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Pollen Analysis of the Cromer Forest Bed Series in East Anglia

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Phil. Trans. R. Soc. Lond. B 1963 **246**, 149-202
doi: 10.1098/rstb.1963.0004

POLLEN ANALYSES OF THE CROMER FOREST BED SERIES IN EAST ANGLIA

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WITH AN APPENDIX ON THE NON-MARINE MOLLUSCA

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(*Communicated by H. Godwin, F.R.S.—Received 4 April* 1962)

[PLATE 7]

CONTENTS

The deposits which have been analyzed lie on the coast between West Runton and Corton. No single pollen diagram shows the complete vegetational history of the period during which the Cromer Forest Bed Series was laid down, but, when considered together, the diagrams show evidence of a sequence which has been divided tentatively into three zones. The first of these (zone *a*) shows a predominance of *Betula* and then *Pinus*; pollen of other trees is either absent or insignificant, and the non-arboreal pollen values are very high in the early part of the zone. *Alnus* is strongly represented throughout zone *b*, which shows the rise and subsequent decline of mixed-oak forest trees and a similar but later change in *Picea*. The mixed-oak forest trees disappear in zone *c*, *Alnus* and *Picea* decrease and probably disappear and *Betula* and *Pinus* return to dominance.

It is possible that these three zones represent a sequence in time; if so, the changes reflect a climatic change from cool or cold conditions through a warm period to increasing cold.

The pollen zones could not be related satisfactorily to the divisions of the Cromer Forest Bed Series which were established by Clement Reid.

The vegetational zones of the Cromer Forest Bed Series are compared with those of other deposits which are believed to be of the same age or to belong to subsequent interglacials. It appears that the Cromerian diagrams have a number of features in common which may be used to distinguish them from diagrams referred to deposits of other interglacials.

The non-marine molluscs found in the Cromer Forest Bed Series at West Runton are listed by Mr B. W. Sparks, who considers that they indicate the formation of that part of the deposit in a marsh cut by sluggish drainage channels.

1. Introduction

The Cromer Forest Bed Series of East Anglia has been known and studied for many years, and a very great number of published papers deal with the problems of its age, its relationship to deposits in the same and other areas, the conditions under which it was laid down and the plants and animals which existed in the region at the time of its formation. However, in spite of the fact that pollen analysis might be expected to throw light on some of these problems, and that many of the exposures of the Cromer Forest Bed Series are of a type suitable for the use of this technique, the pollen in the deposits has received little attention. The only previous work of this nature was carried out by Thomson, who analyzed part of the sequence at West Runton and published the results in a paper by Woldstedt (1950*b*). The present paper gives an account of work designed to fill in some of the gaps in the pollen analytical record of the Cromer Forest Bed Series, and it is concerned with those parts of the deposit which lie on the coast between West Runton in Norfolk and Corton in Suffolk.

Shells collected from the Cromer Forest Bed Series at West Runton were examined by Mr B. W. Sparks, and the results of this examination are given in Appendix 3.

2. The Quaternary deposits on the coast between West Runton and Corton

The Quaternary deposits exposed in the cliff sections and on the beach of the Norfolk coast in this area are very variable and have been interpreted in a number of different ways. A detailed consideration of these deposits and their relationships is outside the scope of the present paper, but a brief description of the Cromer Forest Bed Series itself, and of the deposits immediately preceding and succeeding it, is given below. The most detailed descriptions of the deposits in question and of the coast sections as a whole are those given by Reid (1882, 1890) and Solomon (1932).

The Weybourne Crag, the youngest of the Crag series and the only one which occurs in the part of the coast under discussion, is the earliest known Quaternary deposit in this area. The Weybourne Crag consists of clays, sands, gravels and ferruginous conglomerates and is found between Weybourne and Trimingham. It is frequently shelly, and is characterized by the mollusc *Macoma balthica*. The relationship of the Weybourne Crag to the Cromer Forest Bed Series is obscure, and so is the climatic significance of the molluscs recorded from it. Both the Weybourne Crag and the Cromer Forest Bed Series have been reported to overlie the Stone Bed (flints, often cemented with iron oxide), but it is uncertain whether this is in fact only a single unit.

The Cromer Forest Bed Series consists of deposits exposed sporadically along the coast between Weybourne and Kessingland. Reid (1877) noted that some of the deposits were associated with estuarine and some with freshwater conditions, and he later divided the series into the Lower and Upper Freshwater Beds separated by the Estuarine Bed, the top of which may form a Rootlet Bed. In the present paper, the term 'Cromer Forest Bed Series' has been used to cover all or any of these divisions. Hinton (1926) and Zeuner (1937) consider that the deposits in the vicinity of Bacton are somewhat younger than those of Cromer and Runton, and this has led to the use of the term 'Bacton Forest Bed' for the deposits in that area, but this distinction has not been maintained here.

The most recent lists of plants from the Cromer Forest Bed Series (C. and E. M. Reid 1908, E. M. Reid 1920) cite some 150 species. Most of these still occur in the British Isles today, the few exotics listed in 1920 being *Corema intermedia* Reid, *Hypecoum procumbens* L., *Najas minor* Allioni, *Trapa natans* L. and *Picea abies* (L.) Karst.

The *Leda* (*Yoldia*) *myalis* Bed and the Arctic Freshwater Bed are believed to lie between the Cromer Forest Bed Series and the Cromer Till. The *Leda myalis* Bed commonly consists of false-bedded sand but may be represented by gravel, clay or loam; it occurs sporadically between Weybourne and Overstrand. Only a few fossils—molluscs—have been recorded from this bed, and *Yoldia myalis* is said to be the only one which differs from those of the Weybourne Crag. The Arctic Freshwater Bed is a peaty loam or sand with a few shells, and it has yielded plant remains which include *Betula nana* and *Salix polaris*. The relationships of the two deposits are obscure; Reid (1882) believed that the Arctic Freshwater Bed succeeded the *Leda myalis* Bed, but Solomon (1935) regards the latter as the younger of the two deposits. It has been suggested that both represent cold conditions during the early stages of the glacial episode responsible for the formation of the Cromer Till, the earliest glacial deposit of the coast sections.

The bulk of the deposits which succeed the Cromer Forest Bed Series on the coast are usually believed to have been laid down during glacial periods, and there is now fairly general agreement that three glacial episodes are represented in the area (West 1961). These glacial deposits need be considered no further here.

3. Pollen analyses of the Cromer Forest Bed Series

(*a*) *Collection and identification of samples*

In connection with this investigation of the Cromer Forest Bed Series, the part of the coast between Weybourne and about a mile south-east of Happisburgh was examined twice, and many of the localities between these two points were visited more frequently. The coast at North Gap, Hopton and Corton was also studied. The interpretation of the deposits which were exposed at the time (1952 to 1954) was extremely difficult. They were very variable, and their interrelationships were often obscured by talus, sea-walls, turf and natural vegetation. Even if visible, the deposits of the upper parts of the cliffs were not always accessible, as the cliffs may be very steep and liable to crumble.

Detailed accounts of the deposits (Reid 1882, 1890 and Solomon 1932) refer to conditions as they existed 20 to 70 years before the investigations described here, and the picture has seldom remained unchanged during that interval. The deposits are often of a limited

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

extent, and the rate of erosion of the cliff face is so rapid that many of the strata sampled by the present author during early visits to the area later disappeared or became so altered that it was difficult to recognize them.

The identification of the Cromer Forest Bed Series and its separation from deposits representing the periods immediately before and after it is particularly difficult. The Weybourne Crag, *Leda myalis* Bed and Arctic Freshwater Bed may be of the same type of sand, clay, gravel, peaty material, etc., as the Cromer Forest Bed Series. Even if fossils are found in these deposits, they may be of no assistance in solving the problem—for example, the marine shells recorded from the Estuarine Bed are also found in the Weybourne Crag. In any case, the visits to the area were necessarily brief, so that an extensive search for macrofossils could not be made and they were in fact seldom found.

Difficulties of the type that have been mentioned make it impossible to be certain that all the deposits which have been pollen analyzed belong to the Cromer Forest Bed Series, but it seems probable that most of them are correctly identified. The main deposit sampled is at West Runton, where the exposure has been known and accepted for many years. Most of the other samples consist of dark-coloured organic material, and this is more common in the Cromer Forest Bed Series than in any of the other deposits mentioned. All the deposits sampled were at or near beach level, and in most cases it was possible to establish their position relative to the Cromer Till. The area has been visited in company with some of the scientists who have worked on other aspects of the coastal deposits, and the benefit of their opinions has thus been available. Finally, it may be noted that the results from the pollen analyses seem to be consistent with the identification of the deposits concerned.

The question of the relationship of the pollen zones to Reid's three divisions of the Cromer Forest Bed Series is dealt with later in this paper, but it should be mentioned here that the deposits sampled were not recorded in these divisions because of the difficulty in identifying them. Although peaty or otherwise highly organic material seems to be more or less restricted to the Freshwater Beds, materials such as clays, sands, gravels, etc., may occur in any of the divisions, and there appear to be no constant lithological characters which can be used to separate them. Little trace was seen of the quantities of wood which are usually supposed to be characteristic of the Estuarine Bed, and marine shells were not found, so that it was not possible to relate other parts of the deposit to the Estuarine Bed. If the Estuarine Bed is either absent or unrecognizable in a particular section, then it appears to be impossible to separate the Lower from the Upper Freshwater Bed; according to Reid (1890), 'no evidence has at present been discovered of any change of climate, or variation in the flora and fauna between the periods when the Lower and Upper Freshwater Beds were laid down', and, apart from the evidence from the pollen analyses, the position does not seem to have changed. Exposures of the Lower Freshwater Bed *in situ* are extremely rare and, although Reid (1890) noted two which were below high tide mark, a third was above this point, and hence the divisions cannot be separated on the basis of their levels.

An outline of the stratigraphy of the deposits sampled is given in Appendix 1. The difficulties in identifying the overlying deposits are of the same type as those already noted for the Cromer Forest Bed Series itself, and they are intensified by the fact that no attempt was made to study these deposits in detail; consequently, only the more obvious features are recorded in the appendix, and no exact measurements are given.

The location of the sections from which samples were taken is given in figure 1. These sections have been labelled A to Z, AA to FF according to their position, successive letters referring to sections progressively farther to the east or south-east. These localities were marked on the six-inch maps of the area during the course of the work but, in view of the variability, impermanent nature and restricted extent of the deposits concerned and the

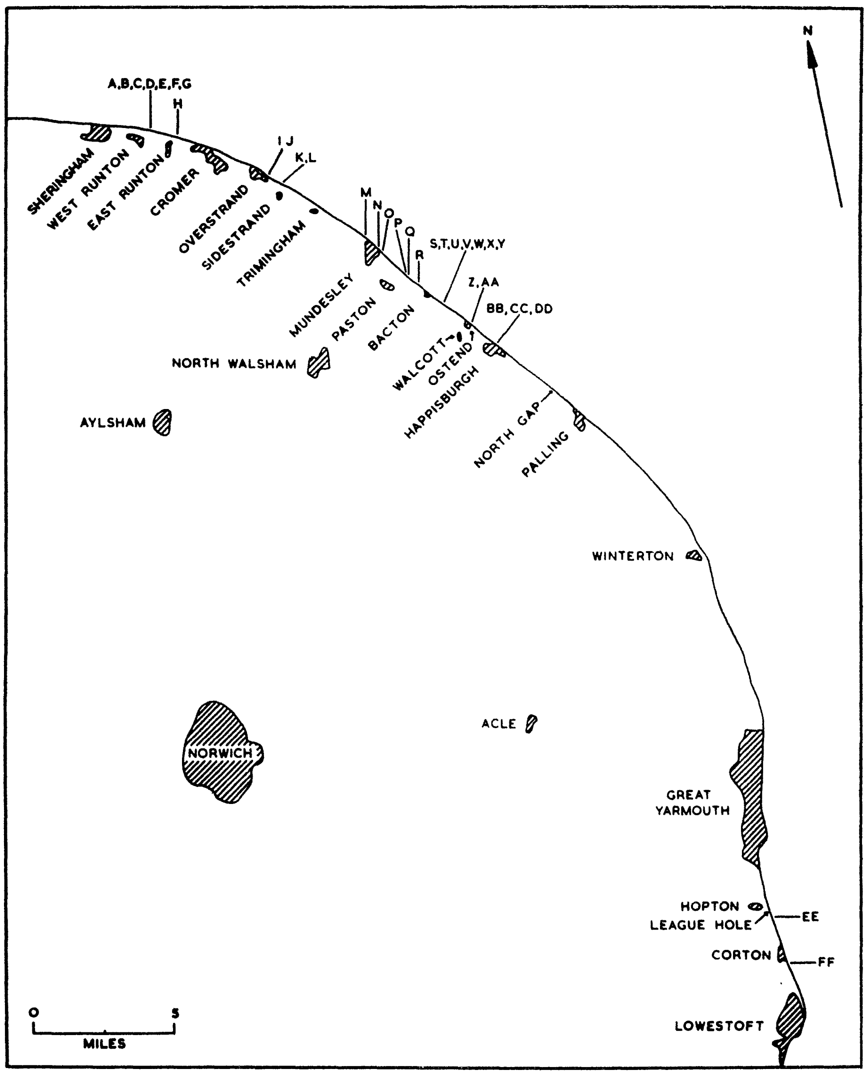

FIGURE 1. Map of East Anglia showing the approximate position of the sites investigated.

paucity of identifiable landmarks along the coast, these records were not considered to be of sufficient importance or accuracy to warrant reproduction here; heights above sea-level were not measured for the same reasons.

(*b*) *Pollen diagrams*

(i) *General notes*

The pollen diagrams or pollen spectra of the deposits sampled are shown in figures 2 to 15. Both the *AP* (arboreal pollen) and the *NAP* (non-arboreal pollen) percentages are based

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

on counts of 150 tree pollen grains (excluding *Corylus* and other shrubs) for each horizon sampled. Spores and the pollen of water plants are omitted from the *NAP* values used in calculating the *AP*/*NAP* ratios.

Most of the pollen is poorly preserved, and this has almost certainly led to some error in the counts. In general, the relative values of *Pinus*, *Tilia*, *Alnus*, *Picea* and *Ulmus* (the pollen grains of which are recognizable under almost any conditions) are probably correct, but the values of *Betula* and *Carpinus* may be a little lower than their actual representation and those of *Quercus* are almost certainly lower. Pollen grains which are definitely referable to *Salix* are scarce, but it is probable that the counts should be somewhat higher than those recorded.

In some groups, counts were not made and the records are shown in the diagrams by abbreviations only. These are as follows:

h—Pinus haploxylon	*B—Botryococcus*
n—Betula nana	*P—Pediastrum*
C—Calluna	*AZ—Azolla*
E—Empetrum	

The state of preservation of the pollen grains was seldom good enough to permit *Betula nana* to be distinguished from tree species of *Betula*, *Pinus haploxylon* from *P. sylvestris* type and *Empetrum* and *Calluna* from Ericales. Consequently, *Betula nana*, *Pinus haploxylon*, *Calluna* and *Empetrum* were noted when their identification was possible, but the absence of records does not necessarily indicate the absence of such types. In no case is it considered likely that pollen of *Betula nana*, *Pinus haploxylon*, *Calluna* and *Empetrum* is responsible for more than a very small part of the values for *Betula*, *Pinus* and Ericales. The remains of *Botryococcus* and *Pediastrum* are of a very fragmentary nature, and hence were not counted.

Records of *Azolla* refer variously to megaspores or massulae found in some of the pollen preparations or in the material sieved off during the manufacture of slides. The megaspores (figure 21, plate 7) are tuberculate and show three floats; the massulae are provided with glochidia which have a single pair of barbs and are usually terminally septate. The identification of these remains as *A. filiculoides* Lam. seems satisfactory, although the tubercles on the megaspores are usually smaller, less numerous and more widely spaced than those of the living plant or of other Quaternary fossils. However, there is an appreciable variation in the tubercle pattern of the living species examined, and the pattern of the Cromer Forest Bed Series fossils is similar to that shown for the living plant by Strasburger (1873) and for German Quaternary fossils by von Rochow (1952) and Hiltermann (1954). The characteristic ring around the tubercles (seen in figure 21) is absent from many of the Cromer Forest Bed Series megaspores, but this appears to be due to the imperfect state of preservation of such remains. The fossils occasionally show extra septa behind the terminal ones in the glochidia, and hence it is not impossible that they should be referred to *A. filiculoides* var. *rubra* (R.Br.) Strasburger.

In discussing the pollen diagrams, the longest and most important ones have been arranged in groups, each of which appears to show distinctive stages in the vegetational sequence. The diagrams are zoned, but the zonation is only a very tentative scheme, subject to revision and designed mainly to facilitate reference to specific parts of the diagrams.

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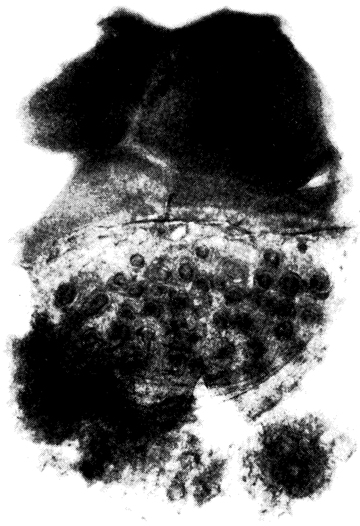

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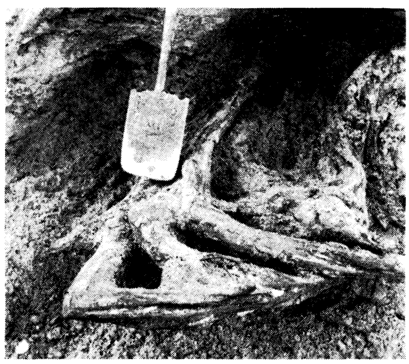

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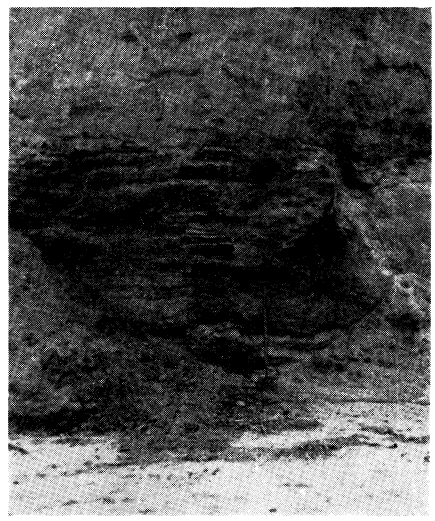

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FIGURE 20. Cromer Forest Bed Series in the form of a dark-coloured step rising from beach level at West Runton. This is the deposit represented by diagrams A to G. Photograph by Dr J. Donner.

FIGURE 21. Megaspore and massulae of *Azolla filiculoides*, showing details of the surface of the megaspore. This specimen was found in the Cromer Forest Bed Series at A (West Runton). Photograph by Dr M. Canny. (Magnification × 100.)

FIGURE 22. Cromer Forest Bed Series in the vicinity of A (West Runton), showing dark-coloured, highly organic mud with shells.

FIGURE 23. Cromer Forest Bed Series in the vicinity of A (West Runton), showing the division into a dark-coloured upper layer and a lighter lower one. This section includes the part shown in more detail in figure 22.

FIGURE 24. Cromer Forest Bed Series at O (Mundesley), showing a large piece of *Taxus* wood. Photograph by Dr R. G. West.

FIGURE 25. Interstratified sand and mud of the Cromer Forest Bed Series at R (between Mundesley and Bacton).

(*Facing p.* 154)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(ii) *Diagrams A to G and Thomson's diagram* (*West Runton*)

The outcrop of the Cromer Forest Bed Series at West Runton (figures 20, 22, 23, plate 7), is represented by eight diagrams (figures 2 to 7). One of these is the diagram drawn up by Thomson (in Woldstedt 1950*b*); it has been reproduced (in a form slightly different from the original) in figures 2 and 3. Diagrams A and B represent parts of the

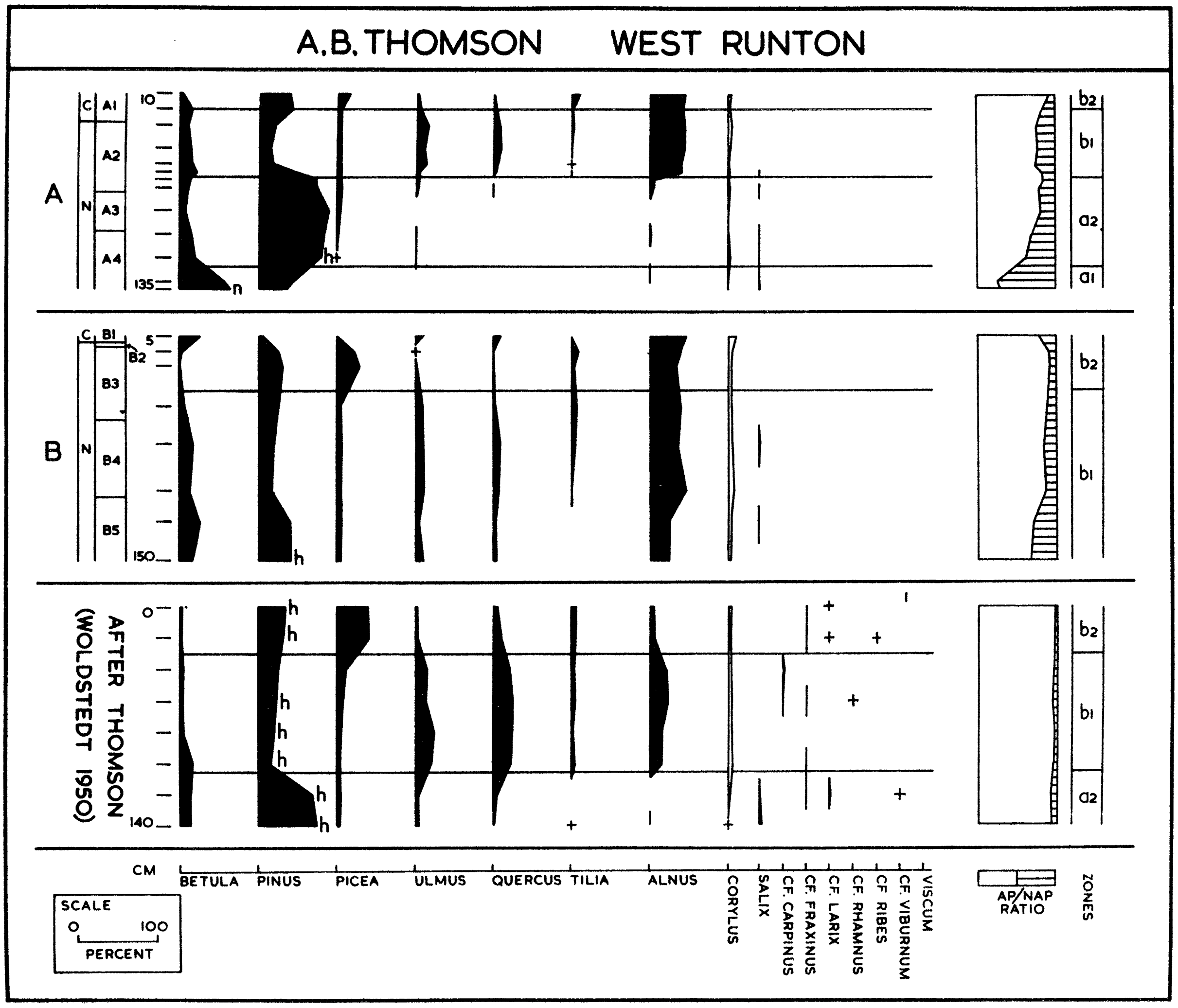

FIGURE 2. Tree pollen diagrams A, B and the diagram redrawn from the one given by Thomson in Woldstedt (1950*b*). An explanation of the abbreviations used in the body of this and subsequent diagrams is given on p. 154, and the symbols used to denote the stratigraphy in each diagram are explained in appendix 1 (pp. 186 to 196).

deposit towards the western and eastern ends of the exposure respectively; the position of these sites in relation to C to G and Thomson's site is not known. Diagrams C to G represent a series of sections from one end of the deposit to the other; their stratigraphy and position relative to one another are shown in figure 17.

Diagram A (figures 2 and 3) is regarded as the most important of the Cromer Forest Bed Series diagrams, as it shows two entirely different vegetational sequences with a clearly marked boundary between them. These two sequences are classed as separate zones, *a* and *b*, and each is subdivided once, so that, from the base, the order is *a*1, *a*2, *b*1, *b*2.

Zone *a*1 shows high but decreasing values for *Betula* and values for *Pinus* which are at first lower than those of *Betula* but which exceed them at the top of the zone. No other trees are represented to any appreciable extent. *Betula nana* is probably present; it is recorded from the lowest horizon and grains from the next one may belong to this plant.

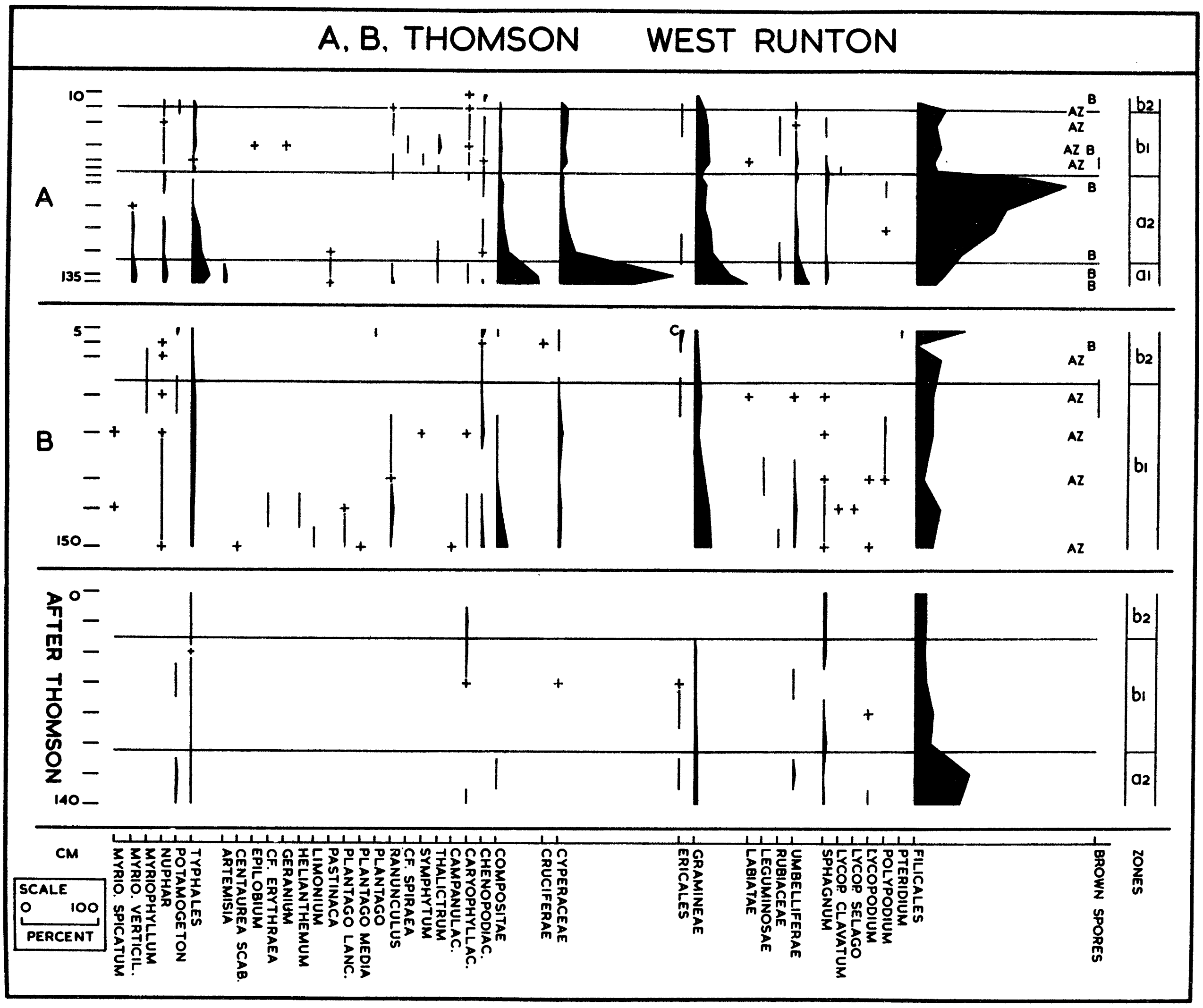

Figure 3. Non-tree pollen diagrams A, B and the diagram redrawn from the one given by Thomson in Woldstedt (1950*b*).

There are low values for *Corylus* and *Salix*. *Viscum* is recorded, but the only grain observed was much eroded and is probably derived. The *NAP* is very high compared with the *AP*, and the *NAP* diagram shows particularly high values for Compositae, Cyperaceae and Gramineae amongst the wide variety of herbaceous types. The values for Filicales are low.

The boundary between zones *a*1 and *a*2 is drawn through the sharp increase in *Pinus* and decrease in *Betula*. This is an arbitrary line in a position which is not clearly marked, but the subdivision of zone *a* is considered to be justified because of the great change in the relative values of *Betula* and *Pinus* within the zone. Furthermore, the *a*1/*a*2 boundary is marked by a sharp decrease in the *NAP* values, which fall from 274 % to 65 % across this line.

Zone *a*2 is characterized by very high values for *Pinus* and rather low ones for *Betula*, while a continuous curve for *Picea* (which starts near the base of the zone) is maintained at low values. *Ulmus*, *Quercus* and *Alnus* are recorded, but show only low values and occur mainly at the top of the zone. The values for *Corylus* remain low and *Salix* is recorded only sporadically. The *NAP* values are moderately high at the beginning of the zone, but they decrease appreciably. The values for Filicales increase from the base to near the top of the zone, where they reach 197 %.

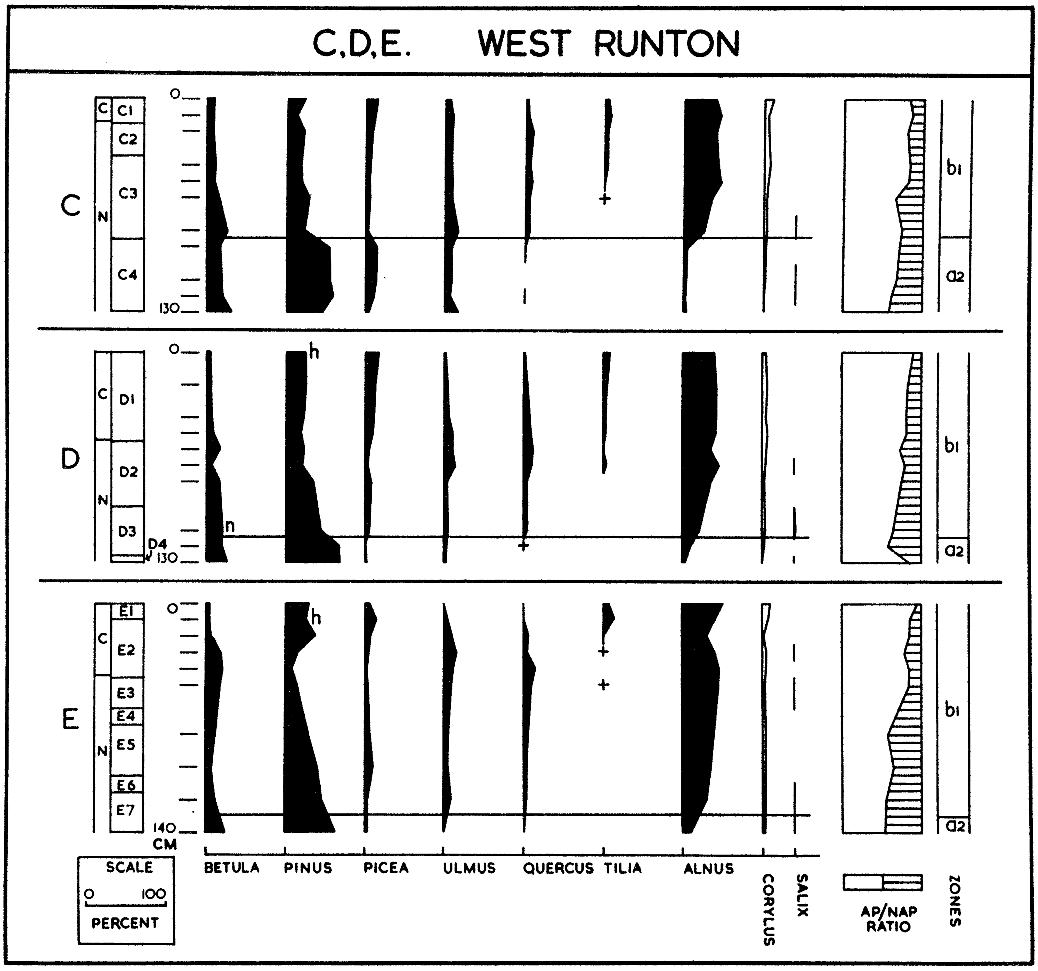

FIGURE 4. Tree pollen diagrams C, D and E.

The *a*2/*b*1 boundary is drawn at a point where there is a sharp decrease in the values for *Pinus* and an increase in those for *Alnus*, and it coincides with the beginning of a continuous curve for *Quercus*. In the *NAP* diagram, the boundary is marked by a very sharp decrease in the values for Filicales. Zone *b*1 is characterized by high and more or less constant values for *Alnus*, and by the rise to a maximum and subsequent decline of *Ulmus* and *Quercus*. *Tilia* shows a low continuous curve from about the middle of the diagram. *Betula* and *Pinus* show moderate values, and low ones are maintained for *Picea*. The values for *Corylus* are low, but rise slightly towards the middle of the zone. The values for *NAP* are moderate to low, but include a wider variety of types than any of the other zones. The values for Filicales remain relatively low. *Azolla* is recorded from all horizons except the lowest one.

Zone *b* 2 is marked by a rise in the values for *Picea* and *Tilia*, and the *b*1/*b*2 boundary is placed at the beginning of this rise. The values of *Pinus* are higher in zone *b*2 than in *b*1, those of *Alnus* are unchanged and those of *Ulmus*, *Quercus* and *Betula* decrease. The values for *Corylus* remain low in *b*2. The *NAP* is low, and both Filicales as a whole and *Azolla* disappear.

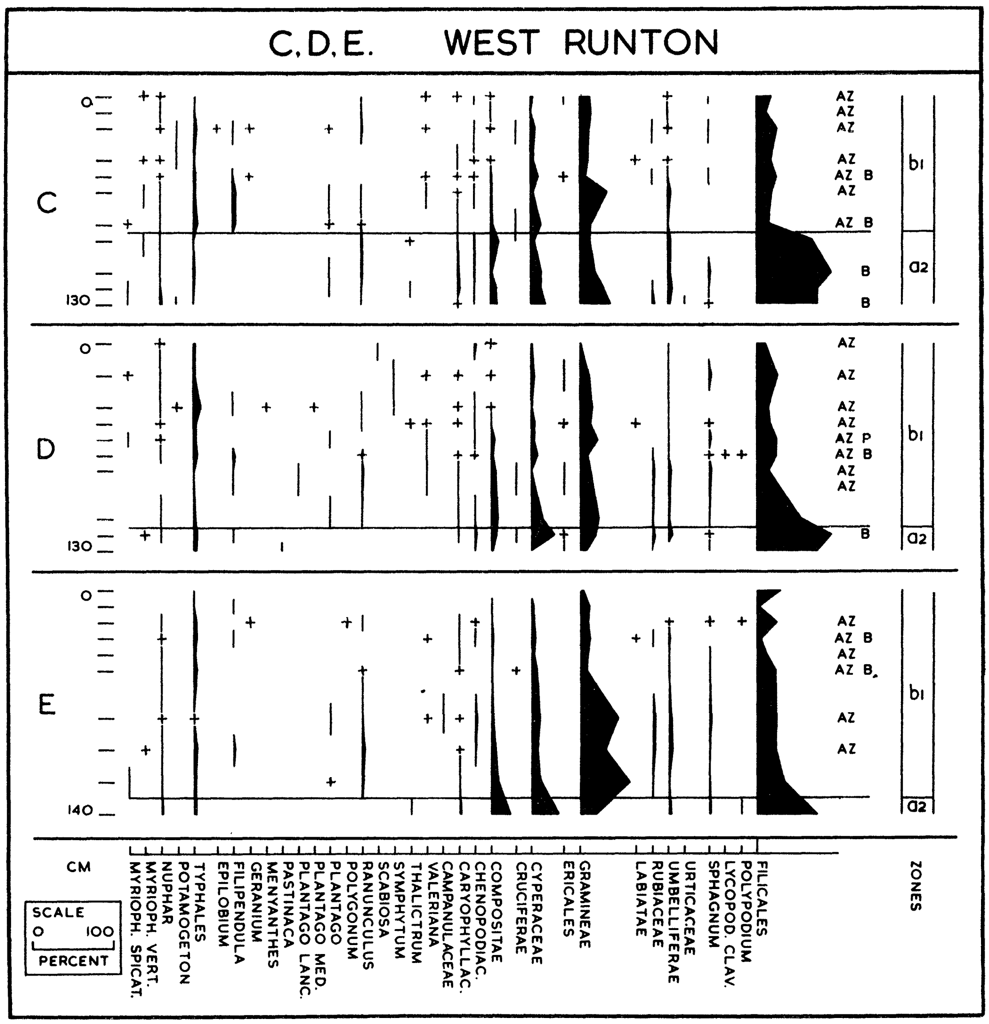

FIGURE 5. Non-tree pollen diagrams C, D and E.

When diagram B (figures 2 and 3) is being considered, it is believed that the pollen spectrum for the horizon at the top of the diagram (5 cm) should be ignored, as it appears to be contaminated by pollen derived from earlier deposits. The greater part of diagram B appears to correspond with zone *b* 1 as described for diagram A. The values for *Alnus* are rather low and those for *Pinus* and *NAP* rather high at the bottom of the diagram, and this, together with the position of the start of the *Tilia* curve, suggests that the *a*2/*b*1 boundary lies close to the base of the diagram. The upper part of diagram B can be related to zone *b*2 as already described. In this zone of B, the higher values for *Picea* compared with those recorded for A (29 % compared with 17 %) and the interruption to the curve for *Ulmus* suggest that the top of B may represent a slightly later period than the top of A.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Thomson's diagram (figures 2 and 3), which was not zoned in its original form, can be divided into zones *a* 2, *b* 1 and *b* 2 as described above. There is no marked increase in *Tilia* in zone *b* 2; this may be due to chance, or the zone may not reach a stage as late as those shown in A and B. Thomson's diagram differs from comparable parts of A and B in having a number of uncertain identifications of additional trees and shrubs, higher values for *Ulmus* and *Quercus*, lower values for *Alnus*, a lower total *NAP* and a smaller number of herbaceous types, and *Azolla* is not recorded. Some of these differences may be due to

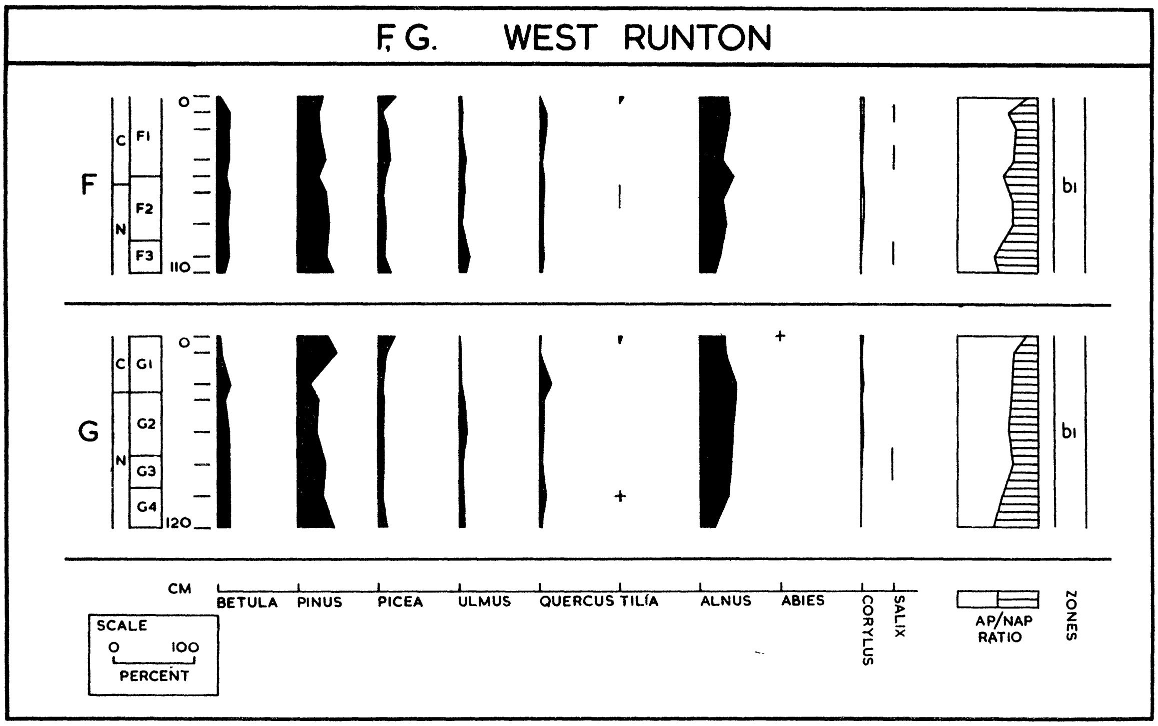

FIGURE 6. Tree pollen diagrams F and G.

chance, but they probably result mainly from the fact that two investigators may differ in their approach to the problem of identifying rather ill-preserved pollen grains. *Azolla* is readily overlooked unless a specific search is made for it.

Diagrams C to G (figures 4 to 7) fit in more or less satisfactorily with the zonation already outlined, but some differences are observed. Diagram C shows a much stronger representation of *Picea* and *Ulmus* in zone *a* 2 than is seen in any of the other diagrams. This cannot be due to special local conditions at C, as all the West Runton sections are close together, but it could result from the incorporation of derived material at this point. The continuous curve for *Tilia* is much shorter in diagrams E to G than in those previously discussed, and in fact it becomes progressively shorter from C to G. This could be caused by a phenomenon—the cessation of deposition, a variation in the rate of deposition, or the removal of existing material—which had a localized effect on some parts of the deposit during its formation, or by a variation in the subsequent compression. The evidence does not favour any one of these causes in particular, and there seems to be no satisfactory explanation for the situation in diagrams F and G (and to some extent in E), where the beginning of the *Tilia* curve is in a position which, judging from the curves of the other trees, should be in or very near zone *b* 2.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

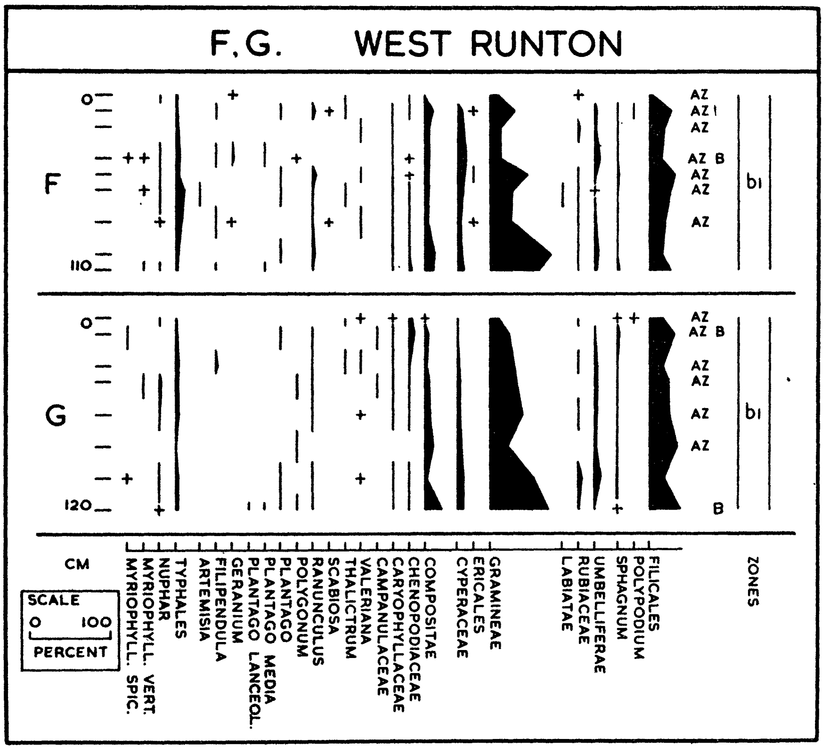

Figure 7. Non-tree pollen diagrams F and G.

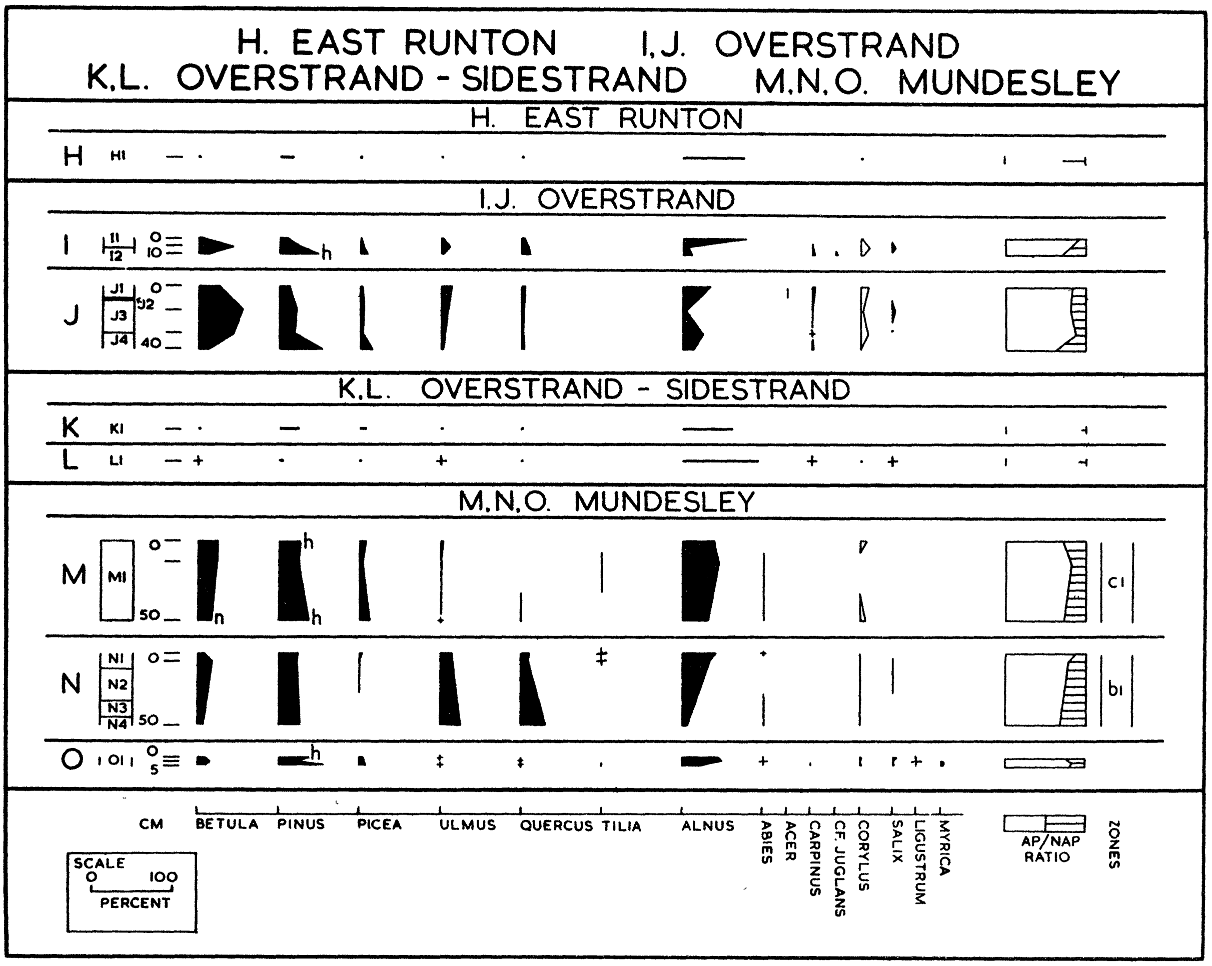

Figure 8. Tree pollen diagrams H to O.

The bottom of the deposit at West Runton is obviously not of the same age throughout. Zone *a* 1 is represented only at A, and diagrams C to E show a decreasing length for zone *a* 2, which is absent from F and G (although the base of these diagrams is probably close to, or even at, the *a* 2/*b* 1 boundary). It is not known whether deposition started in some parts of this particular area before others, or whether deposition commenced everywhere at the

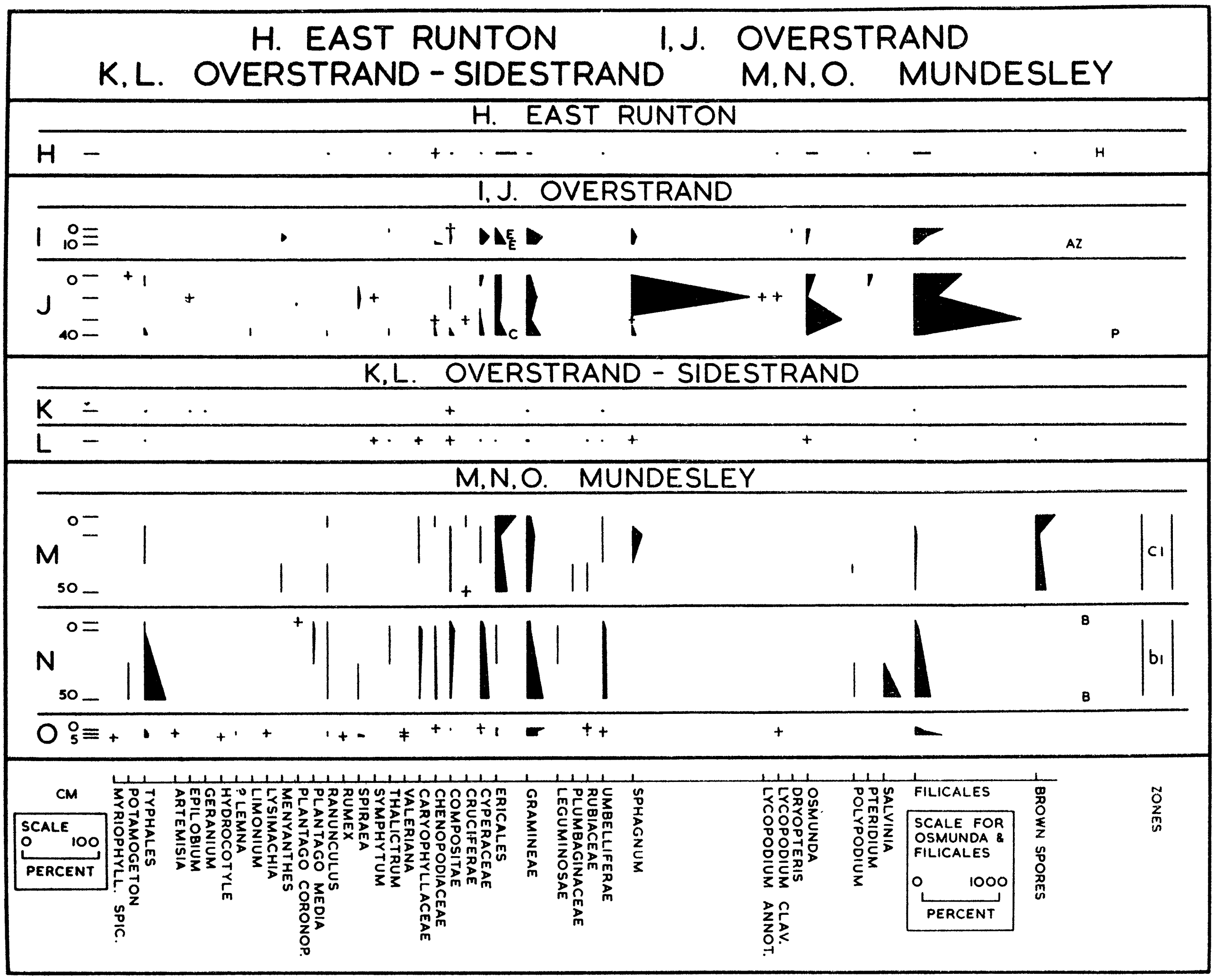

FIGURE 9. Non-tree pollen diagrams H to O.

same time and some of the material was subsequently removed. The stratigraphy of the deposit (figure 17) does not assist in deciding between these alternatives; deposition was not uniform (for example, the sandy layer towards the base of E is not repeated in other sections), but there is nothing to show whether or not any channels were cut and subsequently filled in.

When due allowance is made for the fact that the zones cannot be matched exactly in all the diagrams, the most important and consistent features of each zone can be summed up as follows:

Zone a. Betula–Pinus *zone. Betula* and *Pinus* are dominant, and other trees are absent or unimportant. *Corylus* values are very low throughout. *NAP* values are from high to low. *Azolla* is not present.

*Zone a*1. Betula *phase*. The values for *Betula* are very high, while those for *Pinus* are somewhat lower. The *NAP* values are very high.

*Zone a*2. Pinus *phase*. The values for *Pinus* are high and those for *Betula* low. A continuous, but rather low, curve for *Picea* begins in this zone. *MOF* trees and *Alnus* may appear at the end of the zone. *NAP* values are moderate to low.

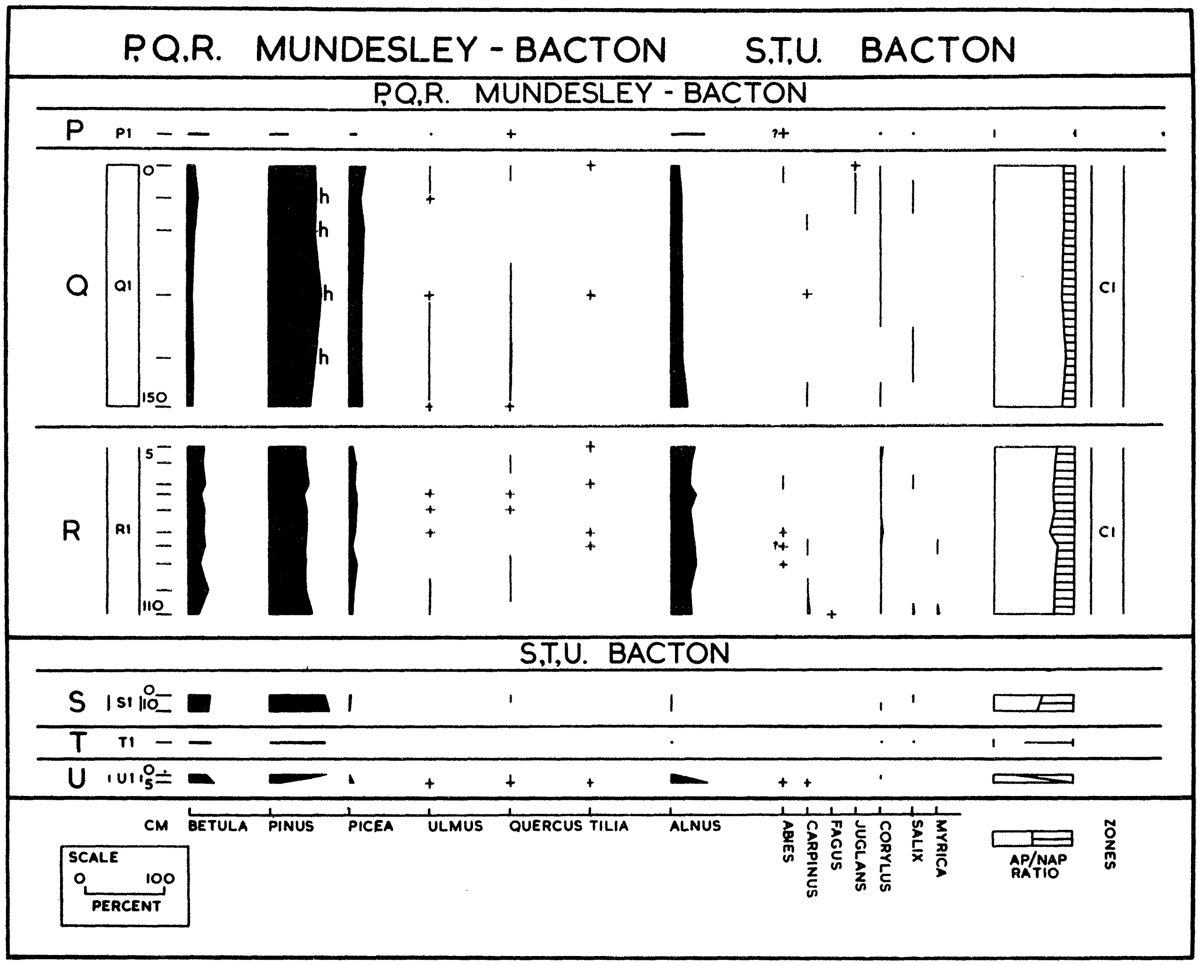

FIGURE 10. Tree pollen diagrams P to U.

Zone b. MOF–Alnus–Picea *zone*. *Ulmus*, *Quercus* and *Tilia* rise to a maximum and then decline; values for *Alnus* are high, and *Picea* may be important. *Pinus* values are variable and *Betula* is rather low. *Corylus* values are very low. *NAP* values are low. *Azolla* may be present.

*Zone b*1. MOF–Alnus *phase*. The values for *Ulmus* and *Quercus* rise to a maximum and then decrease, and a continuous curve for *Tilia* appears for the first time. The values for *Picea* are low. *Azolla* has been recorded from most of the zone.

*Zone b*2. Picea–Tilia *phase*. The values for *Picea* are high and those for *Tilia* relatively high. *Pinus* values may be high and *Alnus* ones moderate. Other trees are of little importance. *Azolla* may be present in the early part of the zone.

(iii) *Diagrams Q, R, U to Y* (*Mundesley to Bacton area*)

Four diagrams of reasonable length (Q, R, X and Y) have been drawn up as a result of investigations in the vicinity of Bacton and between Bacton and Mundesley. In discussing these, it is convenient to include the shorter diagrams from Bacton (U, V, W), as these can be fitted into the same zones. The diagrams appear to be divisible into two groups, with Q, R and V in one group and W, X and Y in the other; U may provide a connecting link between the groups.

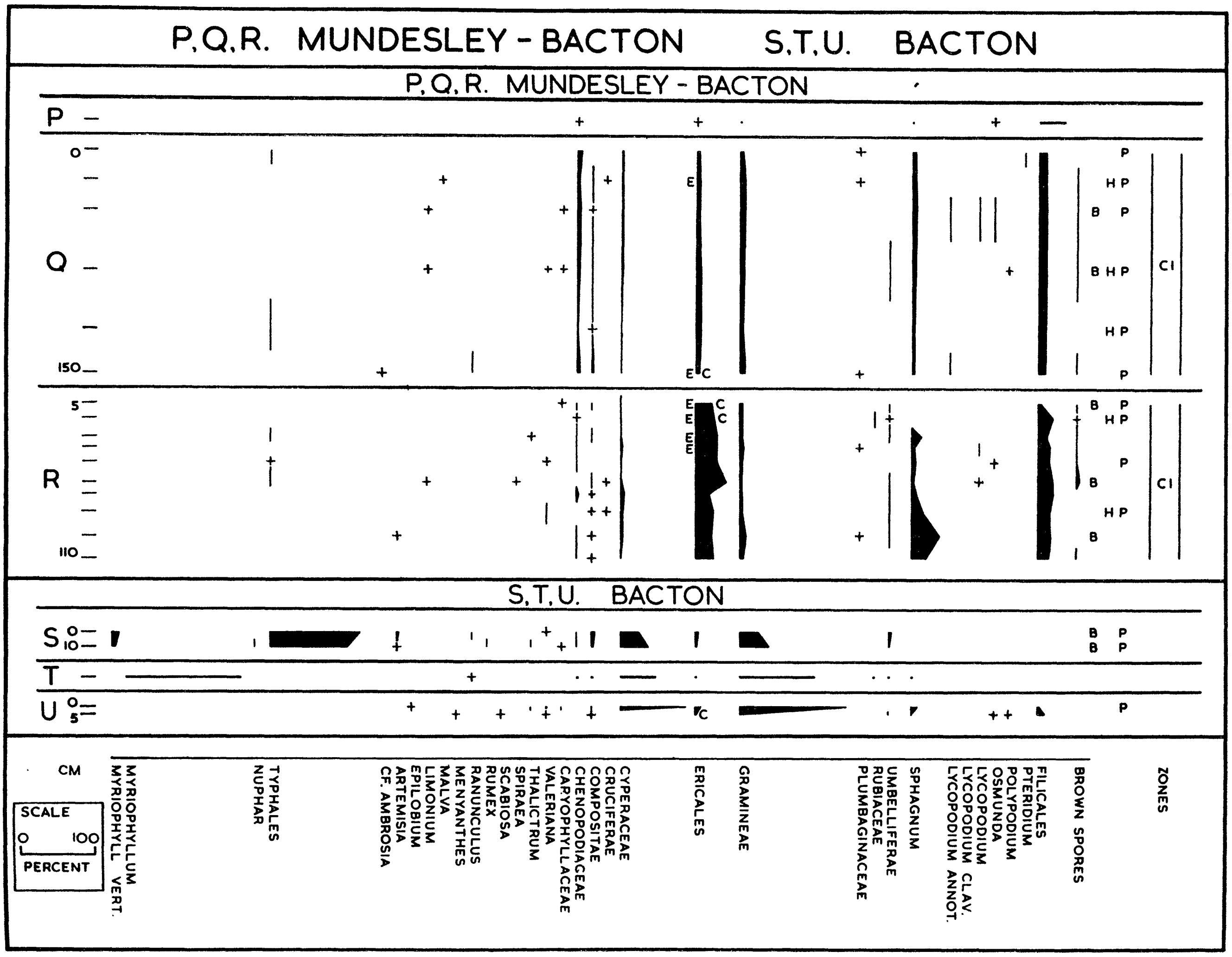

FIGURE 11. Non-tree pollen diagrams P to U.

Diagram Q represents a deposit of laminated sand and clay at the base of the cliff about a mile north-west of Bacton. At the time when the samples were collected, a series of similar deposits was visible for a distance of about 100 yards. R (figure 25, plate 7), represents alternating organic and sandy layers at the base of the cliff about half a mile north-west of Bacton, and V laminated clay in the same position at Bacton. The section at V is illustrated by West & Donner (1958).

Diagrams Q, R and V (figures 10 to 13) are so similar that they can be considered together. The *AP* diagrams show high values for *Pinus* and lower ones for *Betula*, *Picea* and *Alnus*, while other trees are recorded only as traces. *Corylus* shows low values or is absent. The *NAP* values are low; pollen of Ericales is present in all diagrams, and shows high values at R.

If these diagrams belong to part of the sequence shown at West Runton, the absence of any real values for *MOF* trees would place them in zone *a*, and the relatively low *Betula* values are only comparable with those of zone *a*2. It is not impossible that these diagrams represent a late stage in zone *a*2, but some of their features render this interpretation unlikely. In the West Runton diagrams which show the beginning of the *Ulmus* and *Alnus* curves, a continuous curve for *Alnus* starts either at the same time as the one for *Ulmus* or

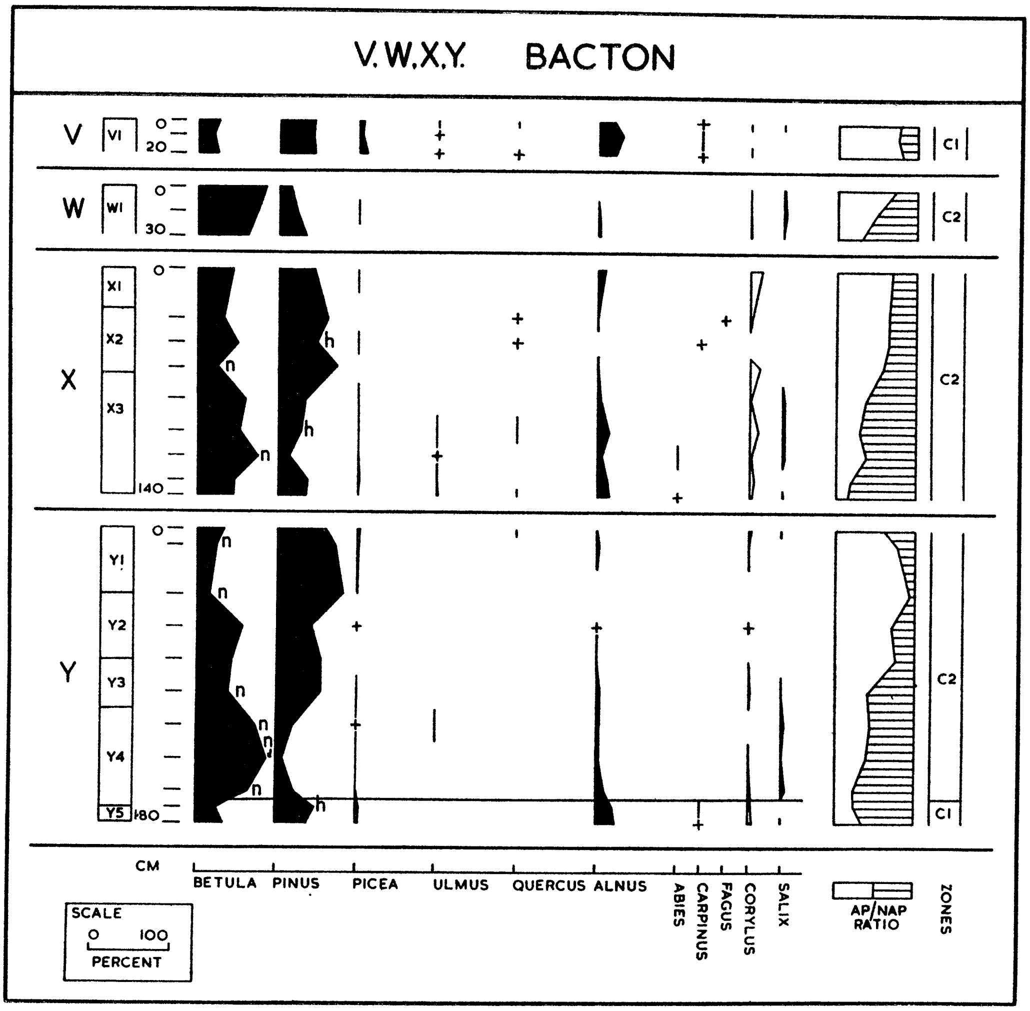

FIGURE 12. Tree pollen diagrams V to Y.

after it. In diagrams Q, R and V there are continuous curves for *Alnus* (with values of 10 to 31 %) at a stage where only traces of *Ulmus* are present. When values of *Alnus* such as those shown in R (22 to 30 %) are present in the West Runton diagrams, the *Ulmus* values may be up to 17 % (24 % in Thomson's diagram) and there is usually a continuous curve for *Quercus*, with values of up to 7 % (24 % in Thomson's diagram). Although high values for *Picea* are not recorded for R and V (the maxima are 9 and 11 % respectively), the values for this genus in Q (13 to 20 %, average 17 %) are much higher than most of those shown in the late stages of zone *a*2 at West Runton. In Q the values for *Alnus* show a general tendency to decrease from the base to the top of the diagram (21, 15, 13, 13, 10 %), whereas they would be expected to show an increase if Q corresponds with the top of

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

zone *a*2. Differences in the *NAP* could be due to local circumstances, but it is of interest that the pollen of Ericales forms a conspicuous part of the *NAP* in Q, R and V (particularly in R, where the values are consistently high and reach 42 %), whereas it is represented only by traces at West Runton.

The evidence is not conclusive, but, until more becomes available, diagrams Q, R and V are assigned tentatively to a separate zone, zone *c* 1, which may possibly represent a period later than any of the West Runton diagrams.

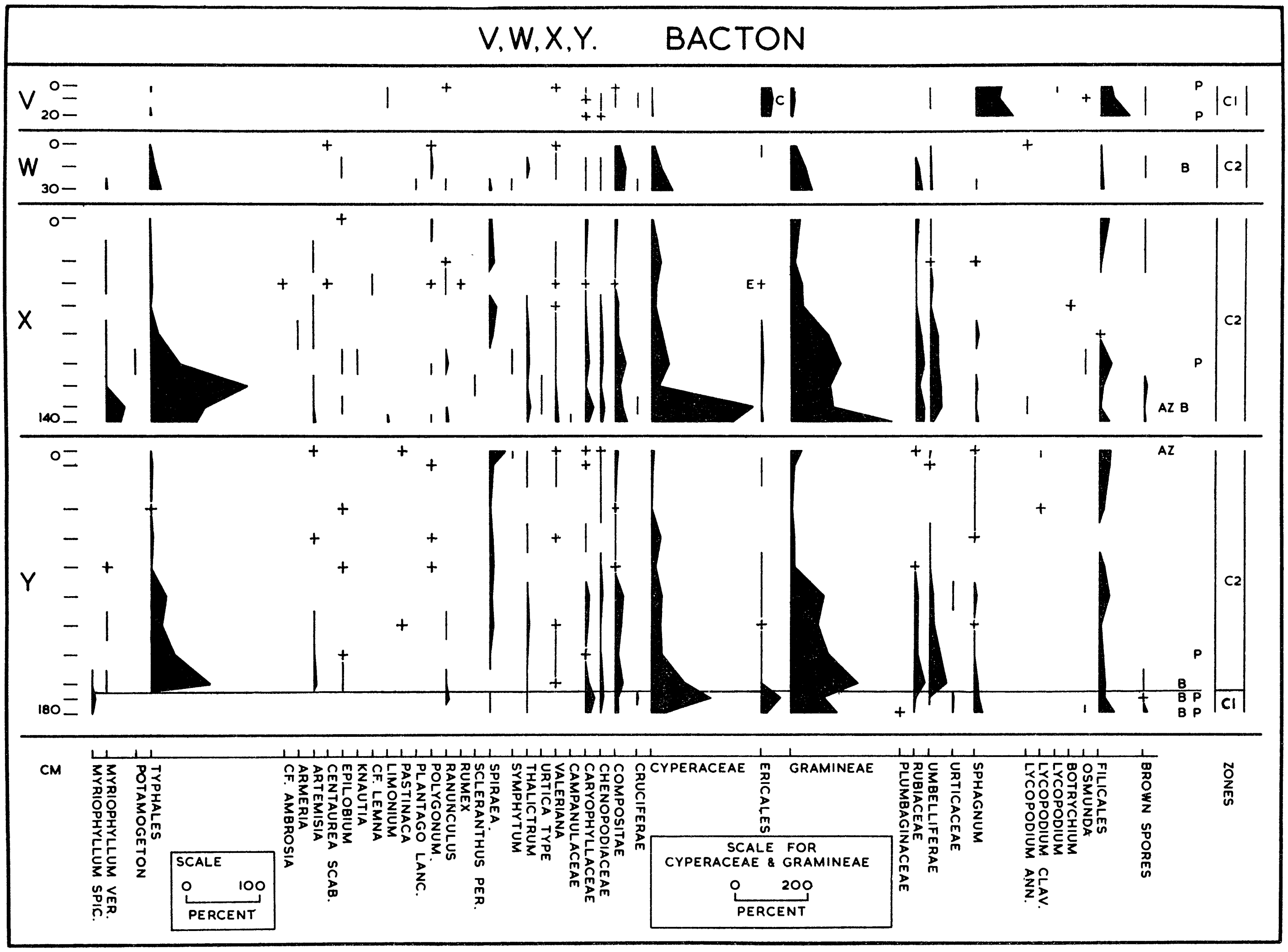

FIGURE 13. Non-tree pollen diagrams V to Y.

Diagrams W, X and Y almost certainly represent parts of a single deposit at Bacton. The three sets of samples were collected at different times in 1952 and 1954, and the severe storms of 1954 so changed the appearance of the locality that the relative positions of the sections could not be determined. However, the sections were all at or near beach level and must have been close together, while the diagrams are so similar that they can be regarded as being part of the same sequence.

Diagrams X and Y will be discussed first, as W is too short for any trends which it may show to be reliable. The diagrams X and Y (figures 12 and 13) show very high values for *Betula* and *Pinus*, the values for *Betula* tending to decrease towards the top of the diagrams and those of *Pinus* to increase. *Picea* and *Alnus* show low and decreasing values, and the curves for these genera become discontinuous in the upper part of the diagrams. *MOF* trees and other trees are represented only by traces, but the curve for *Corylus*, although low and becoming discontinuous, shows some values which are higher than those recorded in other parts of the area.

It is probable that the values from the top horizon of X are less reliable than the others; this horizon consists of sandy clay, in which the possibility of contamination by derived pollen must be considerable, whereas the lower parts of the deposit are all of a highly organic mud. Hence the apparent rise in *Alnus* and *Corylus* at the top of X is not considered to be significant.

The *NAP* values in diagrams X and Y are somewhat unusual if, as will be suggested later, the diagrams represent a period towards the end of an interglacial. The *NAP* values are very high at the base of the diagrams and decrease steadily towards the top, whereas the expected trend would be in the reverse direction. However, it seems probable that the decrease in the *NAP* values is due not to an increase in forest cover but to the gradual drying out of a swamp and the consequent decrease in the number of semi-aquatics surrounding it. The high values for Typhales (and of *Myriophyllum* in X) in the early part of the diagrams, and their subsequent reduction to insignificant proportions, definitely indicate a change towards drier conditions. It is true that Typhales is absent but the *NAP* values are high in the lowest part of Y, but this could mean merely that the other plants producing *NAP* preceded Typhales into the area. Gramineae and Cyperaceae may both be associated with wet conditions; they show values of up to 265% and 276% respectively in the lower parts of the diagrams, and their pronounced decline is largely responsible for the decrease in *NAP* values. With few exceptions, the remainder of the *NAP* towards the base of the diagrams could represent plants associated with wet conditions. The exceptions are *Scleranthus perennis* and *Knautia* (presumably *K. arvensis*, the only British species), but as each of these species is represented only by a single pollen grain the records are of no significance.

Instances of peaks in *NAP* values associated with high values for Typhales are known from other deposits, such as the Last Interglacial deposit at Histon Road, Cambridge (Walker 1953), and the Late-glacial one at Site M4, Nazeing (Allison, Godwin & Warren 1952); the authors of the papers in which these pollen diagrams appear make no suggestion that the *NAP* peaks represent a real decline in forest cover.

Diagram W (figures 12 and 13) probably corresponds with a position somewhere near the middle of X and Y. This is suggested by the fact that the curve for *Alnus* is low and disappears at the top of the diagram, and by the values for Typhales, Cyperaceae, Gramineae, etc. The falling values for *Pinus* and rising ones for *Betula* are probably due to chance fluctuations in these genera, and do not affect the validity of the views expressed regarding the trends in this period.

From the evidence available, it seems that diagrams W, X and the greater part of Y do not fit in with any of the zones already described. The absence of *MOF* trees shows that they do not belong to zone *b*; the two records of *Azolla* (which might otherwise suggest this zone) are each based only on a small fragment and are probably derived. The continuous curves for *Alnus* are not found in zone *a* 1, and the high values for *Betula* do not occur in zones *a*2 or *c*1. *Picea* and *Alnus* show low, diminishing curves which become discontinuous in W, X and Y, and this situation is quite different from the one shown in zones *a*, *b*, and *c*1.

These differences between W, X and Y and the zones already described are considered to be of sufficient importance to warrant placing all these diagrams (with the exception of the base of Y) in a separate zone, zone *c*2. There appears to be a slight overlap with zone *c*1 in diagram Y. The *AP* spectra at 170 and 180 cm are almost identical with zone *c*1 as shown in diagram R and, except for the very high values for Cyperaceae and Gramineae in Y (which are not matched at R), the *NAP* diagrams are also quite similar, the base of Y being marked by high values for Ericales comparable with those of R. The base of diagram X probably lies at or close to the *c*1/*c*2 boundary, which is drawn at the beginning of the rise in *Betula* and at the end of any substantial values for *Picea* and *Alnus*.

Diagram U (figures 10 and 11) may also lie in the vicinity of the *c*1/*c*2 boundary. This is suggested by the sharp decrease in *Alnus*, and by the general resemblance of both the *AP* and *NAP* diagrams to the base of diagram Y. The only difference of any importance is the abrupt rise in *Pinus*, but this could be due to a chance fluctuation. Diagram U gives some support to the sequence previously outlined, but the diagram is too short to be of any great importance.

From a consideration of these diagrams in the vicinity of Bacton and Mundesley, it appears that the zones which are represented may be summed up as follows:

Zone c. Pinus–Betula *zone*. Values for *Pinus* and/or *Betula* are high, and *Picea* and *Alnus* may be of some importance, but no other trees are represented to any real extent. *Corylus* values are low or non-existent. The exact position of *NAP* values is uncertain. *Azolla* is not present.

*Zone c*1. Pinus *phase*. The values for *Pinus* are high, those for *Picea* may be relatively high and those for *Betula* and *Alnus* are moderate to low. *NAP* values are not high, but may include relatively high values for Ericales.

*Zone c*2. Betula–Pinus *phase*. *Pinus* increases, and the *Betula* values rise to a maximum and then decline. The values for *Picea* and *Alnus* decrease and the curves become discontinuous.

(iv) *Diagrams I, J and BB* (*Overstrand and Happisburgh*)

While the longest and most important diagrams have now been discussed, the question of *Carpinus* has been left in abeyance. Small numbers of *Carpinus* pollen grains have been observed in several deposits during the present survey, and E. M. Reid (1920) has recorded macroscopic remains of *C. betulus*, so there is no doubt that *Carpinus* did form part of the forests at some stage during the formation of the Cromer Forest Bed Series. The question to be settled is the position of this stage relative to the zones which have been established.

Carpinus pollen is not recorded in diagrams A to G and, although Thomson recorded 'cf. *Carpinus*' from West Runton, his comments suggest that this pollen may have been derived. Hence it appears unlikely that a *Carpinus* maximum occurred in zone *a* or in zone *b* as far as it has been studied. On the other hand, all the diagrams which have been referred to zone *c* (except the short diagram W) show sporadic low values for *Carpinus*.

The pollen is slightly more common in zone *c* 1 than in zone *c* 2, and up to 3 % has been recorded in the former (at R).

The only diagrams which show more or less continuous curves and relatively high values (although only up to 5 %) are J and BB, and these are discussed here in an effort to clarify the position of the genus. Diagram I is included because it also seems likely to have some bearing on the subject.

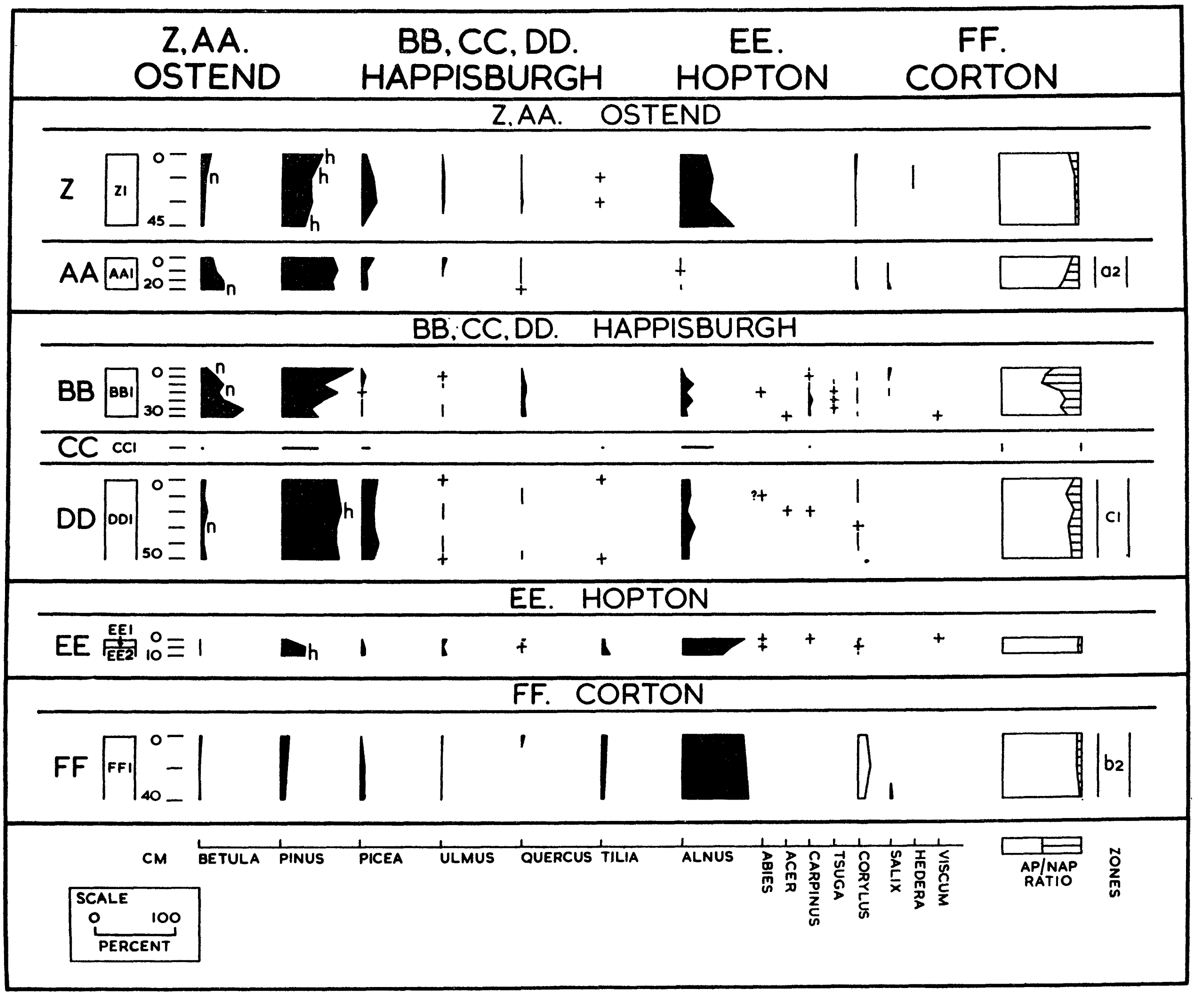

FIGURE 14. Tree pollen diagrams Z to FF.

Diagram J (figures 8 and 9) represents layers of peaty mud lying above grey clay at the base of the cliff at Overstrand (figure 19). Diagram BB (figures 14 and 15) represents samples from peaty mud lying in more or less discontinuous basins of grey clay below high tide level at Happisburgh. The upper layers of the deposit represented by diagram I consist of black, peaty mud, while the lowest horizon is of sandy clay. The deposit is on the foreshore below high tide level, and is some 20 to 30 m from, and at a lower level than, J. The area between I and J is hidden by beach sand, and hence it is impossible to determine whether I is older than J, but it appears probable that this is so.

The pollen in the peaty layers at J is abundant and well preserved, whereas the pollen from the sandy clay is sparse and poorly preserved, and hence the spectrum at the base of the diagram may not be reliable. The material sampled at BB is extraordinarily rich in pollen, the preservation of which is better than that of the pollen in any of the other deposits investigated.

Because of the relatively high values for *Carpinus* and also for *Betula*, the presence of some *MOF* constituents and the absence of *Tilia*, diagrams I, J and BB (figures 8, 9, 14, 15) are believed to represent approximately the same period, although obviously they are not exactly contemporaneous. They are not identical with any of the zones already described, and either they represent a part of the sequence not yet described or the differences are due to local fluctuations.

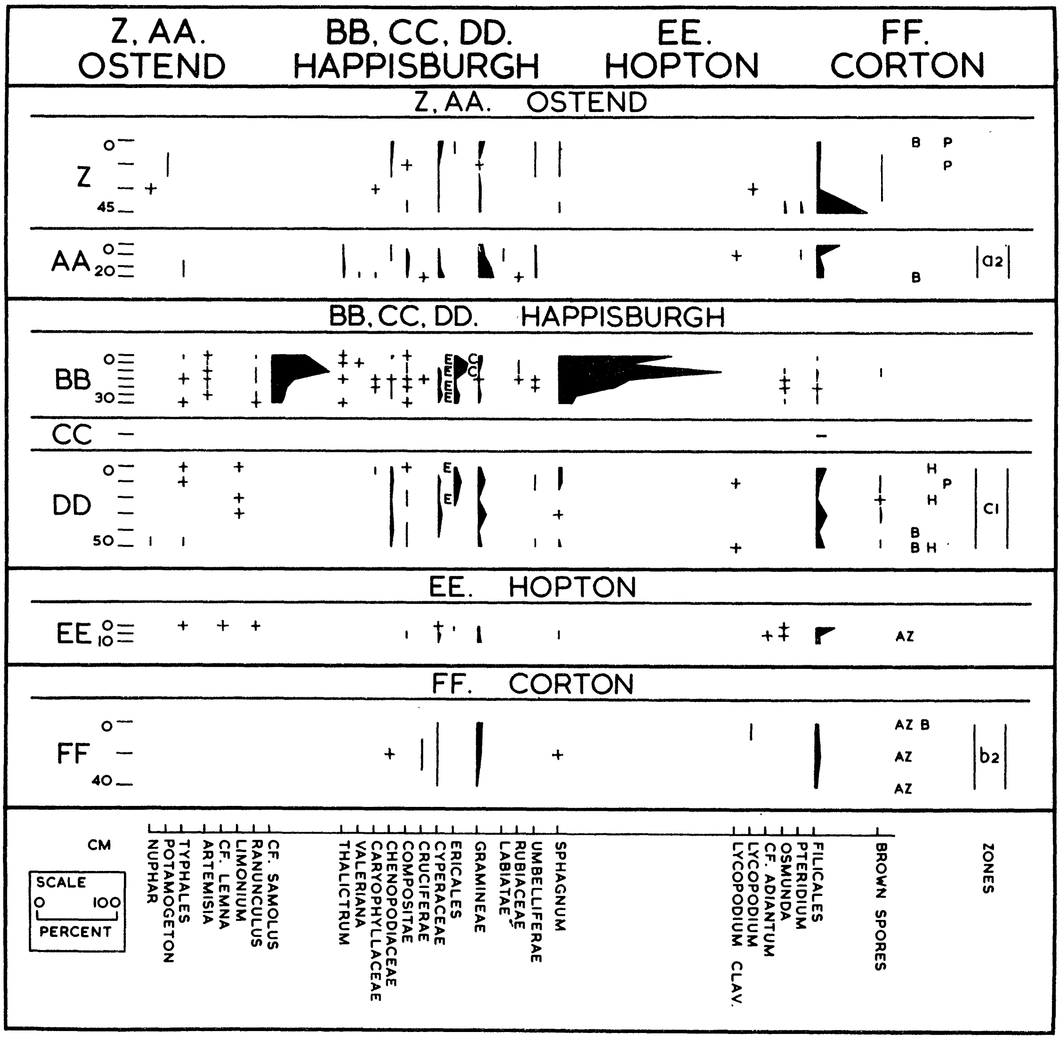

FIGURE 15. Non-tree pollen diagrams Z to FF.

The presence of *Alnus* and some *MOF* trees (excluding *Tilia*) suggest that the diagrams fall just before or just after the *MOF* period, but it is not possible to decide between these alternatives on the basis of the diagrams themselves. However, the evidence from other diagrams representing Interglacial or Post-glacial periods in Europe leaves no doubt that the second is the more likely alternative for, as far as is known, a *Carpinus* maximum has been recorded only at the same time or later than the *MOF* maximum. If, then, the diagrams I, J and BB are placed after the *MOF* maximum, they probably fall in the region of the *b* 2/*c* 1 boundary, as the *MOF* trees seldom show continuous curves after this point, and zone *c* 2 is out of the question.

The sharp and very great rise in *Alnus* in I and *Pinus* in BB, the sharp decrease in *Betula* in BB and the presence of some very high *Betula* values in I, J and BB do not correspond with the situation seen at the end of zone *b* 2 or the beginning of zone *c* 1. The diagrams in question are so short that a great deal of importance cannot be attached to the trends which they show, but if these trends are valid, their explanation may lie in terms of the vegetational sequence investigated by Godwin (1943). He related the stages shown in time (i.e. in pollen diagrams) in certain Post-glacial deposits in England and Germany to those shown in space by living communities in the southern Baltic region (as described by Steffen 1931); both represent a local succession of:

saltmarsh → fen alder-wood → birch-wood → pine-wood → *Sphagnum* peat

with *Sphagnum* playing an increasingly important part from the birch-wood stage. The pollen diagrams which can be compared with I, J and BB are those of St Germans in Cornwall (Godwin 1943), Ynyslas in Cardiganshire (Godwin & Newton 1938) and Sehestedt on the north-west German coast (Profile II, Brinkmann 1934); only the German diagram is complete, but the others show some of the stages particularly well and also show that this type of succession has taken place in Britain at some time during the past.

I may represent the earliest stage in this succession, as it shows values of up to 11 % for Chenopodiaceae (which could result from saltmarsh conditions) at the base, and then a very great rise in *Alnus* values. J can be referred to the next stage, with the replacement of *Alnus* by *Betula* and an increase in the importance of *Sphagnum*. The decrease in Filicales is like that shown at Sehestedt, and a revertance similar to that at the top of J (a decrease in *Betula* and *Sphagnum* and an increase in *Alnus* and Filicales) is shown in the Ynyslas diagram at 15 cm. Diagram BB can be related to the stage in the succession where *Pinus* replaces *Betula*; this change is shown in the diagram, which also shows very high values for *Sphagnum* (to 203 %) and, as in the Sehestedt diagram, low values for Filicales.

The values for Ericales and Gramineae in I, J and BB show a general correspondence with those of the Sehestedt diagram. In the latter, the values for Gramineae are moderately high at the *Alnus* maximum (cf. I), decrease at the *Betula* maximum (cf. J) and are still lower at the *Pinus* maximum (cf. BB). The values of Ericales are low in the early part of the sequence at Sehestedt, but increase with the increase in *Pinus* (cf. BB).

The deposits at I, J and BB all rest on clay (which also forms the base of the British and German deposits under discussion), and the surface of this clay at BB is irregular, suggesting that erosion may have taken place between the deposition of the clay and the overlying peaty mud.

Both *AP* and *NAP* diagrams I, J and BB fit in well with the view that these diagrams show stages in a local succession from saltmarsh to *Sphagnum* peat. If this is accepted, then the values for *Pinus*, *Betula* and *Alnus* in these diagrams may be quite unrelated to those of the other Cromer Forest Bed Series diagrams, where differences in relative values between zones are believed to be due to migration under the influence of climatic change. It is also probable that the values of other trees are depressed in I, J and BB because of the high values of *Alnus*, *Pinus* or *Betula*.

The macroscopic remains of *Carpinus* recorded by Reid confirm the general picture of the vegetation suggested by the pollen diagrams. *Carpinus* was identified only at Pakefield, where it was associated with *Alnus glutinosa*, *Quercus robur* and *Corylus avellana*.

(v) *Diagrams M, N* (*Mundesley*), *Z, AA* (*Ostend*), *DD* (*Happisburgh*) *and FF* (*Corton*)

These are the only diagrams of any length which have not been discussed, and they will be considered together, although in fact they appear to represent a number of different zones.

The earliest of these deposits appears to be the one at AA. This is a black, highly organic mud situated on the foreshore below high-tide level at Ostend. The diagram (figures 14, 15) is characterized by high values for *Pinus* and relatively low ones for *Betula* and *Picea*. Other trees are absent or represented only by traces. The curve for *Picea* excludes this diagram from zone *a*1 and the early part of *a*2, and the absence of a continuous curve for *Alnus* and *MOF* trees shows that it does not belong to zone *b*. The absence of an *Alnus* curve in fact excludes the diagram from any of the later stages of the sequence except towards the end of *c*2, which is not a possibility because of the *Picea* curve. Only zone *a*2 (except for the early part) cannot be eliminated, and consequently AA is assigned to this zone; the diagram appears to be similar in every way to those which represent zone *a*2 at West Runton.

Diagram Z (figures 14, 15) is discussed with AA because the stratigraphical relationship of the deposits concerned is known and has some bearing on the zonation of Z. The deposit at Z is also a black, highly organic mud, and it lies at the base of the cliff immediately opposite AA and some 2 or 3 m above it. Unfortunately, samples of the grey, calcareous clay below the black mud at Z showed no pollen (except for a few battered grains of *Pinus*, probably *P. haploxylon*), so that it was not possible to connect diagrams Z and AA, but it is quite clear that the deposit at Z is younger than the one at AA.

The pollen in the lowest horizon of Z is sparse and much eroded, and this layer is somewhat sandy; consequently the spectrum at the base of the diagram may not be reliable, and has been ignored. The diagram shows high values for *Pinus* and *Alnus*, relatively high values for *Picea*, low values for *Betula*, *Ulmus* and *Quercus* and only traces of *Tilia*. The values for *Alnus* and *Picea* exclude the diagram from zones *a*1, *a*2 and *c*2, while the values for the *MOF* constituents are different from those in the middle part of zone *b*. The values of both *Alnus* and the *MOF* constituents are rather higher than would be expected if the diagram belongs to zone *c*1, and the most probable position appears to be early in *b*1 or late in *b*2. The diagram represents a period later than that of AA, but there seems to be no way of deciding whether it succeeds AA immediately or is separated from it by the *MOF* period.

Diagram N does not in fact represent a single section, but it may reasonably be considered as such. The samples at 0 and 5 cm represent a deposit of laminated sand and mud at the base of the cliff at Mundesley, while the sample at 50 cm is from a band of mud a few metres away. This band lies in a gravel layer which extends underneath the laminated sand and mud sampled at 0 and 5 cm, so that the relationship of the three samples is quite clear.

Diagram N (figures 14, 15) shows relatively very high (the highest recorded during the present investigations) but decreasing values for *Ulmus* and *Quercus*, moderate values for

Betula and *Pinus*, traces of *Picea* and *Tilia* and values for *Alnus* which are low at the base of the diagram but high at the top. The values for *Ulmus* and *Quercus* are so high that the diagram must be placed in zone *b* 1, although it does not exactly match that zone as displayed at West Runton. The position of *Tilia* is somewhat anomalous (but similar to that shown at F and G), but the very low value for *Alnus* at the base (where *Ulmus* and *Quercus* are very high) and the absence of *Picea* at the base and its slight representation at the top are the main features which differ from those of the corresponding zone at West Runton. The very low values for *Alnus* at the base of the diagram are probably due only to the effect of the high *Ulmus* and *Quercus* values but, while these might also be expected to depress the values for *Picea*, it is surprising to find that not even a trace of *Picea* was recorded from the lowest horizon. In view of the separation of the lowest horizon from the upper ones by a layer of gravel, it is, of course, not impossible that the spectrum at 50 cm represents a completely different period from the Cromer Forest Bed Series.

Diagram FF (figures 14 and 15) represents a layer of grey, non-calcareous clay at the base of the cliff at Corton. It shows very high values for *Alnus* (76 to 83 %) and low but continuous curves for *Betula*, *Pinus*, *Picea* and *Tilia*. The curve for *Ulmus* is very low but is also continuous. *Quercus* is recorded only from the top of the deposit, but the preservation of the pollen is poor, and it is probable that there are traces of *Quercus* throughout. The values for *Corylus* are low, but are higher than those in the other parts of the Cromer Forest Bed Series.

The obvious over-representation of *Alnus* (which reduces the values of other trees and conceals any trends which they might otherwise show) makes the position of FF somewhat difficult to determine. However, the fact that, in spite of the over-representation of *Alnus*, *Tilia* shows values as high as 6 % is probably sufficient evidence to place this diagram in zone *b* 2, and the presence of *Azolla* at all levels suggests that it is in the early part of *b* 2.

This grey clay at Corton apparently represents a deposit which has been considered by some authorities to belong to the Crags and not to the Cromer Forest Bed Series, and hence this short diagram may be of importance if the pollen sequences of the Crags are ever worked out. At the moment, all that can be said is that the diagram fits in satisfactorily with those of the Cromer Forest Bed Series.

Diagram M (figures 8 and 9) represents a series of thin organic bands lying in sands near the base of the cliff about half a mile north-west of Mundesley. A relatively large number of 'brown spores', which probably originated in Tertiary deposits, is present, and hence it is possible that the diagram is distorted by the presence of derived pollen.

The diagram shows high values for *Alnus*, quite high values for *Betula* and *Pinus*, moderate to low values for *Picea* and traces of *Ulmus*, *Quercus* and *Tilia*. The curve for *Corylus* is low and discontinuous. *NAP* values are moderate and include a continuous curve at quite high values (to 27 %) for Ericales. The diagram is excluded from zone *b* by the absence of continuous curves for any of the *MOF* trees and from zones *a* and *c* 2 by the high values for *Alnus*. It is referred to zone *c* 1, and it is similar to the other diagrams which represent this zone.

Diagram DD (figures 14 and 15) represents a deposit of laminated clay at Happisburgh. It is very uniform throughout, showing high values for *Pinus*, moderate ones for *Picea* and low ones for *Alnus* and *Betula*. Other trees are not represented to any real extent. The diagram probably belongs to zone *c*1, as it differs from *b* in the absence of *MOF* trees and from most of *a* and *c*2 in the presence of *Alnus*. It could represent a late stage in zone *a*2, but in this case a continuous curve for *Ulmus* would be expected and it would be somewhat unusual to find even traces of *Tilia*. The *AP* diagram matches those assigned to zone *c*1 well, and Ericales is well represented at the top of the *NAP* diagram.

(vi) *Diagrams O (Mundesley), S (Bacton), EE (Hopton) and spectra H, K, L, P, T and CC*

The remainder of the diagrams are so short that any trends shown are not reliable. These, together with the spectra noted above, are included in this paper because in some cases they are the only results from deposits which may be of particular importance, and because any system of zonation must be able to cover all known results, but they merit only slight consideration.

Diagram O (figures 8 and 9) represents a cake of peat lying in sands and gravels near Mundesley. This peat was in the form of a flat, compact block with rounded edges, and was obviously derived from a deposit older than the sands and gravels. Because it was not in its original position, there is no way of determining whether the diagram is shown correctly or whether it is upside down. The diagram is characterized by high values for *Pinus* and *Alnus* and low ones for *Betula* and *Picea*, with only traces of other trees. Diagram O could be placed in the vicinity of the *a*2/*b*1 or *b*2/*c*1 boundaries; the trace of *Carpinus* suggests that the second position is the more probable one.

Diagram S (figures 10 and 11) represents a patch of peaty mud lying in a gravel layer below high tide level near Bacton. It is characterized by high values for *Pinus* and moderate one for *Betula*, with little representation of other trees. It probably corresponds with zone *c*2, but a correlation with some part of zone *a*2 is not impossible.

Most of the diagram EE (figures 14 and 15) represents a grey, non-calcareous clay, but the top 5 cm are black and organic. The deposit occurs at Hopton. The pollen from the organic layer is reasonably well preserved, but that from the two samples below this is poorly preserved and samples from 20 and 60 cm below the top of the deposit failed to reveal pollen in countable numbers. The diagram shows high values for *Alnus*, rather low ones for *Pinus* and low to very low values for *Betula*, *Picea* and *MOF* trees, with a trace of *Carpinus*. *Azolla* is recorded from one horizon. The diagram seems almost certainly to correspond with zone *b*2.

Spectrum H (figures 8 and 9) represents a layer of dark-coloured mud in a clay deposit at the base of the cliffs near East Runton. The clay itself failed to yield pollen in countable numbers. Spectrum H shows high values for *Alnus*, low ones for *Pinus* and very low ones for the other trees; *Tilia* is not recorded. It appears to correspond with a position in the vicinity of the *b*2/*c*1 boundary. It is quite possible that *Alnus* is over-represented, and the situation may in fact be related to the one outlined in the discussion of diagrams I, J and BB.

Spectrum K (figures 8 and 9) represents a thin lamination of mud in current-bedded sands at the base of the cliff at Overstrand. The *AP* spectrum is similar to that of H, and probably represents the same position in the system of zonation.

Spectrum L (figures 8 and 9) represents peaty material lying in the Weybourne Crag near Overstrand. *Tilia* is not recorded and there are only very low values or traces of trees other than *Alnus*, which shows 93% and is obviously over-represented. This makes the problem of zoning the spectrum almost insoluble, but, in view of the absence of *Tilia* and the presence of *Carpinus*, the most likely position appears to be near the *b* 2/*c* 1 boundary.

Spectrum P (figures 10 and 11) represents an organic layer lying in laminated clays corresponding with those at O. It shows moderately high values for *Alnus*, lower ones for *Betula* and *Pinus*, low *Picea*, very low *Ulmus* and only a trace of *Quercus*. The most probable position for this spectrum is zone *c* 1.

During one visit to Bacton, it was found that trenches had been dug on the foreshore and that dumps of grey sand from these remained piled up on the beach. Lumps of dark-coloured mud and a *Picea* cone were found in these dumps of sand, and spectrum T (figures 10 and 11) is the pollen count from one of these lumps of mud. It shows a very high value for *Pinus* and a moderate one for *Betula*; except for 1% *Alnus*, no other trees are recorded. It can be referred only to *a* 2 or *c* 2, but the two alternatives cannot be separated on the evidence of the pollen; the position of T at a lower level than, and not very far from, deposits assigned to zone *c* 1 suggests that the first alternative may be the more probable one.

Spectrum CC (figures 14 and 15) represents a piece of *Pholas*-bored peat found washed up on the beach at Happisburgh. A second piece of peat was found in the same place on the day after this one was discovered, suggesting that the source of the peat lies in that neighbourhood, but examination of the area at low tide failed to reveal the peat *in situ*. A series of three other samples from the peat did not show pollen in countable quantities. The spectrum shows moderately high values for *Pinus* and *Alnus*, a rather low one for *Picea* and very low ones for *Betula*, *Tilia* and *Carpinus*. The *NAP* is extraordinarily low, the only record being that of 1% Gramineae. The presence of 3% *Tilia* in the absence of other *MOF* trees suggests that the spectrum falls in zone *b* 2.

(vii) *The significance of trees represented only by very small quantities of pollen*

Several of the trees with pollen recorded only at 1% or less are of particular interest because they are new records and some may be of importance when comparing the Cromer Forest Bed Series diagrams with those representing other periods of time. Unfortunately, when such small numbers of pollen grains are concerned, the possibility that they are derived, are the chance products of long-distance transport or are contaminants introduced during collection and treatment of the material cannot be excluded. However, the evidence in some cases seems sufficient to permit tentative conclusions to be drawn regarding the question of whether the pollen indicates that the trees actually grew in the area during the Cromer Forest Bed Series period and, if so, at what stage during this period they occurred.

(*a*) *Abies*

A total of nineteen *Abies* pollen grains was observed, and the genus was recorded at nine of the twenty-six deposits from which pollen counts were made. The values recorded are all low, and no more than two *Abies* pollen grains were ever observed in the slides from one sample or more than four in the slides from one deposit.

There are several points which suggest that *Abies* grew in, or at least near, the area during part of the time at which the Cromer Forest Bed Series was being formed. *Abies* does not produce abundant pollen, so that even a small value for this genus may be of some significance. Although *Abies* is not native to Britain at the present time, *Picea* (which is certainly represented in the Cromer Forest Bed Series) falls into the same category, and there are abundant records to show that *Abies* occurred in Britain at some stages of the Quaternary period. Macrofossils of *Abies* have not been recorded from the Cromer Forest Bed Series, but they are also unknown in the interglacial deposits at Clacton, where up to 70% *Abies* pollen has been found (Pike & Godwin 1953), and the *Abies* pollen grains from the Cromer Forest Bed Series considerably outnumber those of *Acer* and *Fagus*, the presence of which has been verified by macrofossils. The state of preservation of the *Abies* pollen is not good, but it is comparable with that of other grains, and hence there is no reason to suspect that it is derived. In interglacial pollen diagrams which show high values for *Abies*, these usually occur in the later stages of the vegetational sequence and, with the exception of G and N (zone *b* 1), all the Cromer Forest Bed Series diagrams which show *Abies* are referred to the second half of the sequence (zones *b* 2 to *c* 2).

It is considered that the presence of *Abies* may be accepted, but it could not have formed a major constituent of the forests at any time represented by the Cromer Forest Bed Series diagrams at present available.

(*b*) *Tsuga*

Six pollen grains referred to *Tsuga* were observed, and the identification of one of these was confirmed by Dr J. Iversen. All the pollen grains were found in material from the deposit BB, and were noted in four successive samples, each of which was 5 cm from the preceding one. The deposit is highly organic and contains little or no mineral matter (suggesting that it was formed without the introduction of much foreign material), and the preservation of the *Tsuga* pollen grains is comparable with the others in the deposit; hence it is unlikely that the *Tsuga* pollen is the product of contamination from either ancient or modern sources.

The arboreal flora with which the *Tsuga* pollen grains are associated is compatible with the view that *Tsuga* actually grew in the area at the time. In the diagrams from the Dutch Tegelen clays, for example, *Tsuga* occurs with a similar flora, and the range of the genus, and in particular of the American species (Hough 1947), at the present day is also in harmony with such a suggestion. Unfortunately, it is impossible to be certain whether *Tsuga* formed part of the forests of continental Europe at the time when the Cromer Forest Bed was being laid down, as correlations are often doubtful and existing records of *Tsuga* sporadic and at low values.

On the whole, it is probable that the records of *Tsuga* pollen do indicate the presence of the genus, although it cannot have formed an important part of the flora at any stage represented by the diagrams. The fact that the pollen was found only in one deposit is not surprising because, as far as is known, BB represents a period which is not exactly the same as any of the other deposits sampled. The deposit BB lies in the second half of the vegetational sequence.

(*c*) *Juglans*

Pollen grains similar to those of *Juglans* were recorded from I and Q. Four were found at I at 10 cm. These were worn and almost unidentifiable, and Dr J. Iversen, who examined one of them, was not satisfied that it did in fact represent this genus. It appears that, even if these grains should be referred to *Juglans*, they are almost certainly derived. The two grains of *Juglans* found at Q seem correctly identified, but their colour and the presence of cell contents point to contamination during the preparation of the slides.

(*d*) *Acer* and *Fagus*

Three grains of *Acer* (at J and BB) and two of *Fagus* (at R and X) have been recorded. The deposits mentioned are all considered to represent parts of the second half of the vegetational sequence—near the *b/c* boundary or in zone *c*. Macrofossils of both genera have been found in the Cromer Forest Bed Series, so that their presence in or near the localities cited may be accepted. However, the absence of *Acer* and *Fagus* pollen from earlier zones may be of no significance, particularly in view of the fact that, during one visit to West Runton, Professor W. B. King picked up a *Fagus* cupule, which almost certainly came from the Cromer Forest Bed Series, beside the deposits exposed at that locality.

(*e*) *Pinus haploxylon*

Pollen grains of the '*haploxylon* type' were recorded from fourteen sites, but only at Z were they present in appreciable numbers (4% at 45 cm). The grains were much worn, and may well be derived. Thomson (in Woldstedt 1950*b*) considered that grains of this type at West Runton could be distorted or abnormal grains of the *Pinus sylvestris* group. In spite of the relatively large number of records, the evidence is not sufficient to establish the presence of *P. haploxylon* during the formation of the Cromer Forest Bed Series.

(*c*) *The vegetational and climatic history of the period during which the Cromer Forest Bed Series was laid down*

The following account sums up the information available from the Cromer Forest Bed Series diagrams and the general conclusions which may be reached from it. The fact that many of these conclusions (particularly those relating to the later stages of the vegetational sequence) are of a very tentative nature has already been stressed and, as a matter of convenience, is disregarded here. A hypothetical pollen diagram for the whole of the period concerned is shown in figure 16; this will require modification when further analyses of these deposits are made, and it has been drawn up mainly to clarify the ideas expressed in the text. It differs slightly from the diagram produced earlier (Duigan 1954) and reproduced by Woldstedt (1958) and West (1960); this is mainly because it was realized that there is no evidence of the relative time scale of the zones, and hence no differences between them are shown in the present diagram.

At the beginning of the period (zone *a*), thermophilous trees were absent and either birch or pine formed the major constituents of the forests. The situation is basically similar to that shown in the Late-glacial period (i.e. towards the end of the last glaciation) in both Britain and parts of Europe and in the early stages of many interglacial periods, and represents cold, or at least cool-temperate, climatic conditions.

In the earliest stages (represented only by zone *a*1 and recorded only from A) birch was the most important forest tree. Faegri & Iversen (1950) include both *Betula* and *Pinus* in a group of trees which produce comparable amounts of pollen, and hence the values for the pollen at the base of A (*Betula* 62 %, *Pinus* 36 %) probably reflect the relative abundance of the trees reasonably well, although the *Pinus* values could have been influenced by long-distance transport, as this has been suggested for comparable situations by Godwin & Tallentire (1951) and Tallentire (1953). *Salix* was present in the area during this early stage, and occasional bushes of *Corylus* may have occurred near ponds and water-courses. Large numbers of herbs of a variety of species were present, those belonging to the Cyperaceae, Gramineae, Compositae and Umbelliferae being particularly prominent. The land was only lightly forested; this is shown by the values for *Artemisia* and the very high *NAP* values (to 274 %).

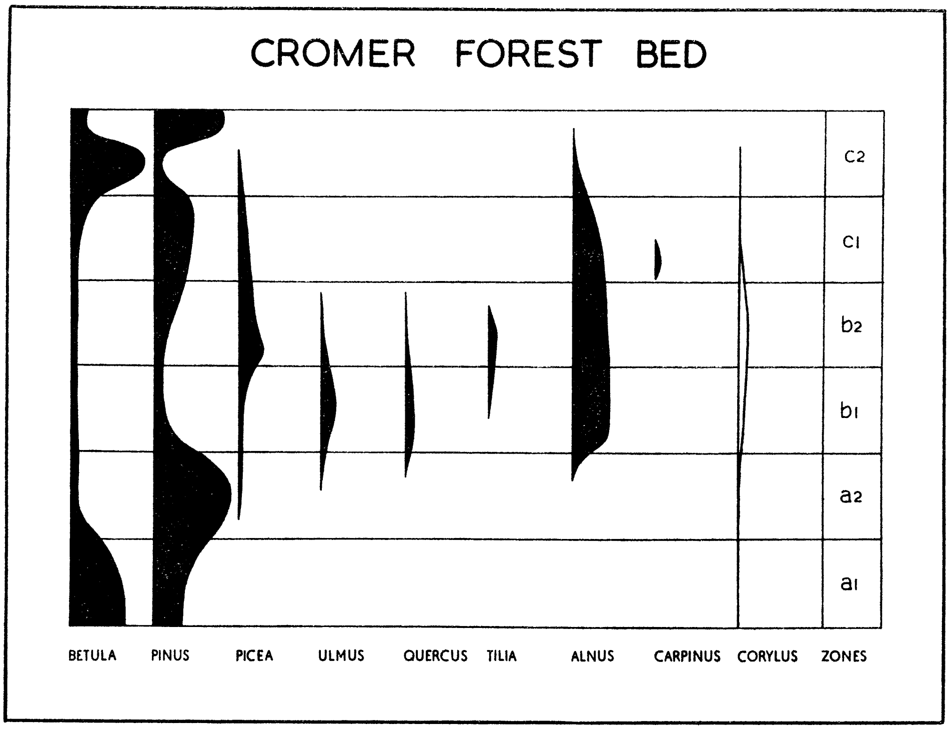

FIGURE 16. A hypothetical tree-pollen diagram of the Cromer Forest Bed Series as a whole.

There is little doubt that the climate was rather cold, particularly if one accepts the views of Zagwijn (1960) regarding the relation of vegetation and climate. The vegetation is exactly similar to the so-called 'subarctic park-landscape' type which Zagwijn considers to be characteristic of glaciations. He states that 'a subarctic park-landscape is indicated by high percentages of herbaceous pollen types (from 30 to 40 % and higher) together with a strong predominance of non-thermophilous trees (*Pinus*, *Betula*)'. There is no suggestion of arctic conditions; *Betula nana* was probably present, but the bulk of the *Betula* pollen unquestionably belongs to tree species.

At a later stage (zone *a*2, as shown in diagrams A, C, D, E, AA and Thomson's diagram) the position of *Betula* and *Pinus* was reversed, *Pinus* (as shown by values of up to 90 %) becoming a much more important forest constituent than *Betula*. *Betula nana* probably disappeared. *Corylus* and *Salix* continued to be sparingly represented in some areas. The forest cover increased and the herbaceous flora became more restricted, showing a decrease in abundance and, at least in some areas, in number of species. The climate probably became more favourable; the evidence for this lies in the decrease in *NAP*, the increase in *Pinus* to high values and the apparent disappearance of *Betula nana*. All these changes are cited by Schutrumpf (1943) as being indicative of climatic amelioration in the Late-glacial period.

MOF trees and *Alnus* appeared in the area somewhere about the end of this stage, and the middle part of the period as a whole (zone *b*) is marked by the rise and subsequent decline of these trees. Their presence is undoubtedly indicative of warmer conditions than those prevailing in the early part of the sequence, and the climatic optimum probably fell in this period.

The exact order in which the *MOF* trees and *Alnus* appeared in the area is not clear, but *Ulmus* probably preceded *Quercus*, while *Tilia* was certainly later than these genera. *Alnus* preceded *Tilia* and probably *Quercus*, and may have entered the area at about the same time as, or a little later than, *Ulmus*.

The earlier part of the *MOF* period is represented by zone *b* 1 (shown in diagrams A to G, N and Thomson's diagram). At this stage, the pine forests declined and were largely replaced by elm and oak forests, which in time also included *Tilia*. *Alnus* colonized the wetter areas and became locally completely dominant. *Betula* continued to be somewhat sparsely represented. The *NAP* values in the diagrams referred to this stage are fairly low, and the forest cover was probably more or less complete. However, some open spaces must have remained, as there are records of a number of plants characteristic of open habitats—*Artemisia*, *Centaurea*, *Epilobium*, *Helianthemum*, *Pastinaca*, *Plantago lanceolata*, *P. media*, *Polygonum*, *Ranunculus*, *Thalictrum*, *Valeriana*, *Lycopodium*, Chenopodiaceae, Caryophyllaceae, Compositae and Ericales. The number of *NAP* species recorded is greater than in earlier zones, but this may be due to the fact that, of the samples examined, many more belong to zone *b* 1 than to either *a* 1 or *a* 2.

During the later part of the *MOF* period (zone *b* 2, represented by diagrams A, B, EE, FF, Thomson's diagram and probably CC) the climate grew more continental. Oak and elm declined, but the maximum of *Tilia* probably occurred at about this time. The *Picea* forests (which had not previously been prominent) expanded, *Carpinus* may have entered the area and occasional stands of *Abies* and *Tsuga* may have been present. There is no evidence of any change in the importance of *Betula*, but *Pinus* may have expanded in some parts of the area. *Corylus* and *Salix* were still only sparsely represented. The forest cover was more or less complete, the herbs being sparse and showing little variety.

The end of the period as a whole (zone *c*) was marked by the disappearance of the thermophilous trees and the return to dominance of *Pinus* or *Betula*. This change, a reversion to the type of vegetation shown in the early stages of the sequence, seems to have been due to increasing cold.

The early part of this final stage is represented by zone *c* 1. This is shown in diagrams Q, R, V, DD and probably in P, while H to M, O, U, Z and BB may represent this stage or a late part of the previous one. By this time all the deciduous trees except *Alnus* had either disappeared or become of only sparse and sporadic occurrence. *Alnus*, although still locally abundant, was decreasing. *Pinus* forests covered large areas and *Picea*, although decreasing, still played an important role in the forests. *Betula* remained relatively unimportant, while *Carpinus* and possibly *Abies* disappeared at some time during this stage.

The forests may have become more open, heaths developed and *Empetrum* and *Calluna* were common.

In the final stage (zone *c* 2, represented at W, X, Y and probably at S) both *Alnus* and *Picea* disappeared, leaving only *Betula* and *Pinus* as forest trees. *Betula* was at first more important that *Pinus*, but the situation was later reversed, possibly under the influence of a temporary climatic amelioration.

Reid (1890) considered that the evidence from the plant macrofossils pointed to a climate during the Cromer Forest Bed Series period which was 'mild and moist' and 'little, if at all, colder than now'. With the exception of Dubois (1905), who believed that the Estuarine Bed was a fluvio-glacial deposit, most authors accepted Reid's views, but Solomon (1935) suggested that 'the Upper and Arctic Freshwater Beds...may well form a continuous series indicating a progressively increasing severity of climate' and Zeuner (1937) regarded the mammalian fauna as indicative of more than one climatic phase. From the present investigations, it is quite clear that the Cromer Forest Bed Series represents a cold period followed by a warm one, and there is some evidence that the warm period was followed by a second cold one. This shows that Reid's interpretation was only partially correct, and fully supports Solomon's view that the Arctic Freshwater Bed is a late stage in the Cromer Forest Bed Series sequence. If the deposits referred to zone *c* 2 do in fact belong to the Cromer Forest Bed Series, then they could belong to the same period as the Arctic Freshwater Bed; if not, they presumably belong to the Arctic Freshwater Bed but cannot be identified as such merely because macroscopic remains of *Betula nana* and *Salix polaris* were not observed.

(*d*) *The relation of the pollen zones to Reid's divisions*

The difficulties of identifying the divisions of the Cromer Forest Bed Series which were established by Reid (1882) have already been discussed in the section dealing with the collection of samples. These difficulties are emphasized when an attempt is made to relate Reid's divisions to the pollen zones. With the exception of O and CC (which are discussed below), there seems no evidence to suggest that any of the deposits sampled belong to the infrequently exposed Lower Freshwater Bed. As all these deposits are organic to a greater or lesser degree, they are more likely to belong to the Upper Freshwater Bed than to the Estuarine Bed. If this is so, then the whole sequence, from zone *a* 1 to zone *c* 2, corresponds with the Upper Freshwater Bed. The same conclusion is reached if the deposit at West Runton (A to G) is considered. This is apparently universally accepted as belonging to the Upper Freshwater Bed and, as it is a large deposit, it is probably part of the one which Reid identified at this locality. If this deposit is Upper Freshwater Bed, then that division must include the pollen sequence from zones *a* 1 to *b* 2, and all the other deposits sampled (which are believed to belong either to part of this sequence or to later stages) must also be accepted as Upper Freshwater Bed or Arctic Freshwater Bed.

The only deposits sampled which might reasonably be placed in the Lower Freshwater Bed are those at O and CC. At O (figure 19), there is a section which shows the classical appearance of the Estuarine Bed. A sandy layer contains a number of wood fragments, including a large one (figure 24, plate 7) identified by Dr R. G. West as *Taxus*, and there are several cakes of peat which are obviously of derived origin. This peat may have belonged originally to the Lower Freshwater Bed. It apparently belongs in the vicinity of the *b* 2/*c* 1 boundary and, even if this position is not correct, is unlikely to be earlier than the *a* 2/*b* 1 boundary. The spectrum CC represents a piece of *Pholas*-bored peat washed up on the beach, and this also could belong to the Lower Freshwater Bed. This spectrum is referred to zone *b* 2. The evidence that the peat at O and CC belongs to the Lower Freshwater Bed is inconclusive, and it is unfortunate that the results of the pollen analysis are so meagre, but these results could suggest that the Lower Freshwater Bed forms part of the sequence *a* 1 to *c* 2 and is not referable to a period before this.

(*e*) *The pollen diagrams in relation to the age of the Cromer Forest Bed Series*

The earliest investigators of the Cromer Forest Bed Series regarded it as Pliocene. This view has since been abandoned, and the position of the deposits in the Quaternary is confirmed by the pollen analyses, which show no evidence of the high values for *Carya*, *Pterocarya*, *Liquidamber*, *Sequoia*, *Sciadopitys*, etc., which are characteristic of European Tertiary deposits. Most modern authorities accept the view that the Cromer Forest Bed Series belongs to an interglacial period but, as this has been questioned by Gams (1954) and Boswell (1958), it is of interest to examine the evidence provided by the pollen diagrams.

Boswell (1958) believes that the Cromer Forest Bed Series is pre-glacial. West & Godwin (1958) suggest that the question of whether this deposit is pre-glacial or interglacial depends largely on the way in which these terms are interpreted. They would accept the Cromer Forest Bed Series as pre-glacial in the sense that there are no known deposits of undoubted glacial origin lying below it. However, they believe that it should be regarded as interglacial because this term now means a period which was of sufficient warmth and duration to permit the full expansion of a temperate or thermophilous forest. Van der Vlerk (1959) and Zagwijn (1957, 1960) express similar opinions regarding the definition of an interglacial. While this definition is obviously acceptable, the construction of the word interglacial makes it difficult to ignore the implication of a preceding glaciation. The most satisfactory compromise seems to be to add to the definition based on the vegetational sequence the proviso that the period is one between recognized glaciations, irrespective of whether there are actual deposits referred to these glaciations in the area in question. Deposits which show this vegetational development, but which cannot be related to known glaciations, could be referred to a stage in the Quaternary covered by a more general term such as warm period. The term pre-glacial would then be confined to that part of the Quaternary which pre-dated the first glaciation.

Irrespective of the exact meaning given to the term interglacial, the middle part of the Cromer Forest Bed Series must be referred to an interglacial if the views of Zagwijn (1960) are accepted. As pointed out previously, his concept of the vegetational development characteristic of glaciations covers the situation in zone *a* 1 and possibly also in part of zone *c*. However, although it is clear that the early part of zone *a* was cold, the evidence at present seems insufficient to prove the occurrence of glacial conditions.

Gams (1954) classes the Cromer Forest Bed Series as interstadial. According to Zagwijn, an interstadial is a short period, within a glacial phase, in which a slight improvement in the climate permits at the most only a partial re-immigration of the thermophilous flora. Similarly, Gross (1956) states that there is no real development of hazel and *MOF* in an interstadial. These views are supported by diagrams referred to interstadial deposits on the continent, and interstadial deposits in East Anglia which are referred to the Allerød oscillation (Godwin & Tallentire 1951; Tallentire 1953) show an *AP* flora of only birch and pine. The Cromer Forest Bed Series shows the full development of a *MOF* phase, with *MOF* values of up to 50%, and, although the hazel values are low, the evidence seems sufficient to refute any idea of an interstadial origin for the deposit. This confirms the view of van der Vlerk (1955), who considers that both the flora and fauna of the Cromer Forest Bed Series indicate greater warmth than an interstadial.

Apart from the question of the pre-glacial, interglacial or interstadial origin of the Cromer Forest Bed Series, there is the problem of the exact part of the Quaternary to which these deposits should be referred. In recent years, there has been a growing tendency to use the Cromer Forest Bed Series itself as a starting point in time correlations, and the period during which it was laid down is widely known as the Cromerian or Cromer Interglacial. This term has been used not only in reference to the English deposits (West & Donner 1956), but as a general name for the period in parts of Europe (Gams 1935; Woldstedt 1958; van der Vlerk 1959, and others), some of which are as far removed from East Anglia as Italy (Zagwijn 1957) and Poland (Borowko-Dluzakowa & Halicki 1957). The Cromerian Interglacial is usually believed to correspond with the Günz–Mindel of the Alps and with a period prior to the Elster or Elsterian Glaciation of Northern Europe (West 1955; Woldstedt 1958; Brelie & Rein 1956; Zagwijn 1957; van der Vlerk 1959, and others). However, Boswell (1958) places the Cromer Forest Bed Series before the Günz Glaciation, and it has been referred to the Mindel–Riss Interglacial by Azzaroli (1951, 1953) and by Hinton (1926), who placed the Cromer Forest Bed Series at Bacton in this period. Although the weight of opinion is undoubtedly against these suggestions, it is still of interest to determine whether a comparison of the Cromer Forest Bed Series diagrams with those of known age in other areas gives any satisfactory evidence as to the age of the deposit, and to examine the evidence which has been used in correlating other deposits with the Cromer Forest Bed Series.

In discussing deposits referred to various interglacials, one set of names has been used as a matter of convenience, in spite of the fact that there is not yet complete uniformity of opinion regarding the relationships of interglacial deposits in different parts of Europe. The names used are those set out by van der Vlerk (1959) in a general subdivision of the Quaternary, and are intended to cover the following periods:

Eemian—Ipswichian, Saale–Weichsel, Riss–Würm
Hoxnian—Needian, Elster–Saale, Mindel–Riss, Holstein
Cromerian—Günz–Mindel } Taxandrian
Waalian }
} —Relationship with Günz and Donau uncertain.
Tiglian }

The implied correlation, which seems to be widely accepted, is derived from the work of van der Vlerk (1957, 1959), West (1958), Woldstedt (1958), Zagwijn (1957), and others.

There are no results available from British deposits which can be considered when comparing the Cromer Forest Bed Series with deposits referred to the early part of the

Quaternary Period. On the continent, the Dutch deposits are the most important ones for this purpose because they are relatively close to East Anglia and may be expected to show a similar vegetational sequence if they are of the same age as the Cromer Forest Bed Series. Diagrams from deposits of Tiglian age (Zagwijn 1957, 1960; van der Vlerk & Florschütz 1953; Brelie & Rein 1952; Brouwer 1949; Florschütz & van Someren 1950, etc.) usually show appreciable values for Tertiary elements (*Carya*, *Pterocarya* and *Tsuga* in particular), high values for *Picea* (to more than 50%) and the presence of *Azolla tegeliensis* but not *A. filiculoides*. These features are not shown in the Cromer Forest Bed Series diagrams, and the differences confirm the view, originally based on a comparison of the plant macrofossils (E. M. Reid 1920) and faunal remains (Schreuder 1945), that the Cromer Forest Bed Series and the Tiglian deposits are not contemporaneous. However, it should be noted that Tertiary elements are sparse or absent in some Tiglian deposits (Canoy-Herfkens Pit, van der Vlerk & Florschütz 1953), *Picea* values may be quite low (Meinweg and Veghel, Zagwijn 1960) and *A. tegeliensis* may not be recorded, while it is possible that low values for certain Tertiary elements may be characteristic of some parts of the Cromer Forest Bed Series. The diagrams which Zagwijn (1957, 1960) refers to the Waalian Interglacial are in general similar to those of the Tiglian, but *A. tegeliensis* has disappeared and is replaced by *A. filiculoides*. Although Tertiary elements are not invariably present in these diagrams, and seldom reach high values, they provide some evidence that Waalian deposits are not contemporaneous with the Cromer Forest Bed Series. Furthermore, it appears from the Zaltbommel diagram that the *Carpinus* maximum coincides with the *MOF* maximum in the Waalian, and Zagwijn believes that there are indications of a cool oscillation in the middle of this interglacial.

It is of interest to observe that the diagrams referred by Zagwijn to the Pre-Tiglian, Eburonian and Menapian Glaciations, which are all rather similar and indicate the park-landscape type of vegetation, resemble closely those parts of zones *a* and *c* in the Cromer Forest Bed Series diagrams which show high *Pinus* values, and it is not impossible that part of zone *a* should be correlated with the Menapian Glaciation.

Zagwijn & Zonneveld (1956), Zagwijn (1957, 1960), Brouwer (1949) and van der Vlerk & Florschütz (1953) show Dutch diagrams which are referred, either directly or indirectly, to the Cromerian Interglacial. These have many features in common with the Cromer Forest Bed Series diagrams, but there are some obvious differences, such as the *Picea* maximum in the *Pinus–Picea* zone (which corresponds with zone *a*2 of the Cromer Forest Bed Series) and the *Tilia* maximum in the early part of the *MOF* phase at Westerhoven (Zagwijn & Zonneveld 1956). The importance of such differences cannot be assessed until a more complete cover of both English and Dutch deposits is available. Van der Vlerk & Florschütz (1953) believe that the Taxandrian in the Netherlands is characterized by the occurrence of both *Azolla tegeliensis* and *A. filiculoides*, but this does not preclude a correlation of the Taxandrian with the Cromer Forest Bed Series, as the authors admit that the occurrence of the two species could be the result of mixing horizons during boring operations, and in any case there is as yet no evidence that *A. tegeliensis* ever reached England.

German and Austrian diagrams which have been referred to the Cromerian include those from Bilshausen, Schwanheim and Johnsbach. The main differences between the diagram from Bilshausen (Lüttig & Rein 1954) and the Cromer Forest Bed Series ones lie in the presence of hornbeam, spruce-fir and beech-*MOF* zones in the former. However, it is by no means certain that the exact period represented by these zones is covered by the Cromer Forest Bed Series diagrams, and in any case the values for both fir and beech are very low. Baas (1932) considered that the Schwanheim diagram belonged to the Günz–Mindel, but the very high values for *Tsuga* and *Pterocarya* effectively distinguish it from the Cromer Forest Bed Series diagrams and support the views of Woldstedt (1958) and others, who place the deposit in the Tiglian (or possibly Waalian; see Zagwijn 1960). Woldstedt (1958) believes that the diagram from Johnsbach (Stark & Overbeck 1932) may represent a Günz–Mindel deposit. This shows many differences from the Cromer Forest Bed Series diagrams, including a long *Abies* curve (starting before the *MOF* period) and very high values for *Pinus* and *Picea* in the meagre *MOF* period. Selle (1958) states that there are many similarities between the diagram from Neuenförde and Thomson's diagram from the Cromer Forest Bed Series, but there are also many differences (e.g. the very early appearance of *Tilia* at Neuenförde) and the age of this deposit is most uncertain.

While Italy and Poland are so remote from England that a close correspondence between the vegetational sequences for a given period in these countries could not be expected, the diagrams from certain deposits in Italy and Poland have been referred directly to the Cromerian Interglacial and hence merit brief consideration. Zagwijn (1957), using the percentages of 'cold' and thermophilous trees as a basis for comparison with the floras of the more northern parts of Europe, relates part of the Leffe diagram (Lona 1950) to the Cromerian Interglacial. This part of the diagram is very different from the Cromer Forest Bed Series diagrams but, as Zagwijn's correlation depends on having an alternating series of glacials and interglacials, a direct comparison between Leffe and East Anglia is impossible. Van der Vlerk (1959) considers that the Polish diagrams from deposits at Janience (Bremowna & Sobolowska 1950), which have been placed in the Cromerian Interglacial (Borowko-Dluzakowa & Halicki 1957), form the basis of 'the only reliable correlation of the Pleistocene of eastern and western countries'. If, as suggested by Bremowna & Sobolowska, the Maksymance diagrams form part of the sequence for the interglacial represented by the Janience diagrams, then the Janience–Maksymance sequence differs from the Cromer Forest Bed Series one in the relative importance of some tree genera and the nature of some of the curves as well as the position at which they appear and reach their maxima. The situation regarding *Corylus*, which reaches 300 % in the early part of the *MOF* period, is also completely different. These differences are such that either Janience–Maksymance deposits must belong to another interglacial, as suggested by Woldstedt (1958), who placed them in the Eemian, or the Cromerian vegetational sequences in England and Poland are almost completely different. Other Polish diagrams referred to this period are also rather different from the Cromer Forest Bed Series ones.

In discussing other diagrams referred to the Cromerian Interglacial, the emphasis has been placed on the differences between such diagrams and those of the Cromer Forest Bed, as it is as yet too early to determine the features which are common to Cromerian diagrams. However, if the diagrams from Italy and Poland (on the grounds of geographical position) and Schwanheim and Neuenförde (because their age is uncertain) are omitted, some tentative conclusions can be drawn. Tertiary elements are either absent or are very sparse compared with those of earlier periods. The values for *Corylus* are always very low; they are usually of the order of 5 or 10 %, and do not exceed 25 % (except in the Bergumerheide diagram, where they reach 40 %). *Carpinus* is absent or only sparsely represented before the *MOF* maximum. The *MOF* phase is preceded by a zone in which *Pinus* is dominant. *Abies* is absent or sparse.

There are several diagrams from British interglacial deposits which are referred to the Hoxnian Interglacial. These deposits are at Hoxne (West, 1956, 1960), Clacton (Pike & Godwin 1953), Nar Valley (Stevens 1960) and Birmingham (Duigan 1956). When comparable stages are present, the following features of the Hoxnian diagrams differ from those of the Cromer Forest Bed: the absence of a phase with high *Pinus* values immediately before the *MOF* period; the high values for *Quercus* prior to the appearance of appreciable values for *Alnus* (except in the Horse Fen diagram); quite high values for the *Corylus* maximum (from about 30 % at Birmingham to over 155 % at Horse Fen); the relative unimportance of *Picea* before the later stages of the *MOF* period; the absence of a *Tilia* maximum towards the end of the *MOF* period; the numerous records (although at low values) of *Ilex* and *Hedera*. It seems quite clear that, even if other independent evidence were not available, the Cromer Forest Bed Series and Hoxnian diagrams could not be referred to the same period of time. *Abies* and *Carpinus* were of obvious importance in the later stages of the Hoxnian Interglacial, but it is not yet certain whether this provides yet another distinguishing feature between the Hoxnian and Cromerian Interglacials in England.

On the continent, a number of pollen diagrams are available from deposits which probably correspond with the Hoxnian ones in England. From the work of Gams (1935), Selle (1941), Woldstedt (1947, 1950*a*, *b*, 1958), van der Vlerk & Florschütz (1953), Rein (1955) and others, it appears that the main features common to these diagrams are a particularly strong representation of conifers and a correspondingly small proportion of *MOF* elements and *Corylus*, while *Alnus* may be very important in some parts of the sequence. Without attempting to compare all the existing diagrams with those of the Cromer Forest Bed Series it may be pointed out that this strong representation of conifers usually distinguishes them from the Cromer Forest Bed Series ones, but that it is not always expressed in the same way. Thus *Abies* may occur at a point where it is absent in the Cromer Forest Bed Series diagrams, as in the Berlin *Paludina* Beds (analyzed by Heck (1930), and accepted as Mindel–Riss by Woldstedt (1958)), where the beginning of the *Abies* curve coincides with the beginning of the *MOF* phase, and the Krefeld deposits (Karrenberg & Rein 1951; Brelie & Rein 1952), where there is from 20 to 40 % *Abies* at a stage where there are *Quercus* values of 10 %; *Pinus* may be much more important in the diagrams from the continent, as in the diagram from Neede (van der Vlerk & Florschütz 1953), if this does in fact represent the whole of the *MOF* phase; there may be high values for *Picea* before the *MOF* phase, as is shown in the diagrams from Ummendorf (Selle 1941) and from Berlin, and this feature is regarded by Gams, Woldstedt and Selle as being characteristic of the diagrams referred to this interglacial. Rein (1955) suggests that the Polish diagrams are similar to those of Germany and the Netherlands, and hence *Larix* may sometimes be included among the conifers (e.g. Nowiny Zukowskie, Dyakowska (1952)). There seems to be a basic difference in the prominence of conifers in the bulk of the diagrams from Hoxnian deposits on the continent compared with those of the Cromer Forest Bed Series, but the difference is not evident in a few of the diagrams which have been referred to this interglacial (e.g. Starup and Harreskov, Jessen & Milthers (1928)).

The position of the interval between the Saale and Warthe ice advances still seems somewhat uncertain. Brelie (1955) regards this interval as an interglacial, the Ohe Interglacial, and discusses a group of pollen diagrams (Neue–Ohe, Ober–Ohe and Munster) which he considers show the vegetational history of this interglacial. However, Woldstedt (1958) regards the interval as an interstadial, and refers these diagrams to the Hoxnian Interglacial. The diagrams all show a greater prominence of *Abies* than could be possible in the Cromer Forest Bed Series diagrams.

A detailed comparison of the Cromer Forest Bed Series diagrams with those of the Eemian Interglacial is neither practicable nor necessary here, but, because the comparison is facilitated by the relatively uniform nature of the vegetational sequence for the Eemian, one or two important differences may be noted. This uniformity is shown by the fact that the system of zonation established by Jessen & Milthers (1928) for Jutland and north-west Germany has been applied satisfactorily, if in a somewhat modified form, to diagrams in a number of other countries, and the features considered by Gams (1935), Selle (1957), Woldstedt (1947, 1954, 1958), Brelie (1955) and others to be characteristic of Eemian diagrams have a fairly general application. The high values and early expansion of *Corylus* in these Eemian diagrams clearly distinguishes them from those of the Cromer Forest Bed Series. As far as English deposits of this period are concerned, a further important difference lies in the very low values for *Alnus* and the prominent curve for *Acer* (West 1957, 1960); these are shown in the diagrams from Cambridge (Hollingworth, Allison & Godwin 1950; Walker 1953), Bobbitshole (West 1957), London (Franks 1960) and Stone (West & Sparks 1960).

While a great deal more evidence is required before completely reliable conclusions can be drawn, it seems that there are some features which are common to the diagrams which are referred to the Cromerian Interglacial, and that these diagrams differ appreciably from those of other interglacials. However, it must be remembered that the differences between the interglacial sequences are comparatively minor ones superimposed on the uniform sequence of a birch and/or pine phase followed by one in which a *MOF* forest develops, with a final revertance to birch and/or pine.

This work was carried out under the direction of Professor H. Godwin, F.R.S., and I wish to express my appreciation of his help, advice and stimulating teaching. I also wish to thank Miss R. Andrew for her invaluable assistance in the identification of pollen grains, and Dr R. G. West for his help in many ways, particularly in respect to the collection and interpretation of material for study. Dr J. J. Donner, Dr D. Walker, Dr M. J. Canny, Mr B. W. Sparks, Dr F. G. Mitchell, Messrs J. E. Sainty, J. Mulvaney, H. E. P. Spencer, E. B. Ellis and D. F. W. Baden-Powell have all helped me in ways too numerous to set out in detail, and my thanks are also due to many of the members of staff and research students of the Cambridge Botany School (and particularly of the Sub-department of Quaternary Research) during the years 1952 to 1954.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The greater part of the work was carried out during the tenure of a studentship granted by the Commonwealth Scientific and Industrial Research Organization, Australia, and I am most grateful for this and subsequent financial assistance.

Appendix 1. An outline of the stratigraphy of the deposits sampled

The letters preceding details of the Cromer Forest Bed Series are those used in showing the stratigraphy in the pollen diagrams. In that part of the diagrams, the letters C (calcareous) and N (non-calcareous) are used to indicate the presence or absence respectively of a visible reaction with 10% HCl.

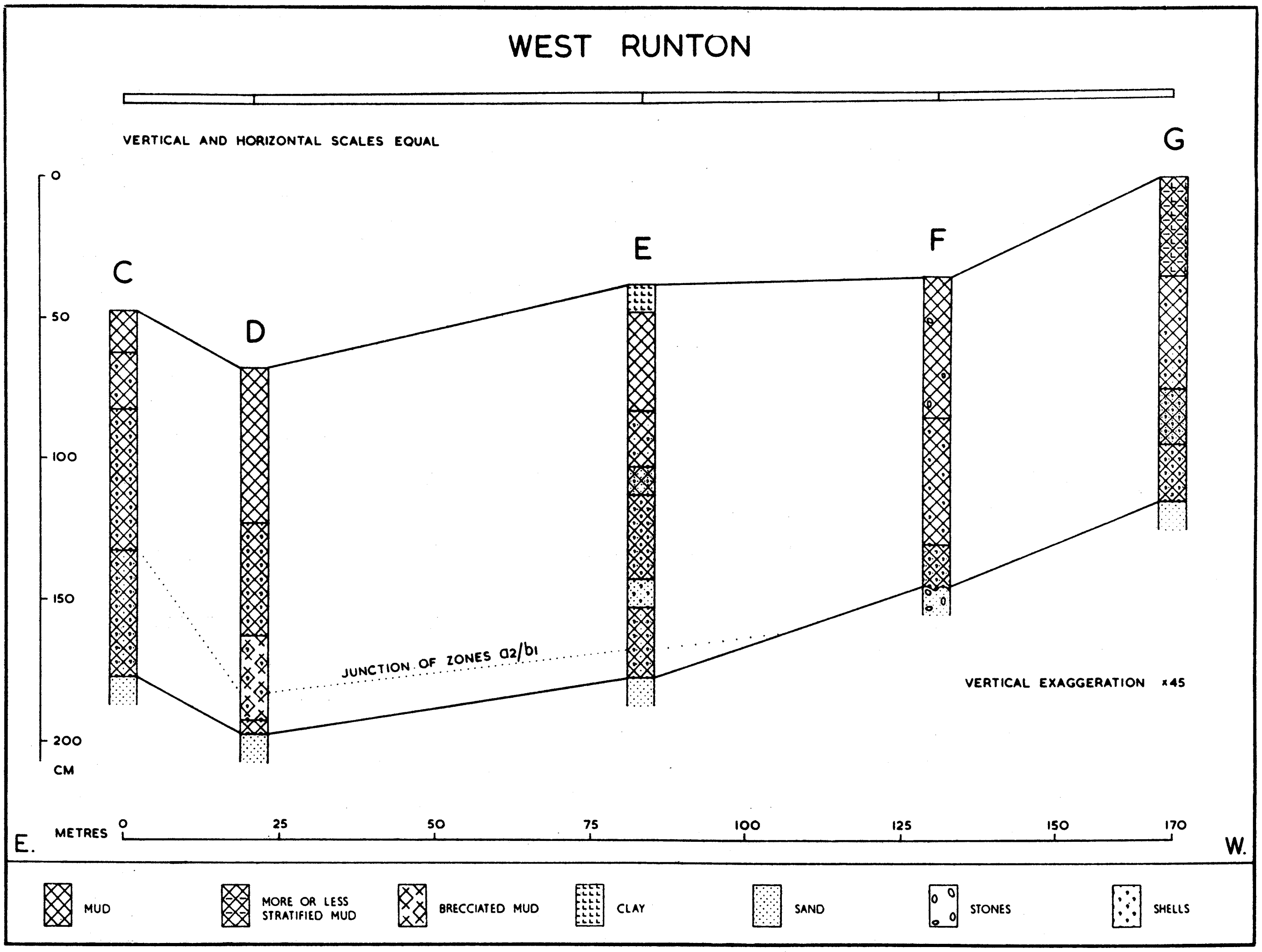

Figure 17. Diagram showing the stratigraphy of the Cromer Forest Bed Series at West Runton (C to G).

In most cases, measurements of the depth of the deposits overlying the Cromer Forest Bed Series could not be made, and any figures given in metres are estimates only.

(a) *Sheringham to Cromer* (*A to H*)

The cliffs are high (of the order of 30 m) along most of this part of the coast, but they are lower at and near the East Runton Gap. They are largely covered by talus, sea-walls and vegetation in the vicinity of Cromer. The cliffs are usually capped by a layer of sand and gravel which often shows an irregular junction with the strata below. Most of the cliff face shows Cromer Till and/or the folded sands and gravels broadly grouped as the Contorted Drift. Midway between Sheringham and West Runton, the Till shows two distinct facies, one being dark grey and the other, containing more chalk and pebbles, being lighter in colour. Two large basins are cut into the Contorted Drift just west of the West Runton Gap; they are filled with bedded, shelly sands which are regarded by Baden-Powell as part of the Corton Beds. A similar large basin occurs between East Runton and West Runton. Stratified sands which are believed to belong to the *Leda myalis* Beds occur below the Cromer Till in the vicinity of the West Runton Gap. Two very large chalk erratics, one of which is of the order of 200 m long, form conspicuous features of the cliffs between West Runton and East Runton.

The most obvious outcrop of the Cromer Forest Bed Series on the whole coast occurs some 200 m east of the West Runton Gap. The overlying deposits have been more or less eroded, leaving the dark-coloured muds of the Cromer Forest Bed Series as a step, up to 150 cm in height, between the beach and the main part of the cliff. The cliff face shows approximately the following structure:

	metres
Coarse, sandy gravel	1
Contorted Drift; laminated sands and clays with occasional beds of gravel, all contorted to a varying degree; non-calcareous	7
Cromer Till; grey, sandy clay with flints and some chalk; calcareous	6
Leda myalis Bed; current-bedded sand with interbedded clay	1
Cromer Forest Bed Series	1·5

The stratigraphy of the Cromer Forest Bed Series at this locality (sites C to G) is shown in figure 17; details of these sites, and of sites A and B, are as follows:

A (*West Runton*) (Figures 20, 22, 23, plate 7).

		cm
A1.	Dark brown, compacted, slightly laminated mud, non-calcareous and slightly sandy	0–28
A2.	Dark grey, shelly, slightly sandy mud with a few small flint fragments; calcareous; sandier at the base	28–64
A3.	Stony, calcareous mud with abundant shells; buff-coloured, streaked vertically with red	64–99
A4.	Brownish buff calcareous mud with a few flint fragments and occasional shells; beach level lies in this layer	99–160
	Sand with shells	160–

B (*West Runton*)

	Very coarse sand interbedded with fine clay; slightly disturbed	40
	Coarse gravel	10
B1.	Fine, grey-brown, laminated, sandy clay; non-calcareous	0–8
B2.	Brown, sandy, calcareous mud with abundant shells	8–13
B3.	Brown, somewhat sandy, non-calcareous mud with some shells to 30 cm	13–65

		cm
B4.	Dark brown, sandy, calcareous mud with abundant shells	65–110
B5.	Grey, sandy, calcareous mud with a few small pebbles and abundant shells. A piece of bone at 125 cm. Beach level lies in this layer	110–158
B6.	Sand with shells, passing over to rounded gravel	158–175

C (*West Runton*)

C1.	Dark, nearly black mud; shells very sparse or absent	0–15
C2.	Dark, nearly black mud with a few shells	15–35
C3.	Dark brown shelly mud	35–85
C4.	Lighter brown, shelly, sandy mud	85–130
	Coarse, rust-coloured sand	130–

D (*West Runton*)

D1.	Dark, nearly black mud; shells very sparse or absent	0–55
D2.	Dark brown shelly mud	55–95
D3.	Brown, brecciated mud with some shells	95–125
D4.	Brown, somewhat sandy mud with some shells	125–130
	Coarse, rust-coloured sand	130–

E (*West Runton*)

E1.	Puce clay	0–9
E2.	Black to dark brown mud	9–45
E3.	Black to dark brown, somewhat sandy mud with a few shells	45–65
E4.	Shelly, very sandy brown mud	65–75
E5.	Dark grey, somewhat sandy mud with numerous shells	75–105
E6.	Coarse, brownish sand and shells	105–115
E7.	Dark grey, shelly, sandy mud	115–140
	Coarse, rust-coloured sand	140–

F (*West Runton*)

F1.	Black, plastic mud with a few stones	0–55
F2.	Harder black mud with some shells	55–95
F3.	Brown, sandy mud with numerous shells; zone of contact with next layer irregular	95–110
	Coarse, rust-coloured sand with stones	110–

G (*West Runton*)

G1.	Puce clay-mud, more or less stratified	0–35
G2.	Black mud with a few shells at the top, becoming shellier and sandier towards the base	35–75
G3.	Brown, very sandy, very shelly mud	75–95
G4.	Black mud, very shelly and somewhat sandy	95–120
	Coarse, rust-coloured sand	120–

Near the East Runton Gap, clays and gravels of the Cromer Forest Bed Series underlie the Cromer Till. The section at H is as follows:

H. (*East Runton*)

Gravel
Contorted Drift
Cromer Till
Cromer Forest Bed Series (base of cliff).

Iron-stained, non-calcareous sand and gravel concretion (20 cm).

H 1. One of the occasional inclusions of sandy mud in a series of irregular layers of dark and light grey clay and rust-coloured, concreted sand which is 30 cm in depth. Beach level lies at the base of this deposit.

(*b*) *Cromer to Sidestrand* (*I to L*)

The cliffs are high in this area and rise to more than 70 m between Cromer and Overstrand, but they are largely obscured by natural vegetation. Where the stratigraphy is visible, the cliffs are seen to consist mainly of Cromer Till and Contorted Drift, with big chalk erratics just east of Cromer and between Overstrand and Sidestrand. The exposures of the Cromer Forest Bed Series at and near Overstrand show the following:

I (*Overstrand*)

Contorted Drift, Cromer Till } 50 m	
Cromer Forest Bed Series (foreshore, below high water mark)	cm
I 1. Black, peaty mud with wood fragments; non-calcareous	0–8
I 2. Brown, sandy, non-calcareous clay	8–10
Blue-grey clay	10–

J (*Overstrand*) (figure 18)

Contorted Drift, Cromer Till } 50 m	
Cromer Forest Bed Series (base of cliff)	
Current-bedded sands	50
Non-calcareous, laminated blue clay with sand partings	100
Sand with seams of gravel	100
Gravelly sands with signs of bedding	100
J 1. Amorphous black mud, sandy and non-calcareous	0–8
J 2. Grey, sandy, non-calcareous clay	8–9
J 3. Black, peaty, non-calcareous mud	9–30
J 4. Blue-grey, sandy, non-calcareous clay with a layer of gravel and inclusions of red sand and gravel concretions; beach level lies in this layer	30–

K (*Between Overstrand and Sidestrand*)

Contorted Drift	
Cromer Till	
Cromer Forest Bed Series (base of cliff).	
Coarse gravel (10 cm).	
K 1. A lamination of black mud in current-bedded sands; beach level lies in this layer	—

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

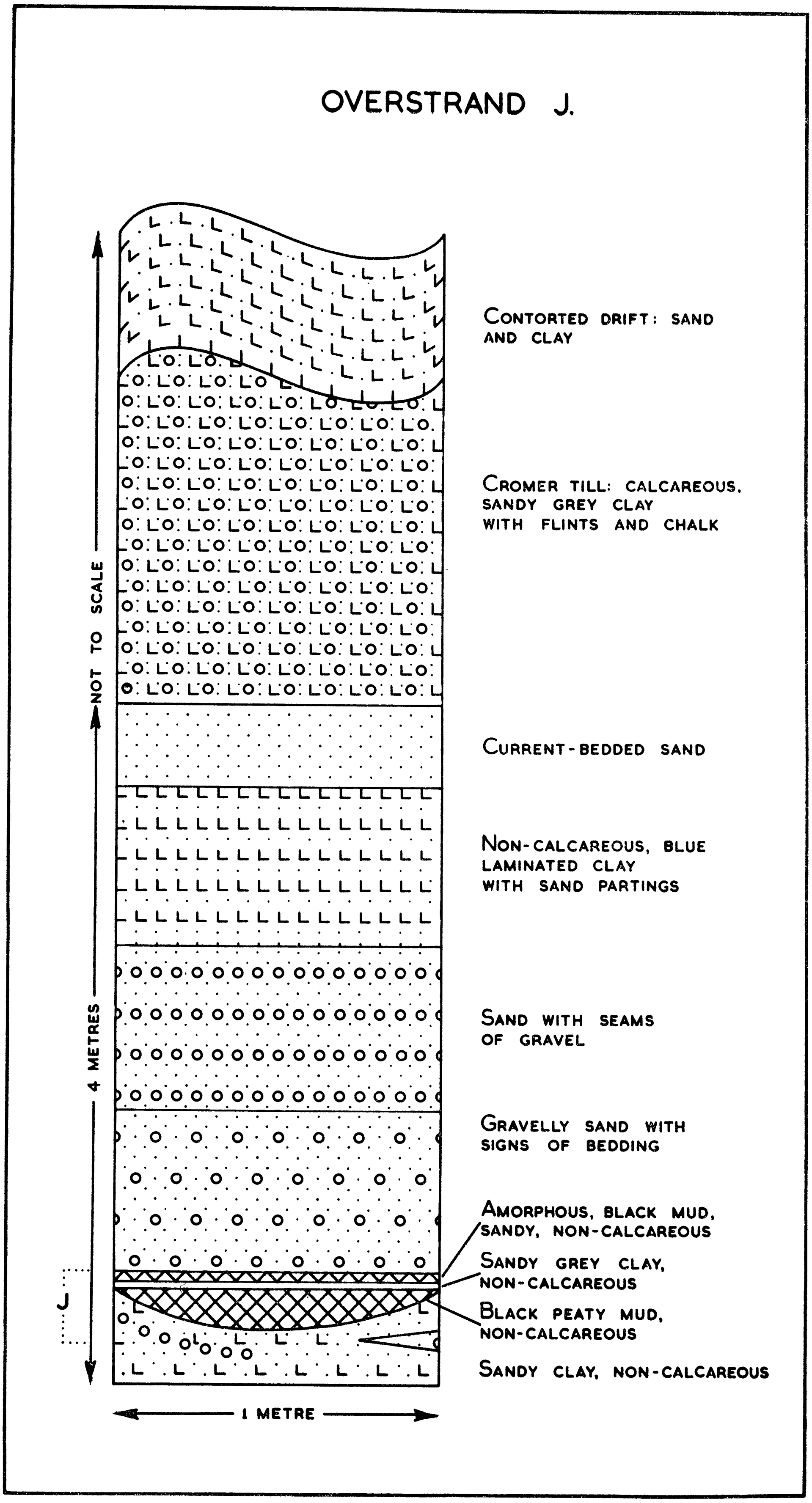

FIGURE 18. Sketch section of the cliff face at J (Overstrand).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

L (*Between Overstrand and Sidestrand*)

L1. A lump of black, peaty mud lying in a pocket in the Weybourne Crag. This piece of Weybourne Crag (a sandy, ferruginous conglomerate) was found on the beach, but had obviously become detached from a similar layer on top of a large chalk erratic in the Contorted Drift at this point

(*c*) *Sidestrand to Mundesley* (*M to O*)

No personal observations were made between Sidestrand and a point about a mile north-west of Mundesley, as this part of the coast lay within a minefield. The cliffs rise to a height of over 70 m, and are believed to show some of the best existing exposures of the Cromer Forest Bed Series.

The cliff in front of Mundesley is largely hidden by sea-wall and turf, but Contorted Drift and Cromer Till are visible to the north-west. The top of the cliff shows a sandy layer with little or no gravel, and more or less horizontally bedded sands may occur below this. Two distinctly different types of Cromer Till are seen near the minefield; one of these contains more chalk and pebbles than the other. It was not possible to distinguish the Mundesley Sands with certainty in the vicinity of Mundesley.

Sands, gravels, clays and muds of the Cromer Forest Bed Series are exposed at intervals below the Cromer Till near Mundesley. The following sections were observed:

M (*Mundesley*)

	Horizontally bedded sands	
	Contorted Drift	
	Cromer Till	
	Cromer Forest Bed series (base of cliff)	cm
	Non-calcareous gravel	3
	Non-calcareous sand in contorted bands	27
M1.	Alternating layers of grey sand and dark grey mud; calcareous	0–50
	Non-calcareous gravel	15
	Orange-brown sand	10

N (*Mundesley*)

	Sandy layer with a gravel base	
	Bedded sands and clays; calcareous	
	Cromer Till	
	Cromer Forest Bed Series (base of cliff)	
	Bedded sands and clays; non-calcareous	100
N1.	Alternating bands of sand and black mud; non-calcareous	0–10
N2.	Coarse orange sand and grey clay; non-calcareous	10–35
N3.	Coarse, buff, non-calcareous sand	35–45
N4.	Gravel containing a few bands of mud	45–

(N.B. The sample at 50 cm is a few metres from the upper ones)

O (*Mundesley*) (figure 19)

	Contorted Drift	
	Cromer Till (*ca.* 20 m)	
	Cromer Forest Bed Series (base of cliff)	cm
	Coarse, bedded sand and fine gravel	7
	Grey calcareous clay with carbonaceous laminations	7
O1.	One of a number of cakes of peat in coarse, slightly false-bedded, yellow-brown sand with occasional small flints, gravel seams and pieces of wood; slightly calcareous	56
	Sandy, iron-stained conglomerate of ungraded round or angular flints; calcareous; pieces of wood and bone are present	20
	Large rounded and angular flints interbedded in grey sandy clay and brownish-yellow sand, iron-stained at the junctions; calcareous; beach level is at the base of this layer	20

(*d*) *Mundesley to Bacton* (*P to U*)

The cliffs are high (over 30 m) at Mundesley, but they become gradually lower until they are only about 3 m high at Bacton. The higher parts of the cliffs are similar to those to the north-west of Mundesley, but the deposits near Bacton are more difficult to interpret. Contortions are no longer present in the upper strata, and the Cromer Till appears to change in character, becoming more or less stratified and decalcified. Coarse gravels (Bacton Valley Gravels) occupy almost the entire cliff face at a point to the north-west of Bacton. Outcrops of the Cromer Forest Bed Series, consisting chiefly of laminated sands, muds and clays, are quite common in this part of the area, and the following sections were sampled:

P (*Between Mundesley and Bacton*)

P1. A small band of mud lying in banded sand and clay corresponding with that at Q

Q (*Between Mundesley and Bacton*)

	Upper layers largely masked by talus	
	Cromer Till	
	Cromer Forest Bed Series (base of cliff)	cm
Q1.	Alternating bands of grey clay and sand which is buff in the upper part and grey in the lower part; non-calcareous; beach level is at the base of this layer	0–150

R (*Between Mundesley and Bacton*) (figure 25, plate 7).

Brown to buff sand	100
Gravel	5
Orange and buff banded sand	300
Gravel	50
Banded buff and brown sandy, calcareous clay presumed to represent the Cromer Till	200

Cromer Forest Series Bed (base of cliff) cm

R1. Alternating layers of black mud and buff sand; non-calcareous 0–110

Confused layers of buff sand, orange sand and grey clay; non-calcareous; beach level lies in this layer 110–

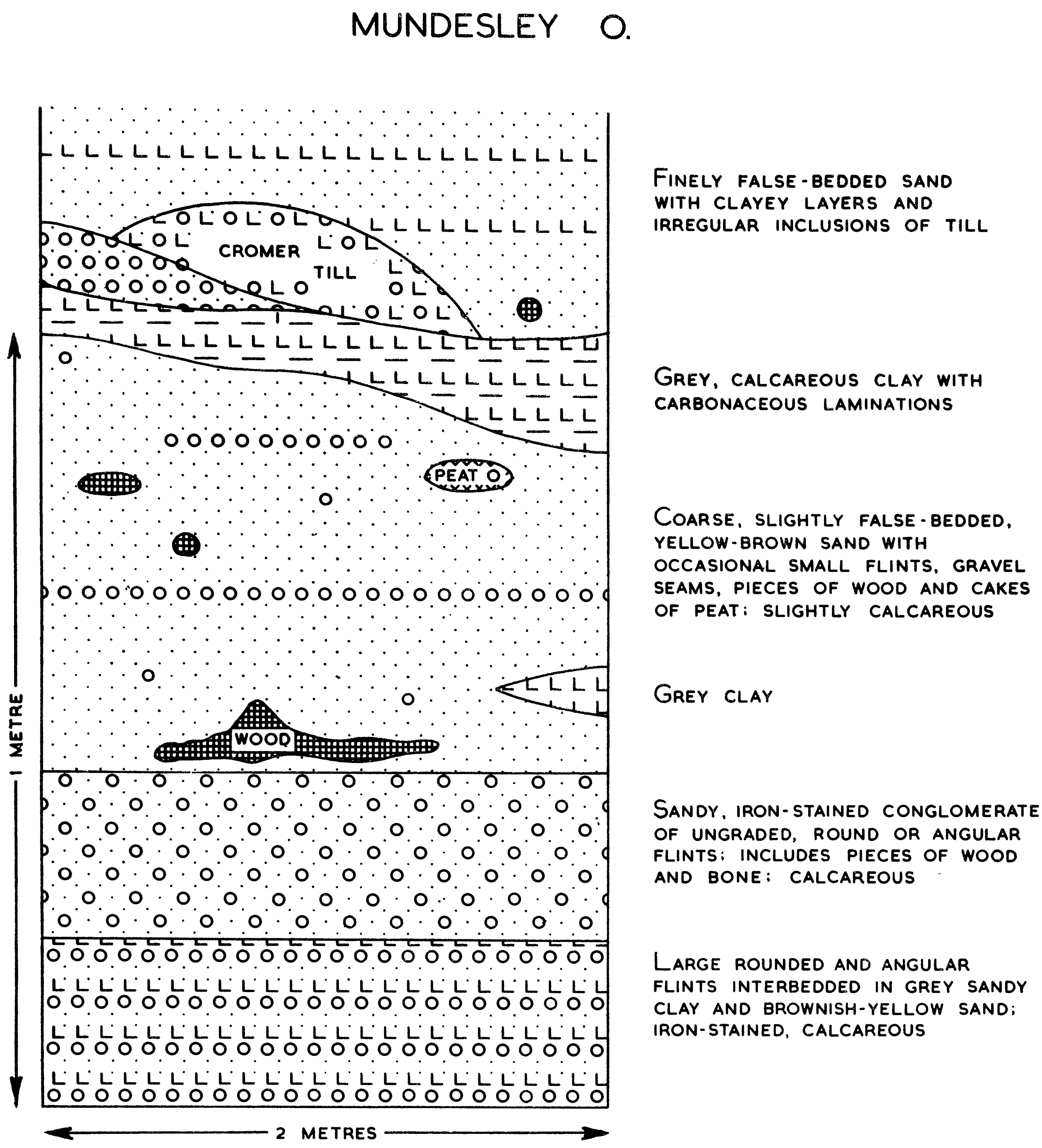

FIGURE 19. Sketch section of the cliff face at O (Mundesley).

S (*Bacton*)		cm
S 1.	A sample from a layer (about 10 cm in depth) of black, peaty mud resting on sandy, ferruginous, concreted gravel on the foreshore below high water mark	—
T (*Bacton*)		
T 1.	A sample from a dump of black, sandy mud thrown out of a trench in the beach	—
U (*Bacton*)		
U 1.	Black mud in clay corresponding with that at V	—
V (*Bacton*)		
	Sand	
	Decalcified Cromer Till	
	Cromer Forest Bed Series (base of cliff)	
	Sand which is disturbed by frost action at the base	100
V 1.	Non-calcareous, laminated sand and clay with pieces of wood; beach level lies at the base of this layer	0–50
W (*Bacton*)		
W 1.	A lump of coarse, sandy mud with sandy laminations; this was exposed on the beach, and probably represents the similar layer at X	—
X (*Bacton*)		
	Orange-yellow sand with a few pebbles and a line of gravel at the base	150
	Slightly calcareous grey, yellow and brown laminated sands and clays presumed to represent the Cromer Till	210
	Cromer Forest Bed Series (base of cliff)	
X 1.	Brownish-yellow, sandy, non-calcaerous clay	0–25
X 2.	Dark brown, non-calcareous mud	25–70
X 3.	Alternating bands of sand and dark brown mud; beach level lies in this layer	70–140
	Grey clayey sand	140–
Y (*Bacton*)		
	Cromer Forest Bed Series (base of cliff)	
Y 1.	Dark grey sandy mud	0–40
Y 2.	Black, somewhat sandy mud, more or less laminated	40–80
Y 3.	Laminated sand and grey mud	80–110
Y 4.	Dark brown mud merging into the following layer	110–170
Y 5.	Mixed mud and sand	170–180
	Sand with a few organic patches	180–

(*e*) *Bacton to Happisburgh* (*Z to DD*)

The cliffs remain low to Walcott, where they are only about 2 m in height, and then rise gradually to about 20 m in the vicinity of Happisburgh. They consist of Cromer Till overlain by various sands and clays, usually laminated but not contorted. The following sections were sampled:

		cm
Z (*Ostend*)		
Orange, sandy, calcareous clay with pebbles		150
Grey, sandy, calcareous clay with sandier laminations		640
Cromer Till		170
Cromer Forest Bed Series (base of cliff)		
Z1.	Dark grey to black laminated mud with some wood; non-calcareous; slightly contorted	0–45
	Blue-grey clay with some wood; non-calcareous; beach level lies in this layer	125+
AA (*Ostend*)		
AA1.	Black mud on the foreshore below high water mark; the position is directly seaward from Z	0–20
BB (*Happisburgh*)		
Laminated sands and clays, contorted in parts		500
Cromer Till		200
Beach sand		100
Cromer Forest Bed Series (foreshore below high water mark)		
BB1.	Irregular basins of black, compressed, peaty material; non-calcareous	0–30
	Dark-grey, laminated clay which dips irregularly; non-calcareous	30–
CC (*Happisburgh*)		
CC1.	A block of *Pholas*-bored, compressed, woody peat cast up on the beach; it probably originated in the neighbourhood, as another similar block was found at the same place on the day after the discovery of the first	
DD (*Happisburgh*)		
Cromer Forest Bed Series (foreshore below high water mark)		
DD1.	Dark, blue-grey, non-calcareous, laminated clay	0–150
	Coarse, yellowish sand and gravel	150–

(*f*) *Hopton* (*EE*)

The cliffs are low in this area, and average only about 7 m in height. They are capped by a layer of sand and gravel; this has an irregular zone of contact with sporadic occurrences of grey, chalky boulder clay (Lowestoft Boulder Clay) or passes directly into current-bedded sands. These sands underlie the boulder clay when it is present, and the Cromer Till occurs below the sands. The Till is a reddish brown sandy clay without many flints, and it shows signs of stratification in places. It appears above beach level in a series of crests. The Till may be underlain by bedded sands and soft clays. The section sampled is as follows:

EE (*Hopton*)

Sands and gravels
Cromer Till
Cromer Forest Bed Series

		cm
	Current-bedded sands	30
	Soft orange clay	3
EE 1.	Blue-grey, non-calcareous clay, the upper 5 cm of which are darker and highly organic	0–133+

(*g*) *Corton* (*FF*)

The cliffs are about 15 m high at Corton. They are capped by gravels (according to Baden-Powell, these are outwash gravels of the Gipping Till) lying on top of the Lowestoft Till, which is a bluish, chalky boulder clay. A large part of the cliff consists of bedded Corton Sands; these overlie the Cromer Till, which is brownish and contains few pebbles and little chalk. Samples were taken at the following section:

FF (*Corton*)

Lowestoft Till
Corton Sands
Cromer Till
Cromer Forest Bed Series

FF 1.	Dark grey, non-calcareous clay	0–40

Appendix 2. New records of plants from the Cromer Forest Bed Series

The following plants from the Cromer Forest Bed Series are not included in the list given by E. M. Reid (1920) or in the pollen statistics of Thomson (Woldstedt 1950*b*). With the exception of *Azolla filiculoides*, all records represent pollen or spores. Records based only on a single pollen grain or spore have been omitted, as they obviously need confirmation.

Lycopodium annotinum
Lycopodium clavatum

Azolla filiculoides
Polypodium sp.
Pteridium sp.
Salvinia sp.

Abies sp.
Tsuga sp.

Artemisia sp.
Calluna sp.
Centaurea scabiosa
Empetrum hermaphroditum
Empetrum nigrum
Epilobium sp.
Geranium sp.
Lemna sp.
Limonium sp.
Myrica sp.
Myriophyllum verticillatum
Plantago lanceolata
Plantago media
Scabiosa sp.
Symphytum sp.
Typha angustifolia
Typha latifolia
Valeriana officinalis
Viscum sp.

Appendix 3. Non-marine Mollusca from the Cromer Forest Bed Series at West Runton

By B. W. Sparks

Three collections of Mollusca were made; a general bulk collection to try to obtain as large a fauna as possible was taken from the top of the bed, while shells were recorded from sections A and B, horizon by horizon. The species found are listed on pp. 198 and 199.

Notes on certain species

Three of the species recorded above appear to be new for the Upper Freshwater Bed; they are *Retinella nitidula*, *Oxychilus ?cellarius* and *Pisidium obtusale*. Some hesitation must be expressed regarding *O. cellarius* as, although it appears to be that species, the specimens themselves consist only of apical fragments.

Most other records of the bed (e.g. Sandberger 1880; Zeuner 1959) list *Viviparus gibbus*, a species founded by Sandberger (1880). Most of the specimens of *Viviparus* in the present collection, although badly broken, do not appear to differ materially from *V. viviparus* (Linné) as described by British authors.

The only shells of *Bithynia* are certainly not *B. tentaculata* and appear to be *B. leachi* var. *inflata*, which is the usual form recorded from the bed. On the other hand, the opercula, which are very common, seem to be those of *B. tentaculata*, although no shells of this species have been found.

Most of the specimens of *Succinea* were badly broken, so that a specific determination of all the shells of this difficult genus was not possible. The complete specimens of *S. oblonga* were elongated specimens with a very oblique suture. Most of the broken fragments consist only of the first whorl or two, but they show a deeper and less oblique suture and a more inflated whorl. They may well be *Catinella arenaria* (Bouchard-Chantereaux), which has been recorded as a Cromerian fossil (Ellis 1951).

Vallonia pulchella var. *enniensis* (Gredler) is the species previously recorded as *V. tenuilimbata* (Sandberger) from which it appears to be indistinguishable (Sparks 1953).

Vitrina semilimax is the shell previously recorded as *V. elongata* (Kennard & Woodward in Marr 1920). *Vitrina* is rare in this bed and I have been able to see only three other specimens from the Kennard collection. They are all the same species and, although broken, are certainly not *V. pellucida*, which has been recorded (Reid 1890) probably in error.

Conditions of deposition

Although the bed belongs to the early Pleistocene, the number of species now extinct in Britain is small: only *Bithynia leachi* var. *inflata*, *Vallonia pulchella* var. *enniensis*, *Discus ruderatus*, *Vitrina semilimax* and *Pisidium clessini*.

Although the majority of the species are freshwater shells, which are not such good indicators of climate as the land species, there are sufficient of the latter to show that the bed indicates reasonably mild climatic conditions. If the shells recorded before and not in this list are considered, the evidence for such conditions is stronger. There are not sufficient land species to differentiate between climatic conditions represented by the various levels in A and B.

General collection from top of bed

	number of specimens		number of specimens
Viviparus viviparus (Linné)	102	*Cochlicopa lubrica* (Müller)	2
Valvata cristata Müller	20	*Vertigo antivertigo* (Draparnaud)	2
V. macrostoma Morch	1	*Vallonia pulchella* var. *enniensis* (Gredler)	4
V. piscinalis (Müller)	777	*Helix* (*Cepaea*) sp.	1
Bithynia leachi var *inflata* (Hansén)	18	?*Hygromia hispida* (Linné)	1
Bithynia sp.	294 (opercula)	*Vitrina semilimax* (Férussac)	3
		Agriolimax cf. *reticulatus* (Müller)	4
Lymnaea truncatula (Müller)	23	*Unio pictorum* (Linné)	2
L. palustris (Müller)	4	*Anadonta anatina* (Linné)	1
L. stagnalis (Linné)	8	*Sphaerium corneum* (Linné)	11
L. peregra (Müller)	4	*Pisidium amnicum* (Müller)	135
Planorbis carinatus Müller	14	*P. clessini* Neumayr	119
P. vorticulus Troschel	5	*P. casertanum* (Poli)	41
P. vortex (Linné)	2	*P. obtusale* (Lamarck)	4
P. leucostoma Millet	7	*P. milium* Held	7
P. albus Müller	39	*P. subtruncatum* Malm	21
P. crista (Linné)	19	*P. supinum* Schmidt	11
Segmentina complanata (Linné)	3	*P. henslowanum* (Sheppard)	96
Acroloxus lacustris (Linné)	20	*P. nitidum* Jenyns	45
Succinea putris (Linné)	2	*P. pulchellum* Jenyns	2
Succinea sp.	20	*P. moitessierianum* Paladilhe	14

Section A

	cm						
	35–45	50–60	65–75	75–85	85–95	95–100	100–110
Viviparus viviparus (Linné)	—	8	1	—	—	—	—
Valvata cristata Müller	—	5	1	7	1	5	2
V. piscinalis (Müller)	50	68	3	—	1	—	—
Bithynia sp. opercula	13	20	2	1	—	—	—
B. leachi var. *inflata* (Hansén)	1	1	—	—	—	—	—
Carychium minimum Müller	—	—	4	9	1	1	—
Lymnaea truncatula (Müller)	4	11	16	10	1	2	—
L. palustris (Müller)	1	—	1	—	—	—	—
Planorbis leucostoma Millet	—	—	—	3	1	1	—
P. albus Müller	4	6	?1	—	—	—	1
P. crista (Linné)	23	21	—	—	—	—	—
Segmentina complanata (Linné)	—	2	—	—	—	—	—
Acroloxus lacustris (Linné)	5	11	1	—	—	—	—
Succinea oblonga Draparnaud	—	1	—	—	—	—	—
S. putris (Linné)	—	—	1	—	—	—	—
Succinea sp.	3	3	5	4	—	1	2
Cochlicopa lubrica (Müller)	—	—	—	1	—	—	—
Vertigo antivertigo (Draparnaud)	—	—	—	1	—	—	—
Vallonia pulchella var. *enniensis* (Gredler)	—	—	—	1	—	—	—
Hygromia hispida (Linné)	—	—	—	2	—	—	—
Discus ruderatus (Férussac)	—	—	—	1	—	—	—
Retinella nitidula (Draparnaud)	—	—	4	2	1	—	1
Oxychilus ? *cellarius* (Müller)	—	—	—	2	—	—	—
Vitrina semilimax (Férussac)	—	1	—	—	—	—	—
Limax sp.	1	3	—	—	—	—	—
Agriolimax cf. *agrestis* (Linné)	—	1	1	4	1	—	—
Sphaerium corneum (Linné)	1	1	—	—	—	—	—
Pisidium amnicum (Müller)	4	3	—	—	—	—	—
P. clessini Neumayr	3	7	—	—	—	—	—
P. casertanum (Poli)	7	9	—	—	—	—	—
P. obtusale (Lamarck)	—	1	—	5	—	1	—
P. milium Held	—	2	—	—	—	—	—
P. subtruncatum Malm	2	4	—	—	—	—	—
P. henslowanum (Sheppard)	8	8	—	—	—	—	—
P. nitidum Jenyns	1	9	—	—	—	—	—
P. moitessierianum Paladilhe	23	25	—	—	—	—	—

The conditions of deposition of Section A varied somewhat. Down to 60 cm fresh-water species predominate, and they may well have been deposited in a sluggish backwater, i.e. something comparable with a modern Fen drain. In the lower and older part of the bed, conditions were apparently marshy, as species typical of such localities occur and the number of species thriving in more open water decreases strikingly. The layer from 65 to 75 cm shows a transition to marshy conditions, which are most strongly represented at the 75 to 85 cm level. There are no dry-loving species at all.

Section B

	cm		
	0–8	65–110	110–135
Valvata cristata Müller	—	2	—
V. piscinalis (Müller)	1	12	36
Bithynia sp. opercula	—	—	7
Carychium minimum Müller	—	—	2
Lymnaea truncatula (Müller)	—	—	7
Planorbarius corneus (Linné)	—	—	1
Planorbis carinatus Müller	—	—	2
P. vortex (Linné)	—	—	1
P. leucostoma Millet	—	—	3
P. albus Müller	—	1	5
P. crista (Linné)	—	4	10
Acroloxus lacustris (Linné)	—	9	1
Succinea oblonga (Draparnaud)	—	—	1
S. putris (Linné)	—	—	1
Succinea sp.	—	—	14
Vallonia pulchella var. *enniensis* (Gredler)	—	1	2
Hygromia hispida (Linné)	—	—	1
Limax sp.	—	—	4
Unio sp.	—	—	frag.
Sphaerium corneum (Linné)	—	—	3
Pisidium amnicum (Müller)	—	—	1
P. casertanum (Poli)	—	3	—
P. obtusale (Lamarck)	—	3	—
P. milium Held	—	2	—
P. subtruncatum Malm	—	1	2
P. supinum Schmidt	—	—	1
P. henslowanum (Sheppard)	—	—	10
P. nitidum Jenyns	—	6	10
P. moitessierianum Paladilhe	—	—	2

Nothing as certain can be concluded about the deposition in Section B. The only level from which a reasonably large fauna has been obtained is at 110 to 135 cm, i.e. towards the bottom of the bed. This fauna shows a mixture of species liking open water with some marsh species. In all probability the best picture of local conditions is one of a marsh cut by sluggish drainage channels.

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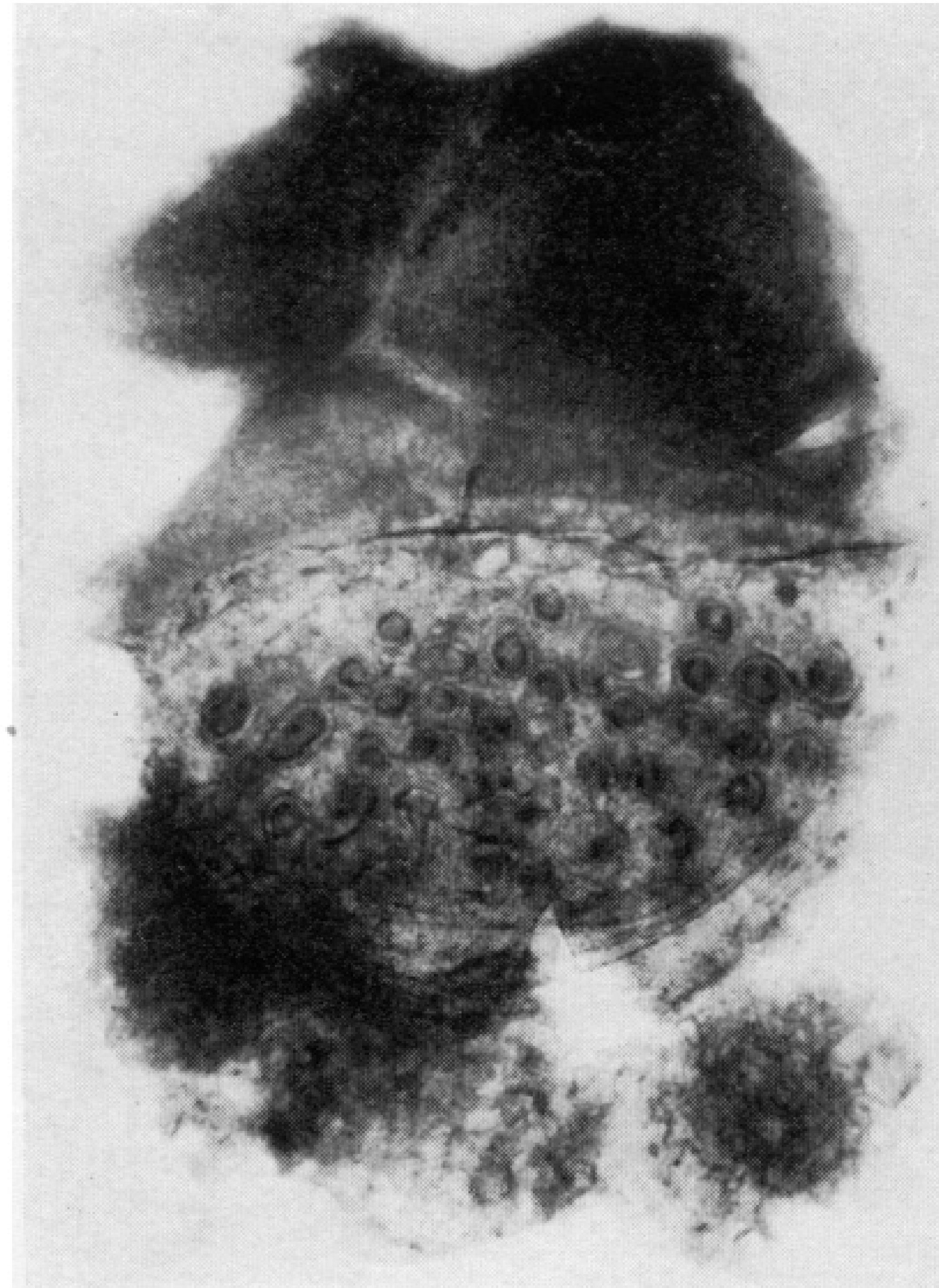
20

21



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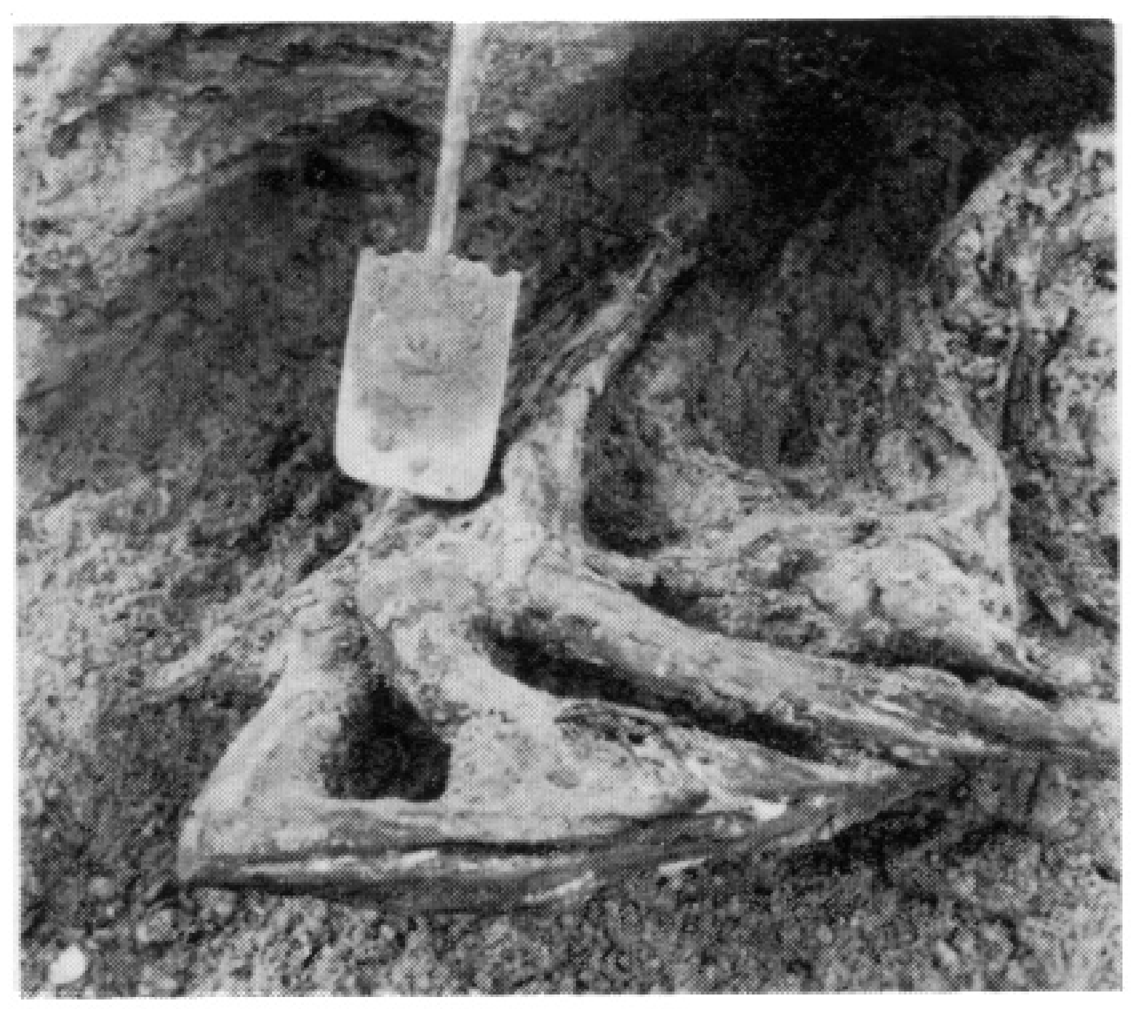

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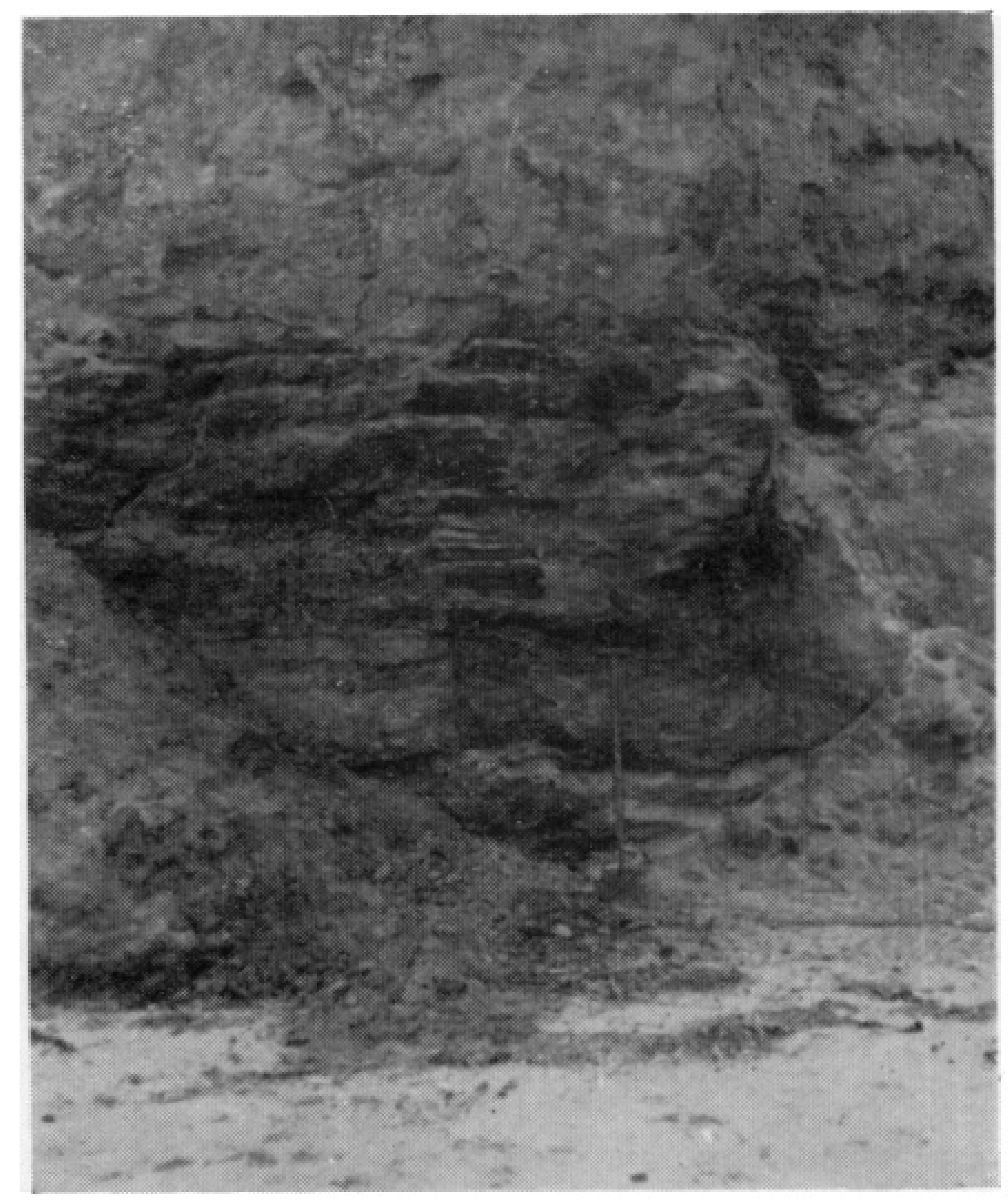

25

FIGURE 20. Cromer Forest Bed Series in the form of a dark-coloured step rising from beach level at West Runton. This is the deposit represented by diagrams A to G. Photograph by Dr J. Donner.

FIGURE 21. Megaspore and massulae of *Azolla filiculoides*, showing details of the surface of the megaspore. This specimen was found in the Cromer Forest Bed Series at A (West Runton). Photograph by Dr M. Canny. (Magnification ×100.)

FIGURE 22. Cromer Forest Bed Series in the vicinity of A (West Runton), showing dark-coloured, highly organic mud with shells.

FIGURE 23. Cromer Forest Bed Series in the vicinity of A (West Runton), showing the division into a dark-coloured upper layer and a lighter lower one. This section includes the part shown in more detail in figure 22.

FIGURE 24. Cromer Forest Bed Series at O (Mundesley), showing a large piece of *Taxus* wood. Photograph by Dr R. G. West.

FIGURE 25. Interstratified sand and mud of the Cromer Forest Bed Series at R (between Mundesley and Bacton).