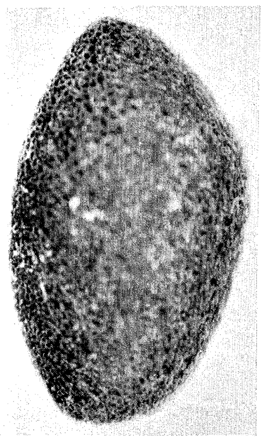

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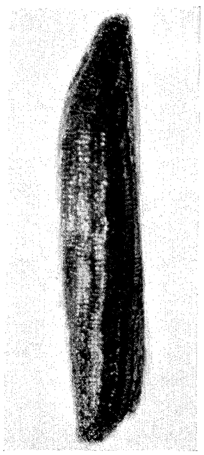

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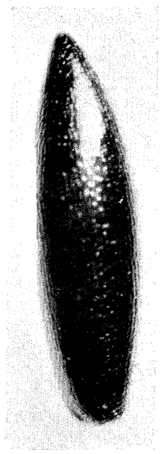

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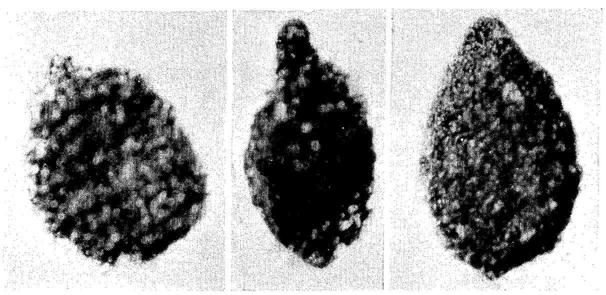

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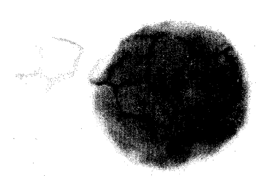

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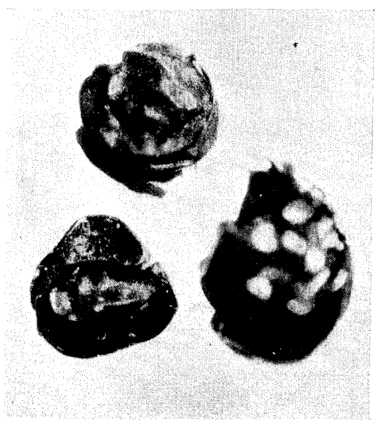

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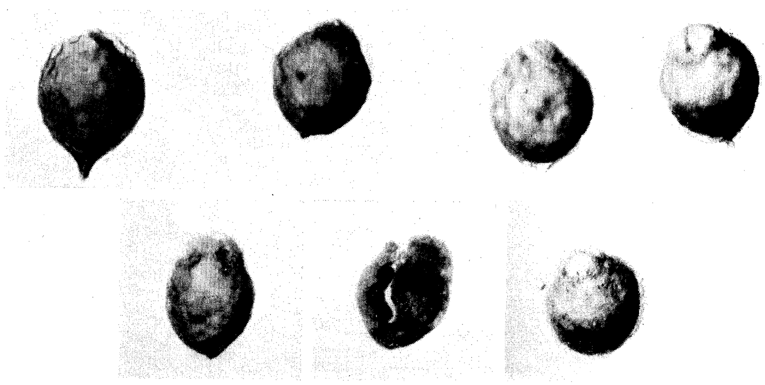

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Corylus first appears in zone *e*, but remains at low values throughout. *Hedera* also appears for the first time at the beginning of the zone, but the values never exceed 1 % of the total tree pollen.

The non-tree pollen remains at its previous low values throughout the zone. Some of the herbs, for example, *Artemisia*, *Pastinaca*, *Plantago lanceolata* and *P. maritima*, indicate a small degree of open ground in the neighbourhood.

Pteridium shows during this zone a marked maximum, which coincides with the maximum of *Pinus*. It is probable that this plant appeared in the field layer of the pine-dominant forest, as it may to-day. Both *Pinus* and *Pteridium* would be favoured by the light acid soils which might be expected on the glacial sand and gravel which cover much of the area south and east of Ipswich.

The list of macroscopic plant remains from the zone *e* samples (7 *b*, 8 *t*, 8*b*, 9 *t*, 9 *b*, A, B, C, D) records thirty-eight species, all aquatic, reed-swamp or fen plants except for the woodland species *Moehringia trinervia* and the open-ground *Chenopodium album*. The list of immigrants in this zone includes several plants with a southerly distribution in Scandinavia (category 5 in table 4), such as *Berula erecta*, *Carex riparia*, *Cladium mariscus*, *Hypericum* cf. *tetrapterum* and *Potamogeton acutifolius*.

The pollen of *Stratiotes aloides* (figure 10, plate 2) occurs first in this zone, but no fruits were found. This plant has a continental type of distribution, ranging latitudinally from middle and south Sweden to northern Italy. The distribution of the sexes is peculiar; female plants occur in the northern part of the distribution area, male plants in the south, and both sexes in the intermediate area (Nolte 1825, quoted by Arber 1920; Clapham *et al.* 1950). In Britain female plants predominate, though hermaphrodite flowers have been

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Description of plate 2

Figure 10. *Stratiotes aloides*; pollen grain. (Magn. × 1460.)

Figure 11. *Sagittaria sagittifolia*; fruit. (Magn. × 13.)

Figure 12. *Ranunculus parviflorus*; achene. (Magn. × 21.)

Figure 13. *Najas marina*; fruit. (Magn. × 17.)

Figure 14. *Najas minor*; fruit. (Magn. × 25.)

Figure 15. *Najas flexilis*; fruit. (Magn. × 25.)

Figure 16. *Nasturtium microphyllum*; seeds. (Magn. × 25.)

Figure 17. *Lemna* cf. *minor*; seeds. (Magn. × 25.)

Figure 18. *Hydrocharis morsus-ranae*; seeds. The loose spiral thickenings of the epidermal cells cause the irregular appearance of the seed surfaces. (Magn. × 30.)

Figure 19. *Hypericum* cf. *tetrapterum*; seed. (Magn. × 45.)

Figure 20. *Salvinia natans*; massula inside the reticulate sporangial wall. (Magn. × 105.)

Figure 21. *Salvinia natans*; megasporangia and megaspores. The top four and bottom right megaspores are within their reticulate megasporangial walls. The bottom left and centre megaspores have lost their megasporangial walls, and the bottom centre one has broken open exposing the inside of the perispore. (Magn. × 25.)

Figure 22. Turbellarian egg-capsules. (Magn. × 25.)

recorded (Clapham *et al.* 1950); in Scandinavia similar conditions are found (Samuelsson 1934). The presence of *Stratiotes* pollen in zone *e* (and zone *f*) is indicative of summers as least as warm as they are in southern England to-day.

There is in zone *e*, as in the previous zones, little indication of marked continentality or oceanicity of climate. Although the coniferous forest remained dominant, perhaps some indication of continentality, plants with oceanic tendencies, such as *Cladium* and *Hedera*, first occur in this zone.

Thus in zone *e*, though *Pinus* remained abundant, the amelioration of the climate had proceeded so far as to allow the great expansion of *Quercus*, the immigration of such warmth-demanding plants as *Corylus* and *Hedera*, and the growth of a lake flora rich in thermophilous species.

(*f*) *Zone f*

Although the depth of deposit formed in zone *f* is considerable, the pollen diagram shows no sign of the immigration of *Carpinus*, the tree which characterizes the next zone, Jessen & Milthers's zone *g*. Thus it is probable that only the first half or so of the total time covered by zone *f* is represented in the pollen diagram.

The part of the zone seen in the diagram shows the dominance of mixed oak forest over *Pinus* (the rise of *Pinus* at the top of the diagram is considered below). *Quercus*, whose pollen production is low compared with that of *Pinus*, reaches a maximum of 69 % of the total tree pollen during the zone, and *Acer* reaches the relatively high value of 11 %. The single fruit of *Acer* cf. *monspessulanum* found in this zone suggests that the *Acer* pollen may belong to this species. *Betula* and *Ulmus* remain at low values, and *Alnus*, *Fraxinus*, *Picea* and *Hedera* occur intermittently throughout the period.

The frequency of *Corylus* rises rapidly at the beginning of the zone and reaches high values (the maximum is 288 % of the total tree pollen) towards the top of the diagram. One nut of *Corylus avellana* (not recorded in the plant list, table 3) was found in the zone *f* deposits. The shrub must have played an important part in the oak forest.

The changes in the pollen percentages of the different trees from core 6 upwards must now be considered. Table 1*B* shows the change in organic content of the sediment from core 6 to core 1. The organic carbon falls above core 6. Such a change may have been caused by a change in primary deposition and/or by post-depositional weathering. A change in the sedimentation towards the top of the lake deposits is discussed in §4(*g*). In support of the second explanation we have the facts that weathering effects, described in §2(*b*), were observed in stratum B and the top of stratum C, the sediments of which form the cores 1 to 6; that in cores 1 and 2 only those pollen grains and spores are found that are known to be resistant to weathering, e.g. *Pinus*, *Corylus* and Filicales; and that the changes in the pollen percentages seen at the top of the diagram are those that would be produced by the destruction of *Quercus*, the pollen of which is known to be sensitive to weathering effects. For example, I demonstrated (West 1956) that in the interglacial deposits at Hoxne, Suffolk, the *Quercus* pollen percentages could be greatly reduced by weathering effects, and this resulted in changes in the pollen percentages of the other trees. At Hoxne the *Quercus* decrease was also coincident with a fall in the organic content of the sediment. It thus seems probable that the change in organic carbon from core 6 upwards and the change in pollen content towards the top of the diagram are both related, in part at least, to post-depositional weathering, and that the decline in *Quercus* in the upper part of zone *f* is not a reflexion of changing forest conditions.

The *AP/NAP* ratio and tree-pollen frequency fall throughout zone *f*, and it perhaps appears from this that closure of the forest at this time was by no means complete. The increase of *Artemisia* in cores 3 and 4 also bears witness to this. But, in addition, there are rises in the pollen of reed-swamp plants, such as *Alisma*, *Sparganium* and *Typha latifolia*, indicating that the reed-swamp zone of the lake moved nearer to site no. 4 as the lake filled with sediment. It is shown later that the same explanation probably applies to the rising curves of other pollen types, such as Cyperaceae and Umbelliferae.

Fifty-one species are recorded from this zone in the list of macroscopic remains. Water plants are again well represented, including the three species of *Najas*, *N. flexilis* (figure 15, plate 2), *N. marina* (figure 13, plate 2) and *N. minor* (figure 14, plate 2), but the list has a greater number of land species than in previous zones, as shown in figure 7. Thus we have species often found in scrub or open ground, including *Acer* cf. *monspessulanum*, *Cornus sanguinea*, *Crataegus* sp., *Prunus spinosa*, *Ranunculus parviflorus* (figure 12, plate 2) and *Verbena officinalis*. The increase in land species agrees with the opening out of the forest suggested by the pollen diagram.

The general affinities of the plant list from zone *f* are well seen in table 4. The increase in the number of southern forms (categories 5 and 6) again occurs, several of the species appearing for the first time in zone *f* having a distinctly southern and often continental distribution in north-west Europe at the present day. Such plants are *Acer* cf. *monspessulanum*, *Cornus sanguinea*, *Najas minor*, *Ranunculus parviflorus*, *Teucrium scordium* and *Verbena officinalis*.

The relatively large number of southern and continental species present in zone *f* suggests a considerable summer warmth, and the nature of the aquatic flora bears out this suggestion.* First there is the extension into Britain at that time of the two species *Naias minor* and *Salvinia natans*, both of which have a southern and continental distribution, and whose north-western limits to-day just reach the Netherlands (Glück 1936). Secondly, in zone *f* seeds were found of *Hydrocharis morsus-ranae* (figure 18, plate 2), a plant which, although fruiting on the continent, rarely if ever finds conditions good enough to permit setting of the seed in Britain (Arber 1920; Clapham *et al.* 1950). Lastly we have as evidence of the warmth of the summers the occurrence of *Stratiotes* pollen, noted previously, and perhaps also the presence of seeds of *Lemna* cf. *minor* (figure 17, plate 2), a plant whose fruits are not commonly found in Britain to-day.

The distributional evidence taken as a whole would seem to point to a conclusion that during zone *f* (and perhaps also in zone *e*, where *Hydrocharis* (one seed), *Stratiotes* pollen and *Salvinia* were all found) the summers were rather warmer than at the present day.

The warmth of the summers does not necessarily imply a continental climate. The presence of the mixed-oak forest, with large percentages of *Corylus*, and also with *Hedera*,

* Szafer (1954) has stressed the value of water plants as indicators of thermal conditions. He points out that 'the vegetation of stagnant waters, being above all a reflexion of their specific thermal climate, is a better indication of the influence of the regional (zonal) climate on the vegetation than the extremely differentiated vegetation of the land, whose character is influenced not only by the general climate (temperature, humidity, wind) but also, and specially so, by the influence of the greatly differentiated local climate'.

suggest no change in this zone towards continentality. The large rise in *Corylus* which marks the beginning of zone *f* may indicate rather a tendency towards oceanic conditions starting in this zone. According to Jessen (1948) in the Post-Glacial Period the size of the *Corylus* maximum varies with the extent of the oceanic influence in the climate in the south of Sweden, in central Europe and in England; other factors being suitable, oceanicity apparently favours the plant's growth. The high values of *Corylus* in zone *f* suggest some degree of oceanicity.

Some indication of the winter temperatures is also given by the presence of pollen of *Hedera*. Iversen (1944) deduced the 'thermosphere' of *H. helix* from its present distribution, and he demonstrated that the plant will not tolerate an average temperature of the coldest month below $-1\cdot5^\circ$ C. The result indicates that from zone *e*, when *Hedera* immigrates, onwards into zone *f* the winter climates were not colder than this.

(*g*) *The history of the lake vegetation in zones e and f*

The number of macroscopic plant remains from the sediment series in the cores 3 to 9 of the borehole at site no. 3 made it possible to construct a diagram (figure 7) showing the changing frequency of the remains of different plants. Only in the sample from the top of core 3 (sample 3 *t*) were plant remains scarce enough to prevent a percentage representation.

The plants in the diagram are those which show distinct peaks in their vertical distribution. All of them are plants which can be associated with the lake flora, either aquatic or swamp plants. The species are arranged so that the peaks of the different curves ascend from top to bottom as we move from left to right along the diagram.

The frequency of remains of land plants is shown in a separate column, the following being represented in the total: *Acer* cf. *monspessulanum*, *Betula* sp., *Chenopodium album*, *C. polyspermum*, *Cornus sanguinea*, *Crataegus* sp., *Prunus spinosa*, *Ranunculus parviflorus*, *Rubus fruticosus* and *Verbena officinalis*. The number of remains of land plants at each level is shown as a percentage of the total number of lake-flora specimens at that level. The frequency of turbellarian egg-capsules is expressed in the same way.

In such a diagram as figure 7 the changing percentages of the different plants must be a reflexion of the changing plant communities which occupied or surrounded the lake during the deposition of the sediment in the cores, that is, during zones *e* and *f*. Recognition of these plant communities is thus made possible, and this gives some further evidence of the environmental conditions in which the flora thrived and also provides knowledge of local vegetational conditions which can be used in the interpretation of the pollen diagram.

The plants in the diagram are divisible into three major groups on the basis of the distribution and positions of the peaks of their curves. First, there are plants abundant at the base, but rare or absent at the top of the diagram, e.g. *Ceratophyllum*, *Myriophyllum*. Secondly, there are plants most abundant in the middle, many of which are also quite frequent at the top part of the diagram, e.g. *Sparganium*, *Ranunculus-Batrachium*. Thirdly, there are plants which are most abundant at the top of the diagram, e.g. *Alisma*, *Ranunculus repens*.

The grouping clearly admits of an ecological interpretation. In the first group the majority of plants are submerged or floating-leaf aquatics, in the second many are

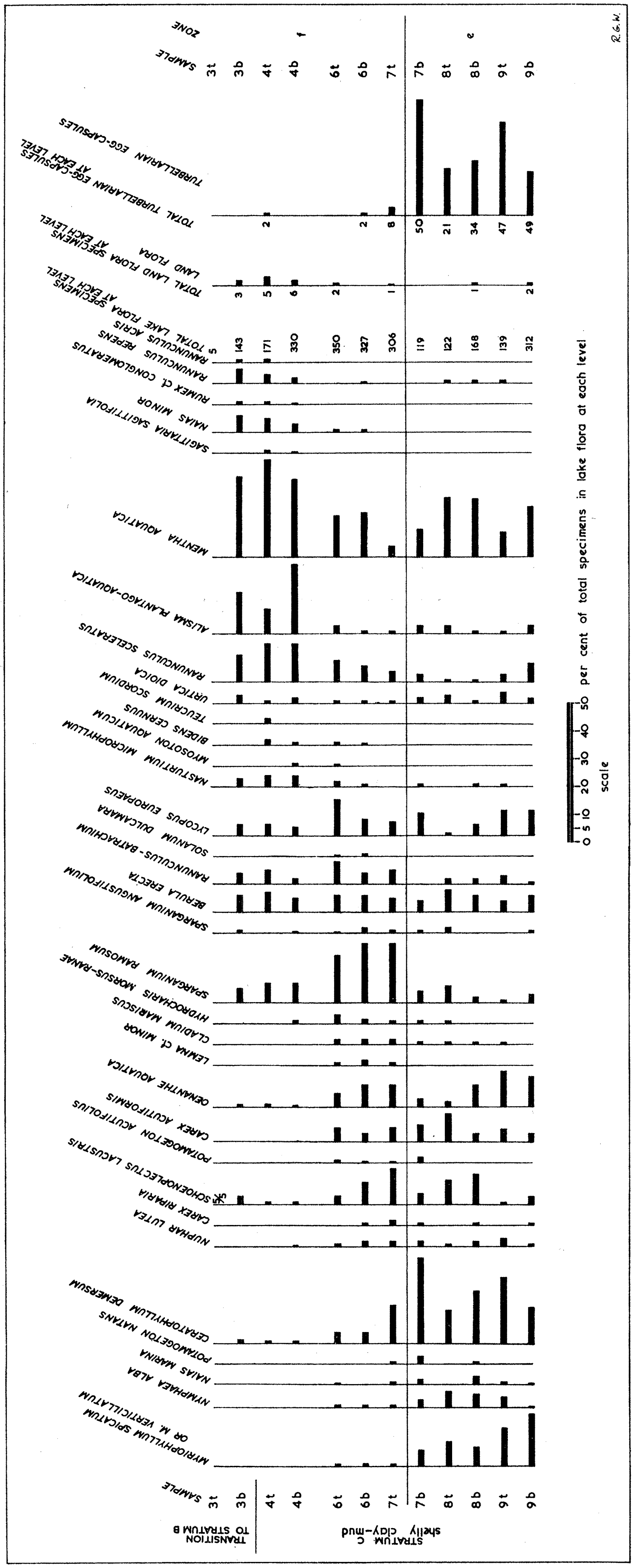

FIGURE 7. Diagram of the changing frequencies of various macroscopic remains from the cores 3 to 9 of the borehole at site no. 4, showing the succession of lake vegetation.

reed-swamp plants, while in the third they are mostly fen or marsh plants. Thus the change from the base to the top of the diagram represents a natural plant succession as the lake filled with sediment.

In the following discussion reference is made mainly to the plants with curves in figure 7 which show a distinct rise and fall, that is, to those plants which are probably the most local. The other curves conform to the general conclusions.

The submerged aquatics *Ceratophyllum demersum*, *Myriophyllum verticillatum** and *Najas marina* occur most frequently towards the base of the diagram. With them are the floating-leaf species *Nuphar lutea*, *Nymphaea alba* and *Potamogeton natans*. The turbellarian egg-capsules, with frequencies shown at the right-hand end of figure 7, are also the most abundant with the submerged and floating-leaf plant community. By analogy with the vegetation of the Norfolk Broads described by Pallis (1911), it may be suggested that in the interglacial lake at this stage there was a moderate circulation of slowly flowing water with a depth near site no. 4 in the order of 2 m. Such a general environment would satisfy some turbellarian species.

The increase in frequency of *Schoenoplectus lacustris* near the base of the diagram appears to mark the transition of the submerged and floating-leaf community to open reed-swamp as the lake filled with sediment. The increase is accompanied by relatively high values of *Nymphaea alba*, commonly found with *Schoenoplectus* in the open reed-swamp of some of the Norfolk Broads.

The next clear stage is the increase of *Sparganium ramosum*, probably marking the change from an open to a more closed reed-swamp as the water shallowed further. The change occurs at the transition from zone *e* to zone *f*. *Carex acutiformis*, *C. riparia* and *Cladium mariscus* are present in the reed-swamp, together with a number of floating-leaf plants, including *Hydrocharis*, *Lemna* and *Potamogeton acutifolius*.

In the upper part of the diagram the submerged and floating-leaf plants and many of the reed-swamp plants decline or disappear, and their place is taken by a community of plants which indicate marsh conditions—*Alisma plantago-aquatica*, *Mentha aquatica*, *Ranunculus acris*, *R. repens*, *R. sceleratus* and *Rumex* cf. *conglomeratus*. The change to marsh is also reflected in the increase of land species shown at the top of the diagram. The only plant which might appear to be out of context is *Najas minor*, whose frequencies also rise in the top part of the diagram. In communities described by Backman (1951), this plant occurs with submerged and floating-leaf aquatics, and, according to Glück (1936), mostly in water 40 to 120 cm deep. The other plants well represented at the top of the diagram suggest rather shallow water, probably less than half a metre deep.

The changes shown by the sediment analyses are such as would be expected in a vegetational change from reed-swamp to marsh, that is, the soil substratum becomes more inorganic. Throughout the lower cores the sediment is a uniformly brown shelly clay-mud. The analysis of sample no. 5 in table 1 *B* gives a good indication of its composition. However, above core 6, from which this sample came, the clay-mud becomes greyer and the organic content decreases in favour of the inorganic, as shown in sample no. 4 from core 4. This change thus corresponds to the development of the marsh flora.

* Although the nutlets of *Myriophyllum spicatum* and *M. verticillatum* are very similar, the pollen of *M. verticillatum* only was found, so the nutlets are referred to this species.

The autogenic succession from open-water vegetation to reed-swamp would normally be continued with the formation of fen communities, with the sediment becoming more organic, not less organic as at Bobbitshole. An external and gradual change in the sedimentary environment must have resulted in the gradual increase of the inorganic material. Such an increase could have resulted from several causes: a local loss of plant cover which allowed more surface water run-off from the area drained, an increase in the precipitation which might have increased the water velocity and thus changed the sediment type, the growth of deltaic deposits out over the lake, or periodic flooding and drying out.

It is tempting to seek a cause of these changes in the rise of level of the so-called Eem Sea, then occupying the place of the present North Sea, a rise known to have taken place during the zones *d* to *f* of the Eemian (Last) Interglacial (Jessen & Milthers 1928; von der Brelie 1954), but there is little or no direct evidence of brackish- or salt-water conditions either in the pollen diagram or in the macroscopic plant remains.* Such a rise could possibly cause a change in sedimentation by the backing-up and flooding of the fresh waters.

The vegetational change, open-water to reed-swamp to marsh vegetation, explains many of the changes seen in the pollen diagram. The gradual rise in Cyperaceae, *Sparganium* and Filicales corresponds to the development of the reed-swamp and marsh at the transition from zone *e* to zone *f*, and the peaks of Caryophyllaceae, Compositae, Umbelliferae and *Alisma* are all probably related to the development of the marsh flora. Thus the rise in the proportion of *NAP* to *AP* seen in the pollen diagram in zone *f* corresponds with the development of the reed-swamp and marsh.

The scarcity of pollen and macroscopic remains in stratum B and the weathering at the top of stratum C may be explained by the knowledge of the vegetational changes. The onset of marsh conditions suggests a fluctuating water-level rather near the level of deposition, and in this environment any organic matter deposited would be liable to destruction by oxidation.

5. Comparisons and conclusions

(*a*) *Palaeobotany*

(i) *Vegetational history and pollen diagrams*

Comparisons with continental interglacial deposits. The vegetational history of the Eemian (Last) Interglacial in the Netherlands, north-west Germany and Denmark is known in detail; it has been described by, amongst others, Jessen & Milthers (1928) and van der Vlerk & Florschütz (1950). The general similarity between the continental Eemian pollen diagrams and the diagram from Bobbitshole will have already been made clear by the ease of application of Jessen & Milthers's Eemian pollen zones to the Bobbitshole diagram. We may note that the nearest continental Eemian deposit to Bobbitshole is near Vollenhove, at the south-east edge of the north-east Polder of the Netherlands, a distance away

* Certainly some species frequently found in brackish water occur in the interglacial deposits, e.g. *Najas marina*, *Ranunculus sceleratus*, *Zannichellia palustris*, but the evidence is not conclusive. The pollen of *Plantago maritima*, found infrequently throughout the deposits, is an indication of neighbouring maritime conditions.

of about 215 miles. The pollen diagrams from Vollenhove, given by van der Vlerk & Florschütz (1950), cover the first part of the Eemian Interglacial and are very similar to the diagram from Bobbitshole.

There is, however, one outstanding difference between the Bobbitshole diagram and the continental Eemian diagrams. This is the absence at Bobbitshole of any marked frequency of the pollen of *Alnus*, a tree which in the continental pollen diagrams usually appears in quantity soon after the rise of *Corylus* in zone *f*, where its frequencies may reach 50 % of the total tree pollen. This absence of high frequencies of *Alnus* is made particularly surprising by the presence at Bobbitshole of traces of *Alnus* pollen, combined with ecological conditions which would appear to be favourable to the growth of the tree.

The same difference, an absence of *Alnus* pollen in any frequency, extends to the pollen diagram from the interglacial deposits at Histon Road, Cambridge, described by Walker (1953), and correlated with the Eemian Interglacial. A part of this diagram covers the *Carpinus* zone, zone *g*, of Jessen & Milthers. Although continental diagrams show marked frequencies of *Alnus* in this zone, it is present in very low percentages in the Cambridge diagram, even though again these deposits suggest an ecological situation satisfactory for *Alnus*.

Thus at Bobbitshole, *Alnus* in any quantity is missing up to the top of the pollen diagram, which is some way through zone *f*, while at Cambridge, in zone *g*, it is also practically absent. Only a small segment of the middle of the interglacial is therefore unrecorded, and *Alnus* may appear in this. It remains for future investigation to decide whether the absence of high frequencies of *Alnus* is characteristic of East Anglian Eemian deposits, or whether it is by chance that this absence is found in the two Eemian pollen diagrams so far obtained from East Anglia. If the absence were to become consistent, there would be interesting plant-geographical problems raised, and the frequency of *Alnus* in an East Anglian interglacial pollen diagram would be an important diagnostic feature for the identification of the different interglacial periods.

Comparisons with other British interglacial deposits. In previous papers (West 1955, 1956) I have compared the vegetational history shown by the pollen diagrams from the four British interglacial deposits which have been studied palynologically—the Cromer Forest Bed Series (Woldstedt 1950), the Hoxne Interglacial (West 1956), the Clacton Interglacial (Pike & Godwin 1953), and the Histon Road, Cambridge, deposits (Hollingworth, Allison & Godwin 1950; Walker 1953). It was shown that these deposits could be assigned on geological and palynological grounds to three separate and distinct interglacial periods. Thus the Cromer Forest Bed Series was formed in the oldest (Cromerian) interglacial period in East Anglia, the Hoxne and Clacton Interglacials belong to a middle (Hoxnian) interglacial period, and the Histon Road, Cambridge, deposits to the youngest (Eemian) interglacial period.

The finding of an interglacial deposit with a typical Eemian order of forest immigration only 22 miles from Hoxne emphasizes the validity of the distinction between the forest developments seen in the Eemian and Hoxnian Interglacials, which I have already described (West 1955, 1956) on the basis of the continental Eemian pollen diagrams. The difference in the behaviour of the *Corylus* curve in each is particularly apparent. The slow rise of the curve in the Hoxnian Interglacial contrasts with the rapid and earlier rise seen in the Eemian Interglacial. The absence of *Hippophaë* at Bobbitshole and its abundance at Hoxne at the beginning of the interglacials appears to be another difference between the early parts of these two interglacial periods.

The Eemian Bobbitshole diagram does not overlap the diagram from the Cambridge interglacial deposits described by Walker (1953), for in the former the final zone is zone *f*, while in the latter zone *g* is the earliest zone represented. A single pollen spectrum from a lower horizon in this deposit was described by Hollingworth *et al.* (1950). This spectrum resembles those at Bobbitshole towards the end of zone *e*, except that in it *Acer* and *Hedera* are more abundant than at Bobbitshole.

(ii) *Species*

No plant species characteristic of the Eemian Interglacial are certainly known. Nevertheless, it is useful to make a few remarks on the species list from Bobbitshole compared with those from other interglacial deposits.

The Bobbitshole aquatic flora, with, amongst others, *Ceratophyllum demersum*, *Najas minor*, *Stratiotes aloides* and *Salvinia natans*, appears as an impoverished, yet still evident, edition of the rich Eemian thermophilous aquatic flora of the continent, which includes such plants as *Aldrovandia vesiculosa*, *Brasenia purpurea* and *Trapa natans*.

Certain similarities with the plant list from the Histon Road, Cambridge, interglacial deposits may be mentioned. It is notable that the three *Najas* species at Bobbitshole, *N. flexilis*, *N. marina* and *N. minor*, were also described from the Cambridge deposits by Hollingworth *et al.* (1950). In addition, the two deposits also share a large number of species, in particular some rather southern species, such as *Cornus sanguinea*, *Potamogeton trichoides* and *Verbena officinalis*.

At Bobbitshole a single fruit referred to *Acer* cf. *monspessulanum* was found. This southern and central European species was also found by Reid (1899) in interglacial deposits of uncertain age at Stone, Hampshire, and at Selsey, Sussex.

(*b*) *Stratigraphy*

As described in §2, the interglacial deposits in the valley at Bobbitshole appear to be later than the Gipping Boulder Clay forming part of the local plateau. The dating of the interglacial deposits to the Eemian Interglacial therefore indicates a pre-Eemian date for the ice advance which deposited the Gipping Boulder Clay, the Gipping ice advance of West & Donner (1956). I have previously described (West 1955, 1956) evidence for a correlation of the Gipping ice advance with the Saale Glaciation of north Germany, which is also the glaciation preceding the Eemian Interglacial. Thus the correlation of the Bobbitshole interglacial deposits with the Eemian Interglacial is in agreement with the previous correlations.

The stratum of sandy gravel above the interglacial deposits, probably deposited in a cold period, must be correlated with some stage of the Last Glaciation.

Both the Cambridge and Bobbitshole deposits of Eemian age lie in valleys, unlike the deposits of the previous interglacials in East Anglia, whose positions appear to be unrelated to the present topography. Thus it seems probable that an important period of valley

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formation took place between the retreat of the Gipping ice and the deposition of the Eemian organic deposits. A period of erosion at this time has been described by Shotton (1953).

(c) *Land- and sea-level changes*

Although there are no direct marine influences seen either in the sediments or in the pollen diagrams and plant remains, the occurrence of fresh-water deposits below sea-level and within the present tidal range of the Orwell estuary has some bearing on the relative land- and sea-level during the Eemian Interglacial.

The fresh-water sediments now extend below Ordnance Datum. For this to have occurred the sea must have been more distant than now from the site, which perhaps is a suggestion of a relative sea-level lower at the beginning of the interglacial than at present (assuming, amongst other things, that the present valley system was in existence at that time). As mentioned in §4 (*g*), it is tempting to relate the formation of marsh vegetation during zone *f* to the marine transgression of the Eem Sea, known to have taken place on the continent at about this time (Jessen & Milthers 1928; von der Brelie 1954), but the evidence hardly warrants such a conclusion.

The lack of any marine or brackish-water deposits at Bobbitshole indicates that no marine transgression to the level at which the youngest fresh-water deposits are preserved, about 1 m O.D., took place during the part of the interglacial covered by the pollen diagram. The sea-levels reached during the Eemian Interglacial are usually supposed to be the Monastirian levels of about 18 and 7 m above present mean sea-level (Woldstedt 1952, 1954). If this correlation is correct, the absence of clear marine influences at Bobbitshole may indicate a down-warping of the area since the Eemian Interglacial. In the Netherlands and north Germany the Eem marine deposits do not appear to reach higher than about 7 m below present mean sea-level, and it has been suggested that the well-documented Pleistocene subsidence in the region of the southern North Sea caused this deviation from the Monastirian levels (Woldstedt 1952; Dechend 1954). Thus the same subsidence, though not so marked as in the Netherlands and north Germany, may have extended to the Bobbitshole area, also marginal to the southern North Sea.

My best thanks are given to Mr H. E. P. Spencer, of the Ipswich Museum, who showed me the deposits at Bobbitshole and who gave me valuable assistance with the investigations. I also thank the Ipswich Corporation for permission to investigate the site, for facilities given me during the field work and for providing plans of the site and borehole data. I am indebted to Dr S. L. Duigan, Dr C. L. Forbes, Miss C. A. Lambert and Mr B. W. Sparks for their indispensable help with field and laboratory work, and to Dr I. W. Cornwall and Mr H. H. Nicholson for their help with the sediment analyses.

In conclusion, I tender my thanks to Dr H. Godwin, F.R.S., for his constant encouragement and interest in the work.

Appendix. Records of boreholes and sections

The capitals on the left of the descriptions relate the different deposits to the strata described. Abbreviations used in the descriptions are as follows:

NC No visible reaction with 10 % HCl (non-calcareous)
C Reaction with 10 % HCl (calcareous)

Site no. 1. Height O.D. 6·7 m. Section to 360 cm, the rest bored.

A	0 to 160 cm.	NC. Red and brown sandy gravel, irregularly banded and sorted, with clay and sand layers.
A	160 to 175 cm.	NC. Dark red coarse sand.
D	175 to 200 cm.	NC. Grey clayey silt.
D	200 to 340 cm.	Mostly C. Grey clayey silt, with sandy red patches, slightly stratified.
E	340 to 385 cm.	C. Light brown chalky boulder clay.
E	385 to 443 cm.	C. Brown sandy clay with sand inclusions.

Site no. 2. Height O.D. 5·8 m. Section.

A	0 to 240 cm.	NC. Grey and brown sandy gravel, roughly sorted in some places, with clay and sand layers.
D	240 to 280 cm.	NC. Brown-red silty clay.
D	280 to 325 cm.	C. Grey silt with a few small flints.
D	325 to 380 cm.	C. Grey silt with red streaks.

Site no. 3. Height O.D. 4·8 m. Section with bottom metre bored.

A	0 to 370 cm.	NC. Red sandy gravel, irregularly sorted, with clay and sand layers.
B	370 to 400 cm.	NC. Grey and red clay with a purple layer at 390 to 400 cm.
B	400 to 435 cm.	C. Grey and brown shelly sandy clay.
C	435 to 445 cm.	C. Grey shelly clay-mud, slightly sandy.
C	445 to 590 cm.	C. Brown shelly clay-mud, slightly sandy.
	590 to 600 cm.	C. Transition.
D	600 to 720 cm.	C. Grey silt.

Site no. 4. Height O.D. 3·7 m. Borehole with 4-inch cores.

A	0 to 250 cm.	NC. Red sandy gravel.
	250 to 260 cm.	Transition.
B	260 to 355 cm.	C. Mottled red, grey and yellow shelly clay (cores 1 and 2).
	355 to 395 cm.	C. Transition (core 3).
C	395 to 618 cm.	C. Brown shelly clay-mud, slightly sandy, going greyer towards the top (cores 4 to 9; core 4 greyer).

Site no. 5. Height O.D. 4·8 m. Section.

A	0 to 395 cm.	NC. Red sandy gravel, roughly sorted.
	395 to 405 cm.	Transition.
B	405 to 495 cm.	C. Red and yellow shelly sandy clay with race at the top.
C	495 to 730 cm.	C. Brown clay-mud, slightly sandy.
D	730 to 735 cm.	C. Transition to grey silt.

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Site no. S1. Height O.D. 2·75 m. Borehole by Ipswich Corporation.

	0 to 30 cm.	Topsoil.
A	30 to 90 cm.	Clay and sand.
A	90 to 215 cm.	Clay, sand and gravel.
A	215 to 245 cm.	Sand and gravel.
A	245 to 305 cm.	Sand.
A	305 to 395 cm.	Sand and gravel.
A	395 to 425 cm.	Sand.
A	425 to 455 cm.	Gravel.
B, C?	455 to 580 cm.	Alluvium and clay.
?	580 to 610 cm.	Alluvium and gravel.

Site no. S7. Height O.D. 9·45 m. Borehole by Ipswich Corporation.

	0 to 30 cm.	Topsoil.
A	30 to 90 cm.	Sand and gravel.
A	90 to 180 cm.	Clay.
A	180 to 240 cm.	Sand.
	240 to 305 cm.	Clay.
	305 to 520 cm.	London Clay.

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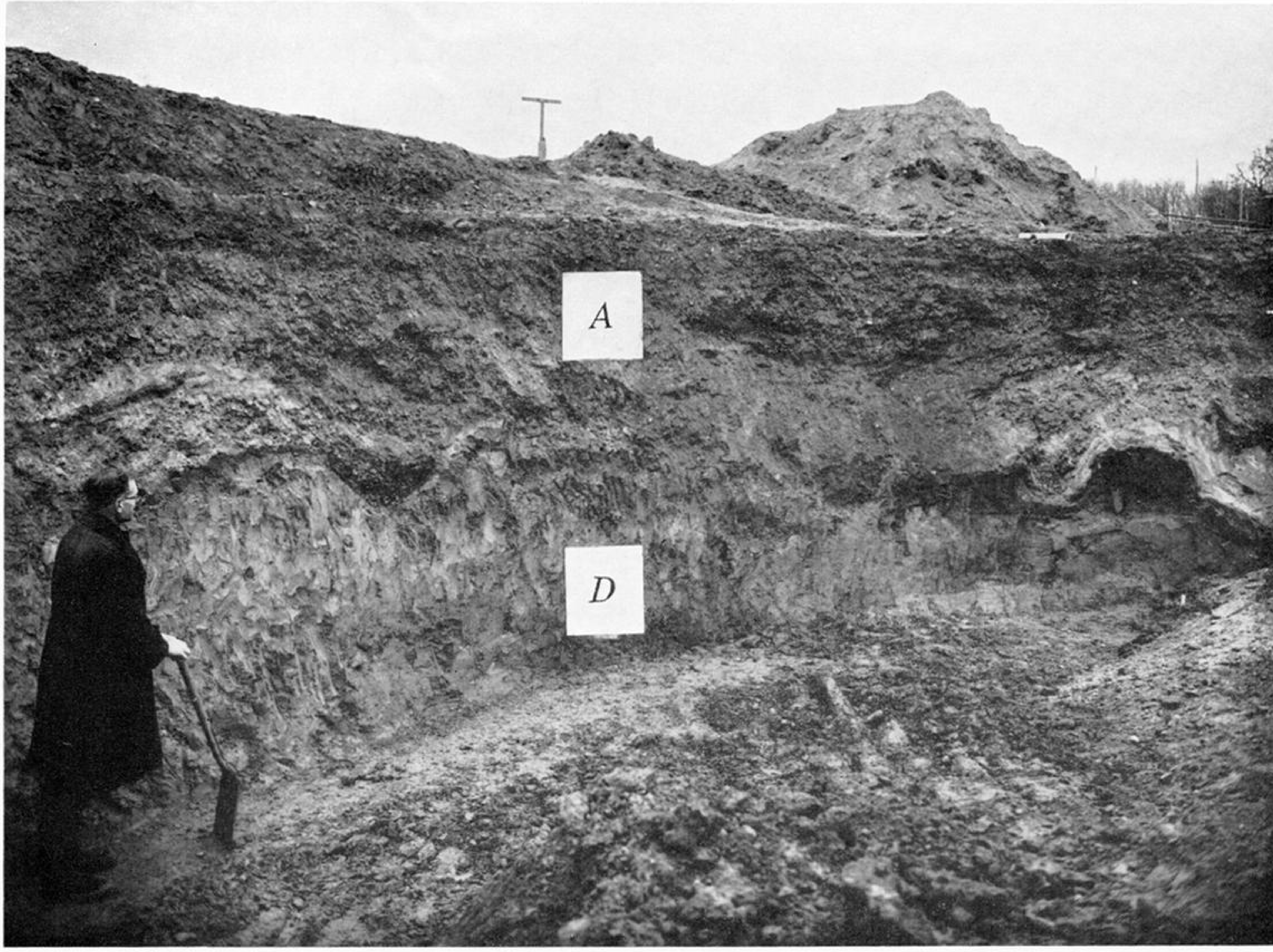

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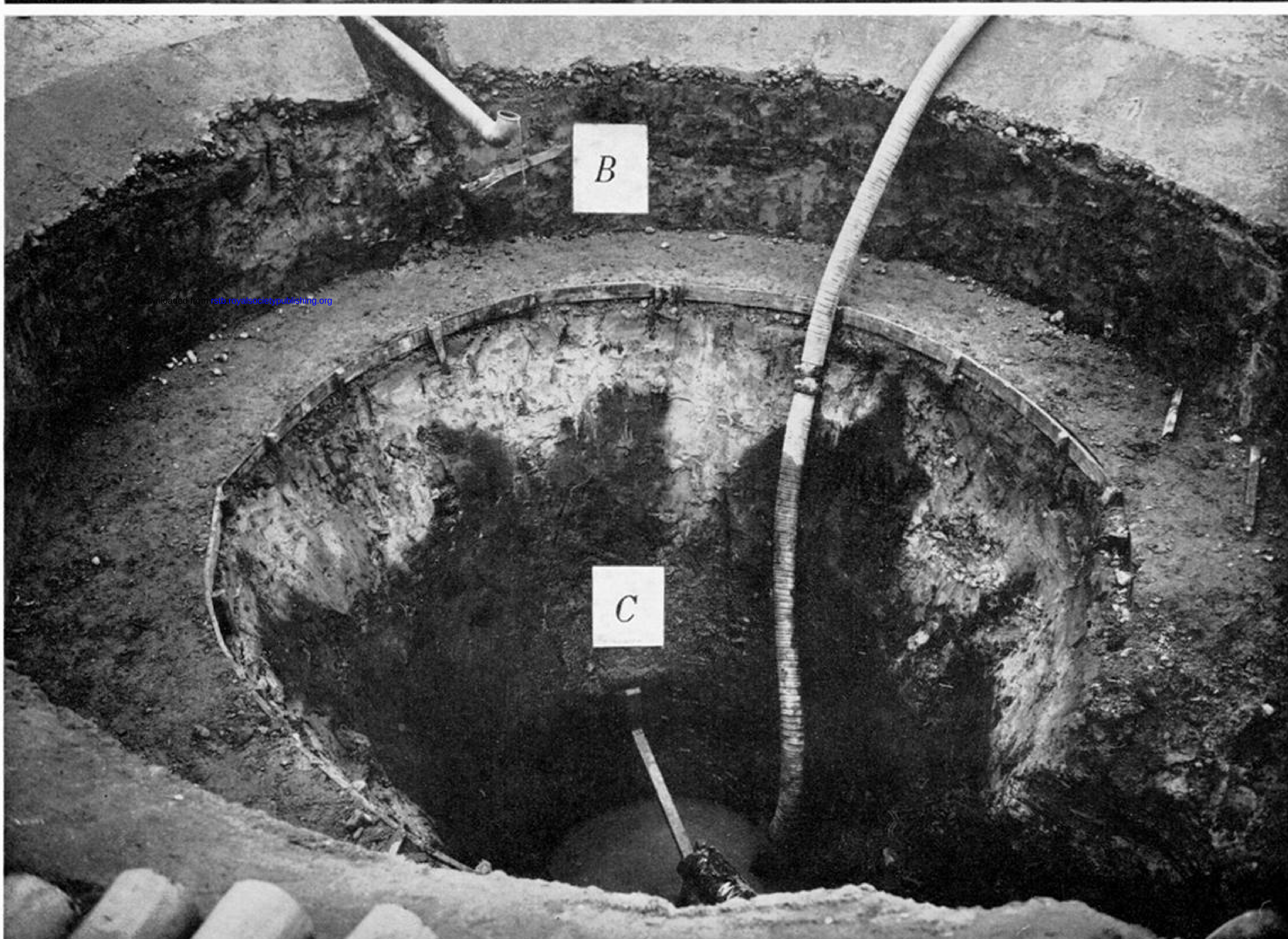

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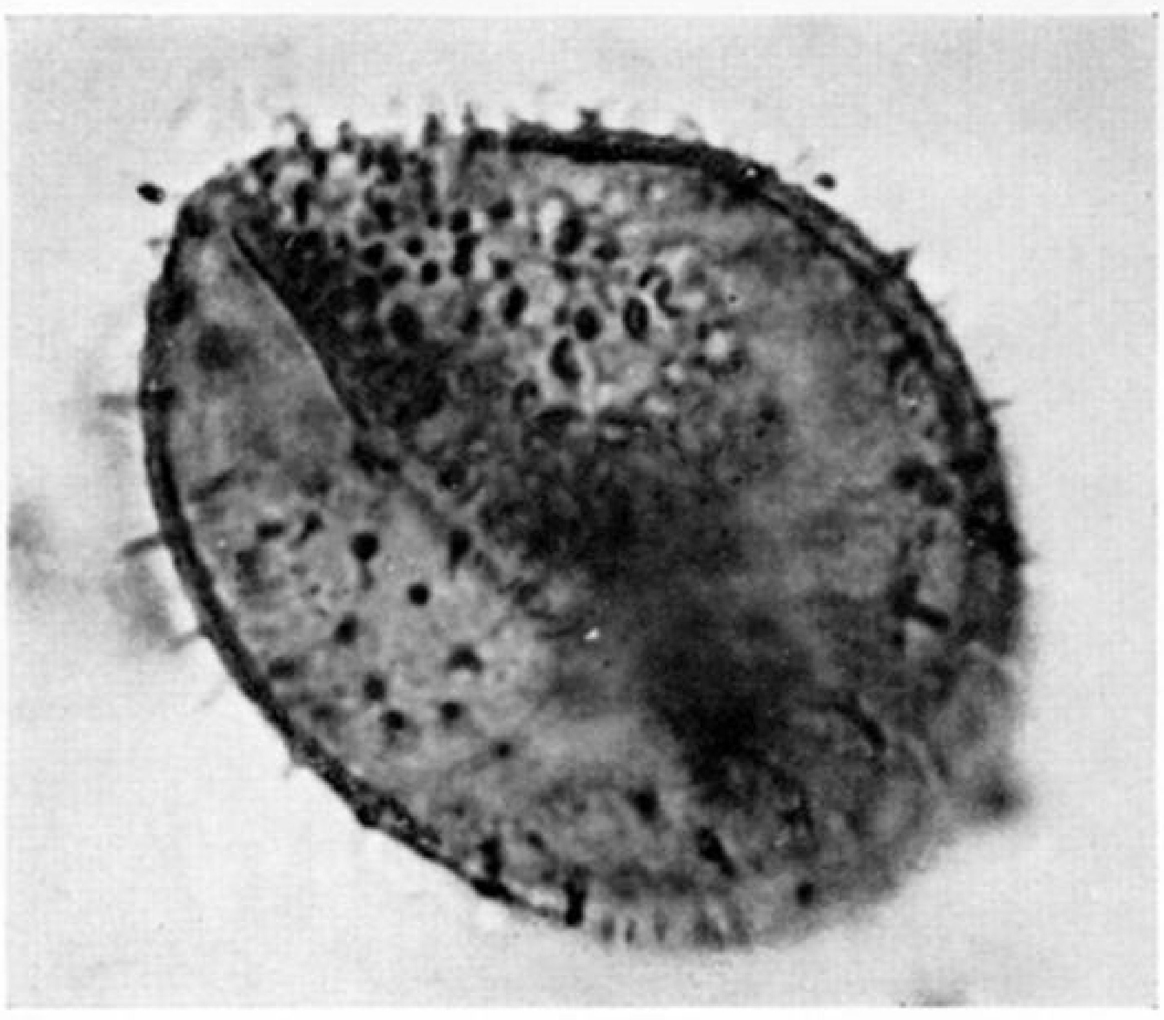
FIGURE 8. Section at the south end of the profile, near site no. 1. The sandy gravel of stratum A is seen lying unconformably on and cutting into the silt of stratum D.

FIGURE 9. Section at site no. 5. The clay of stratum B lies on the clay-mud of stratum C, the top of which is irregularly weathered.



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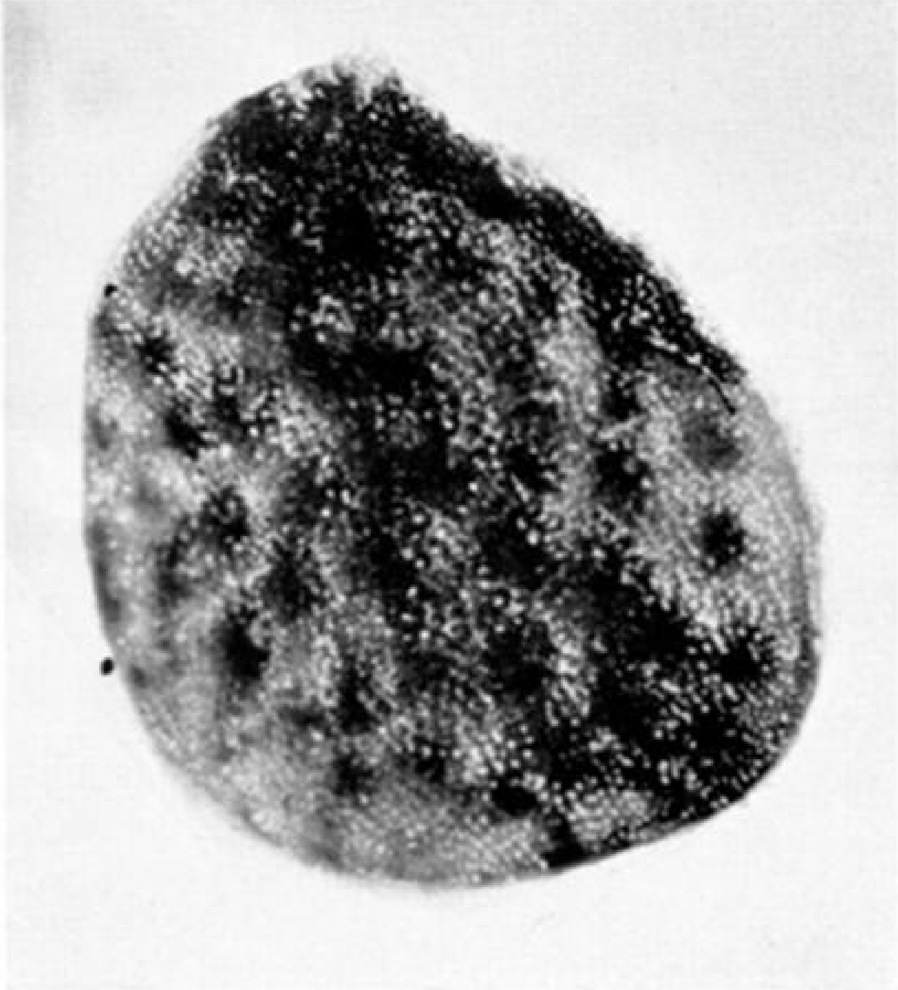

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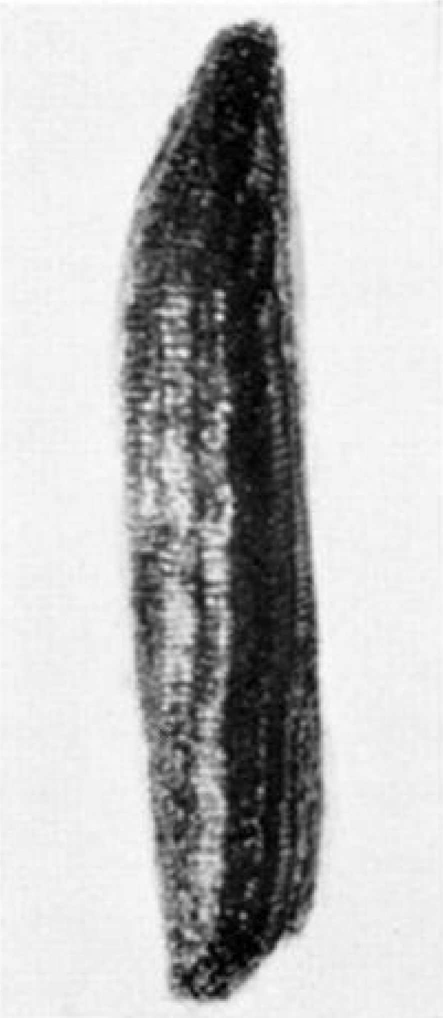

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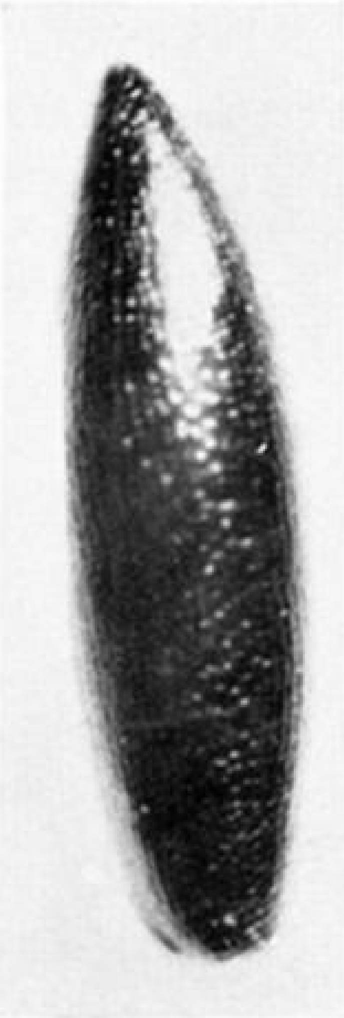

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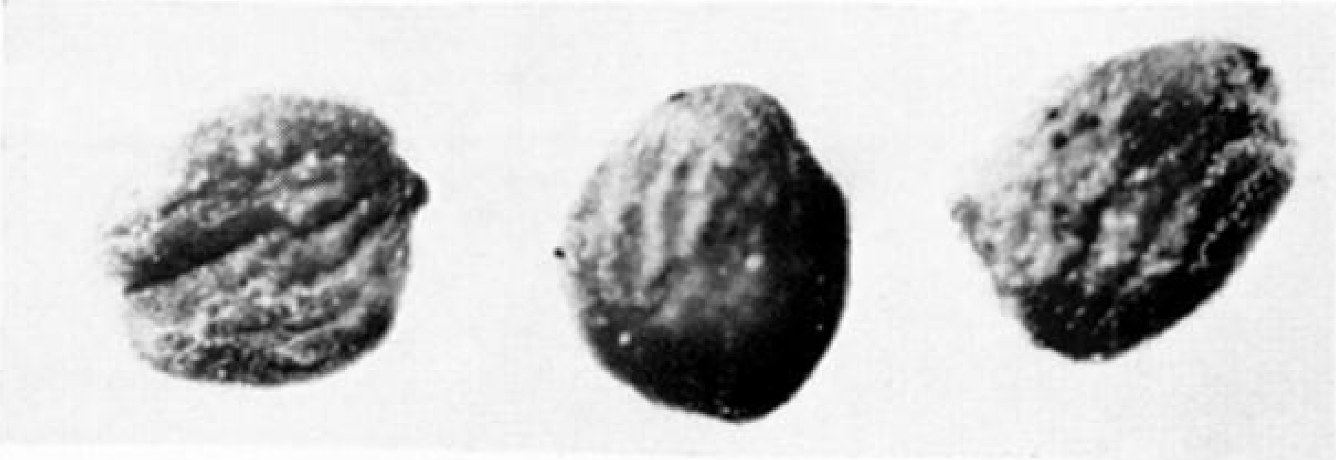

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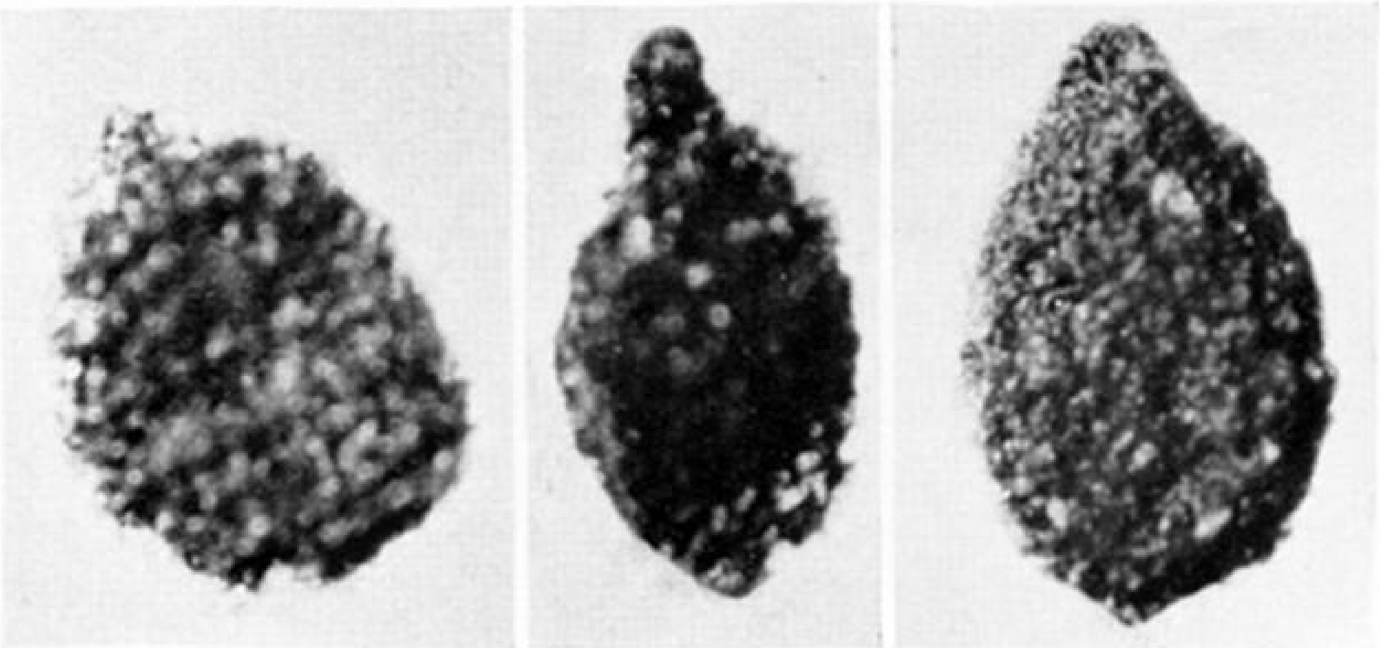

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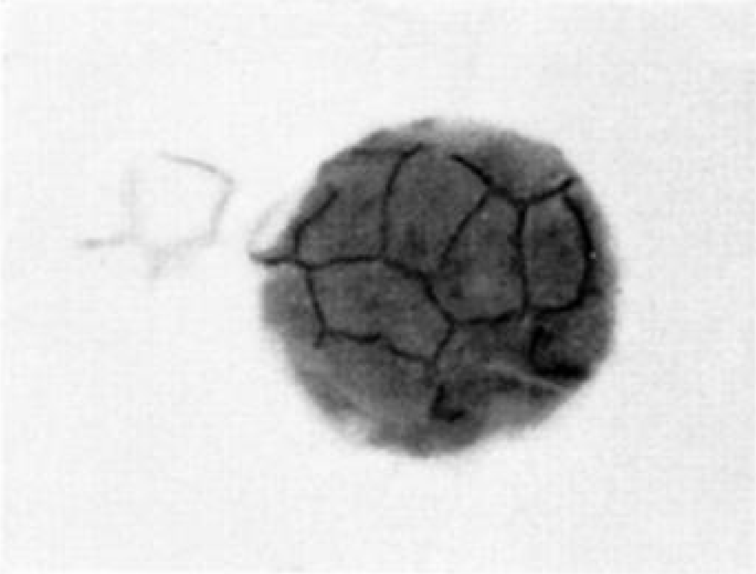

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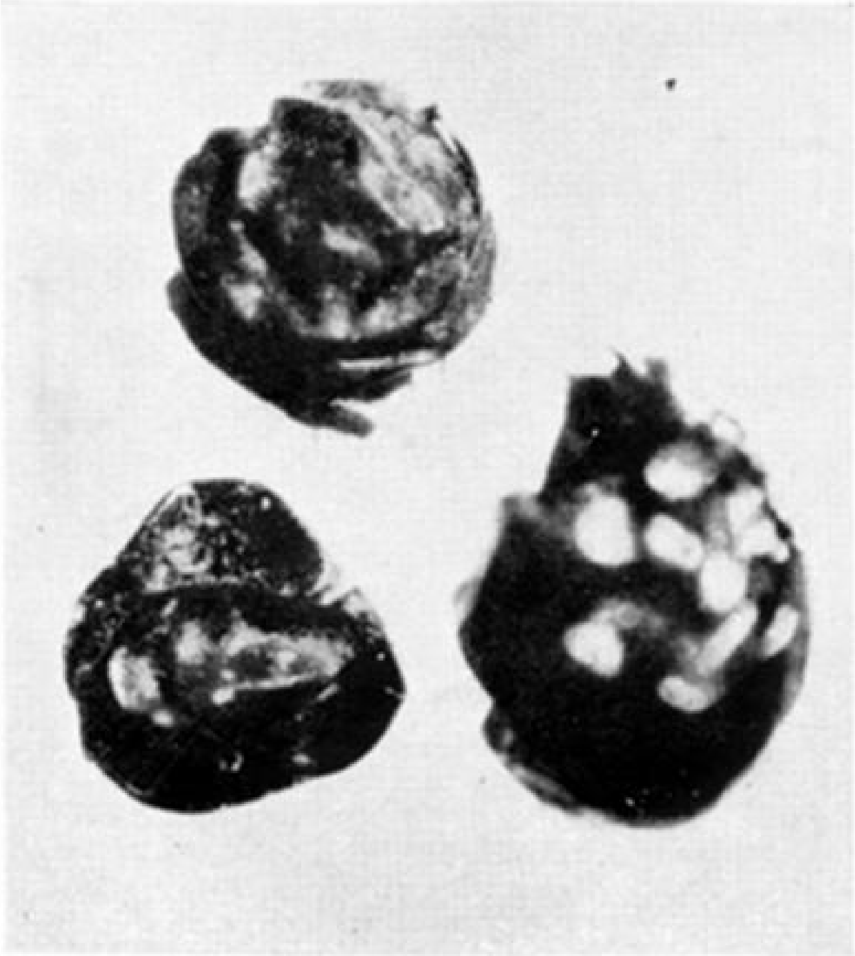

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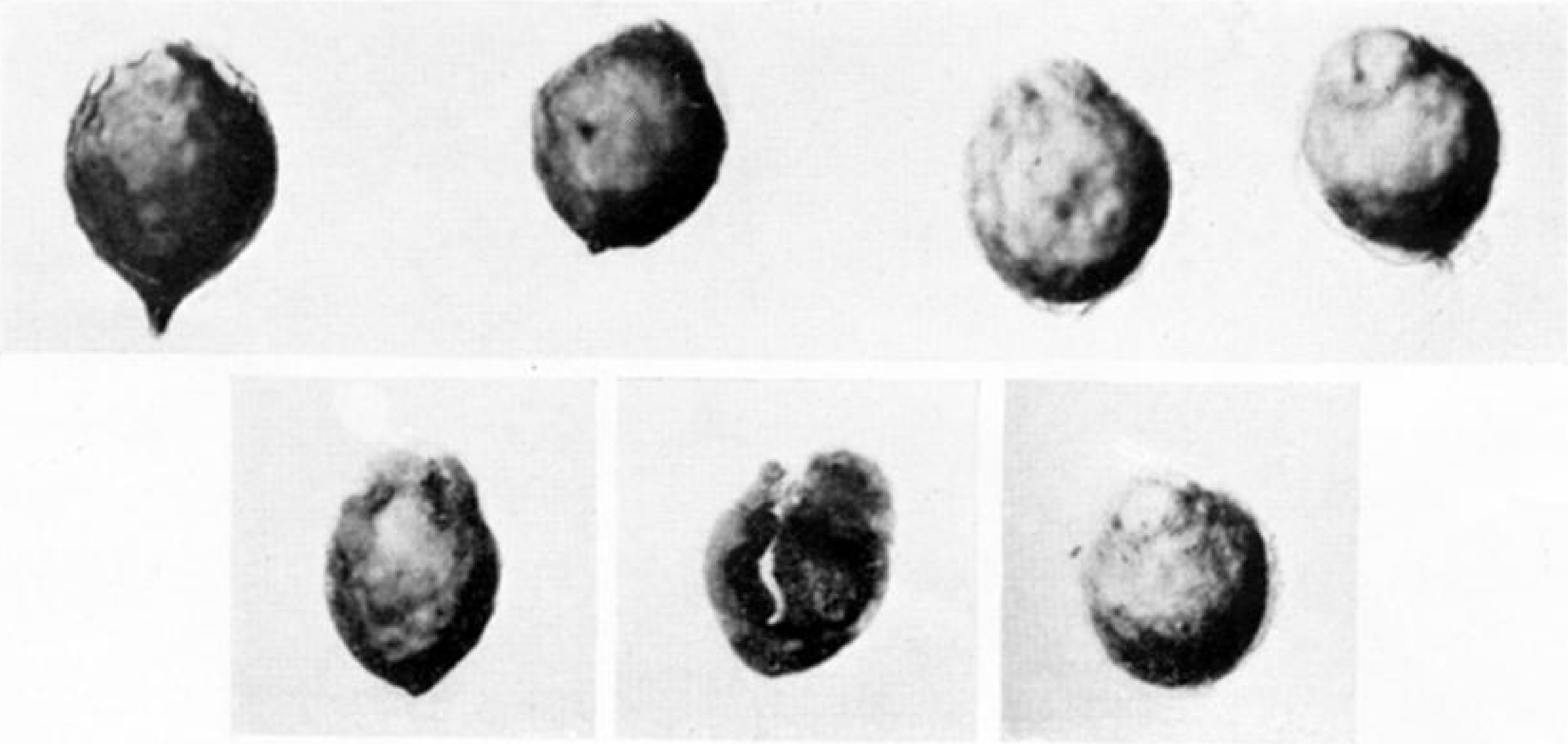

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Description of plate 2

Figure 10. *Stratiotes aloides*; pollen grain. (Magn. ×1460.)

Figure 11. *Sagittaria sagittifolia*; fruit. (Magn. ×13.)

Figure 12. *Ranunculus parviflorus*; achene. (Magn. ×21.)

Figure 13. *Najas marina*; fruit. (Magn. ×17.)

Figure 14. *Najas minor*; fruit. (Magn. ×25.)

Figure 15. *Najas flexilis*; fruit. (Magn. ×25.)

Figure 16. *Nasturtium microphyllum*; seeds. (Magn. ×25.)

Figure 17. *Lemna* cf. *minor*; seeds. (Magn. ×25.)

Figure 18. *Hydrocharis morsus-ranae*; seeds. The loose spiral thickenings of the epidermal cells cause the irregular appearance of the seed surfaces. (Magn. ×30.)

Figure 19. *Hypericum* cf. *tetrapterum*; seed. (Magn. ×45.)

Figure 20. *Salvinia natans*; massula inside the reticulate sporangial wall. (Magn. ×105.)

Figure 21. *Salvinia natans*; megasporangia and megaspores. The top four and bottom right megaspores are within their reticulate megasporangial walls. The bottom left and centre megaspores have lost their megasporangial walls, and the bottom centre one has broken open exposing the inside of the perispore. (Magn. ×25.)

Figure 22. Turbellarian egg-capsules. (Magn. ×25.)

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