PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

A Submerged Late-Quaternary Deposit at Roddans Port on the North-East Coast of Ireland

M. E. S. Morrison, N. Stephens, Margaret Jope, S. P. Dance, F. W. Anderson, F. E. Round, H. Godwin and E. H. Willis

Phil. Trans. R. Soc. Lond. B 1965 **249**, 221-255
doi: 10.1098/rstb.1965.0011

A SUBMERGED LATE-QUATERNARY DEPOSIT AT RODDANS PORT ON THE NORTH-EAST COAST OF IRELAND

By M. E. S. MORRISON

Botany Department, Makerere University College, Kampala, Uganda

and N. STEPHENS*

Geography Department, Queen's University, Belfast, Northern Ireland

with Appendixes on:

I. The Mollusca by Mrs Margaret Jope (*Queen's University, Belfast*) and S. P. Dance (*British Museum Natural History*)
II. The Ostracoda by F. W. Anderson (*Geological Survey, London*)
III. The Algae by F. E. Round (*Botany Department, University of Bristol*)
IV. Radiocarbon dates by H. Godwin, F.R.S., and E. H. Willis (*University Subdepartment of Quaternary Research, Cambridge*)

(*Communicated by H. Godwin, F.R.S.—Received* 17 *March* 1964)

[Plates 29 to 31]

CONTENTS

Recent coastal erosion has cut into the filling of a former inter-drumlin lake and exposed an excellent sequence of Late-glacial deposits. These have been investigated by pollen analyses, identification of seeds, Mollusca, ostracods, and Algae; by stratigraphic studies and by radiocarbon dating. The coincidence of all this evidence strongly confirms that the greater part of the depositional sequence embraces the north-west European Late-glacial stages of the Older and Younger Dryas or *Salix herbacea* clays, with the intervening milder Allerød oscillation. This sequence is overlain by a small thickness of Post-glacial peat. The Late- and Post-glacial filling is shown to be sandwiched between deposits laid down during two phases of marine submergence; the earlier transgression is represented by a red marine clay which had a widespread occurrence on the Co. Down coast, and the later transgression is represented by the local development of the Post-glacial raised beach.

---

* Senior Research Fellow in Geography, University of Tasmania, Hobart, for the academic year 1964–65.

The pollen analyses from the close sampling of the organic Allerød phase muds have yielded unusually detailed data on vegetational conditions in the Late-glacial period. The radiocarbon dates, while fully confirming the age attribution, have not enough precision to give a close measure of the duration of the Allerød phase.

The pollen evidence on vegetation and climate is augmented and clarified by identifications of seeds, shells, ostracods and Algae. The ostracods confirm the marine character of the early red clay, and freshwater shells were found in the overlying Allerød mud. The algal species from the Late-glacial layers have been compared with recent algal floras from Ireland, and with those found in Late- and Inter-glacial sediments elsewhere. The most notable feature is the prominence of species representative of a base-rich habitat.

1. Introduction

The deposits are included between layers which were laid down during the two major episodes of marine submergence, one in the early Late-glacial period and the other in the mid-Post-glacial period. Analyses of pollen, macroscopic plant remains, shells, ostracods, and Algae have been made and these allow a reconstruction of the site, and permit limited correlations. An outline of this history, which is summarized diagrammatically in figure 2, will provide a guide to the more detailed descriptions and discussion in subsequent sections.

The general setting is the well-developed drumlin landscape which was left behind by the decay of the last ice in Co. Down. These drumlins rest upon an irregular rock basement of highly folded Ordovician and Silurian slates, shales and grits. The drumlins vary considerably in height with many tops rising to between 50 ft. (15 to 16 m) and about 100 ft. (30–31 m) above the marshy flats and lakes which occur between them. Some of the marshy ground lies around the 25 ft. (7 to 8 m) contour in the Strangford or Ards peninsula, and was submerged during two phases of marine transgression in the Late-glacial and Post-glacial periods. The Late-glacial sea left behind an unctuous red clay which is probably the base of the Roddans Port deposits. When the continuing isostatic recovery of the land caused this sea-level to fall away, a freshwater, or perhaps at first a slightly brackish water, lake remained. An unbroken succession of typical and clearly developed Late- and Post-glacial sediments accumulated in this basin. This accumulation ended abruptly when a grey lagoon clay buried the fen communities. This marked the onset of the Post-glacial marine transgression at this level.

This marine transgression had been encroaching on the land through much of the preceding Post-glacial period and brought within reach of coastal erosion the drumlins on the seaward side of the peninsula. Waves armed with enormous quantities of material, derived from these seaward drumlins, constructed spits and bars which linked together some of the drumlins and effectively cut off parts of the inter-drumlin hollows from the sea, or turned them into quiet brackish water lagoons. In this fashion we may envisage the burial of the Post-glacial deposits at Roddans Port under the grey lagoon clay. Subsequently, the entire deposit was buried by the movement further inland of the beach bar. This, of course, contributed a massive burden to the underlying deposit, compressed it, and to some extent prevented its further erosion. Eventually, these beach deposits became raised above the reach of the sea as a result of continuing isostatic recovery.

Further readjustment of land and sea-levels has involved the erosion of these raised beaches for some time. Wave attack is now cutting into the overlying beach deposit at Roddans Port and has removed much of this and re-exposed the greater part of the formerly buried lake sediments. In places this raised beach is protected by a substantial sea wall and but for this the sea would long ago have destroyed the coast road and completed the destruction of the site. The rate of recession of this coastline can be estimated from Praeger's

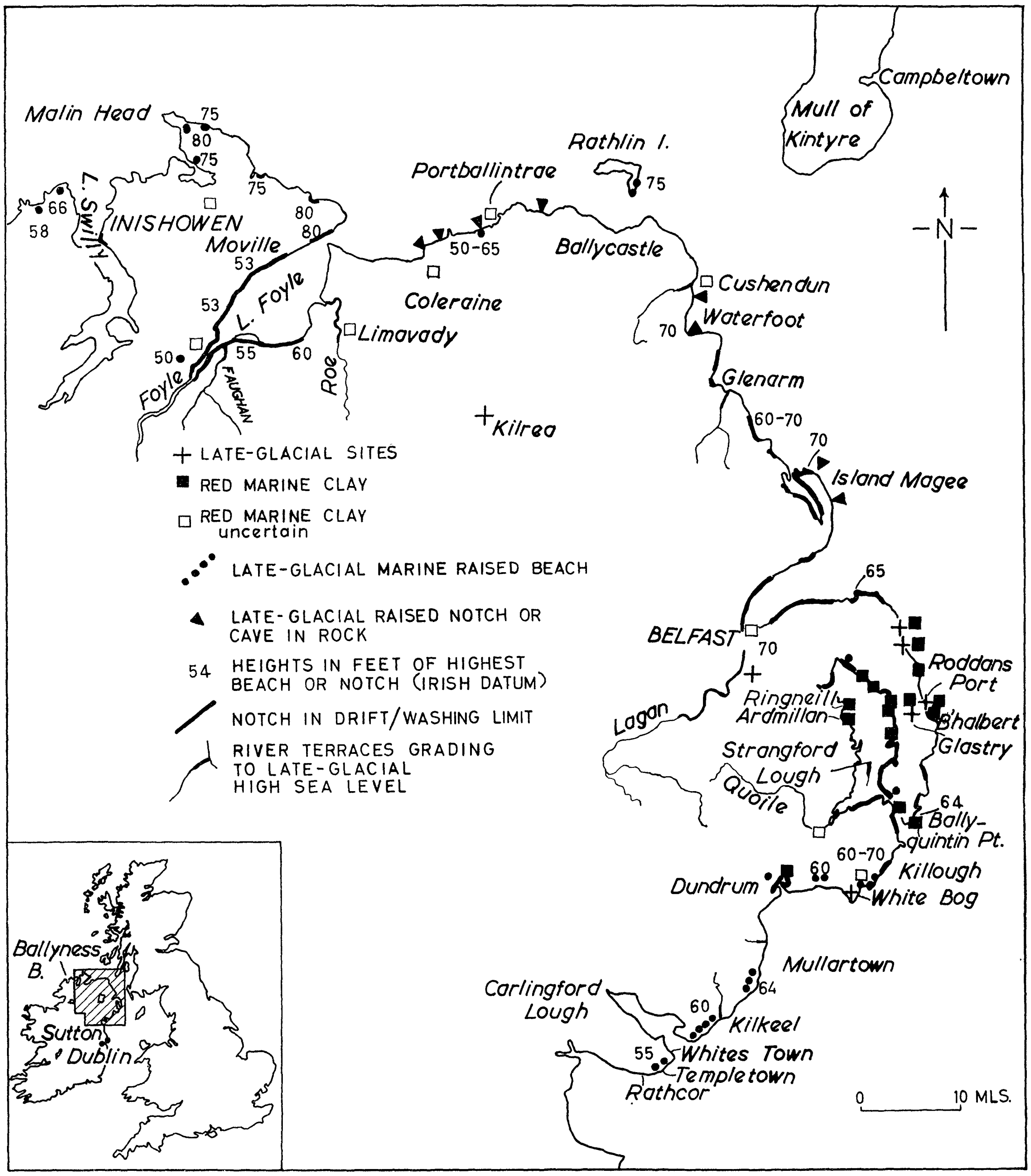


FIGURE 1. Location map for Late-glacial coastal sites in the north of Ireland. The map shows the possible widespread distribution of the red marine clay and some shoreline features, such as fossil notches, caves and shingle beaches; average heights of these features are given in relation to the Old Irish Datum, which is some 8 ft. below English Datum. It should be understood clearly that the use of the same cartographic symbol, or the equality of height between sites on different parts of the coast does not imply contemporaneity for the Late-glacial shoreline features.

(1897) brief description of the site, and from the first Ordnance Survey map which was made in 1834 at a scale of 6 in. to 1 mile. Praeger gave the following description:

'A slope of large pebbles occupies the upper portion of the shore to about half-tide level; below that the boulder strewn shore stretches with very slight slope to low-water mark.

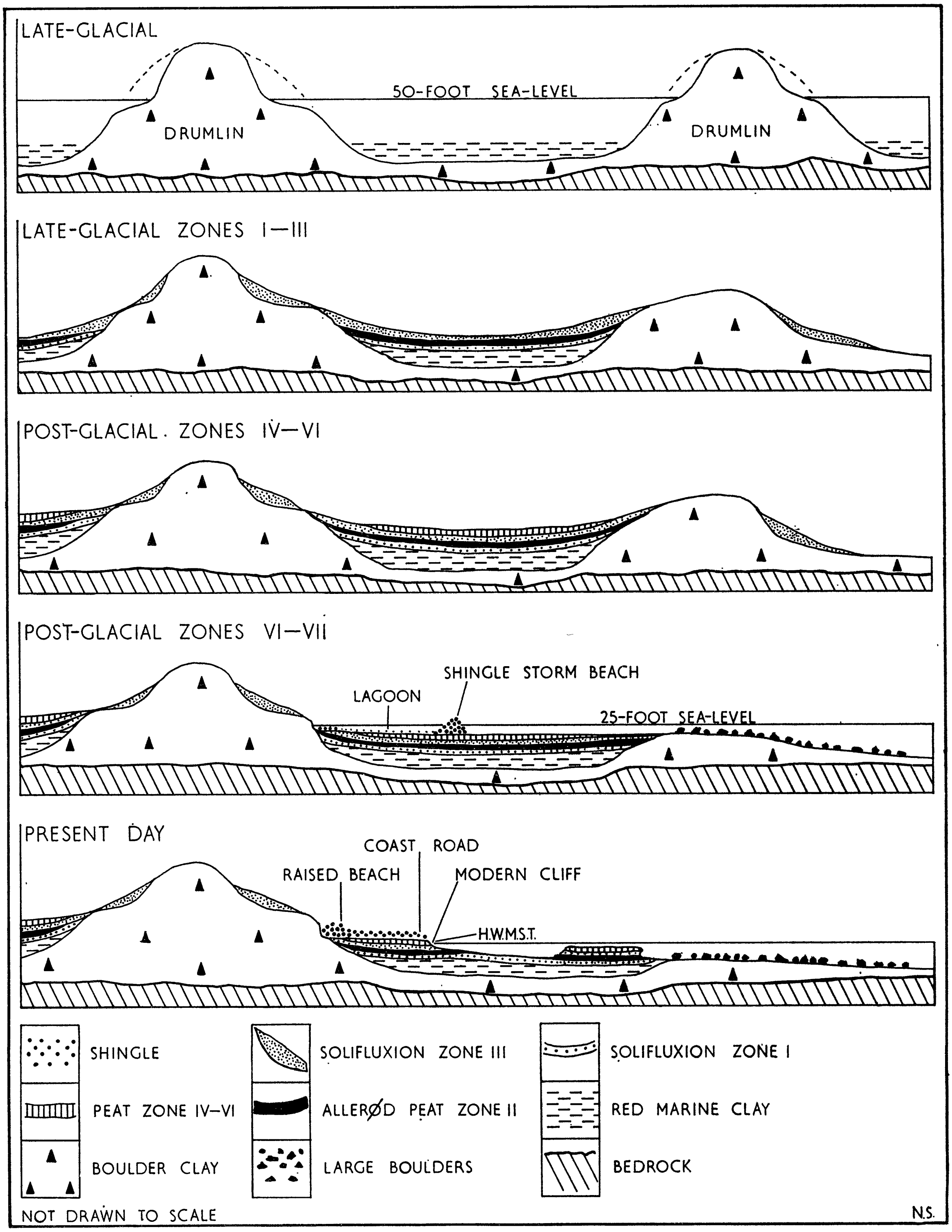


FIGURE 2. Schematic diagram to show the sequence of events during the Late-Quaternary at Roddans Port.

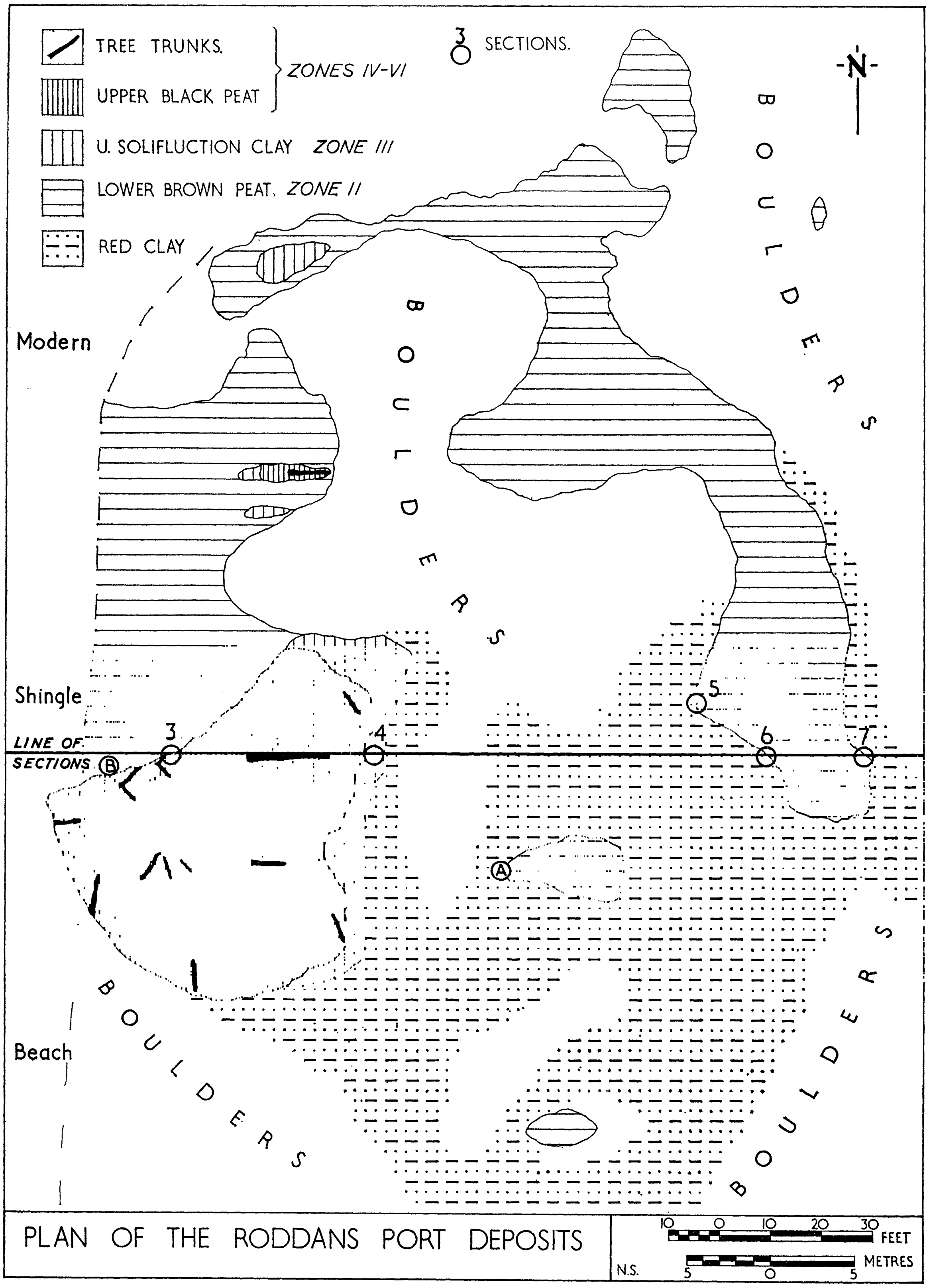


FIGURE 3. Plan of the Quaternary deposits outcropping between high- and low-water mark at Roddans Port. The position of the line of section (figure 4) and points where excavations were carried out are indicated by numbers and letters.

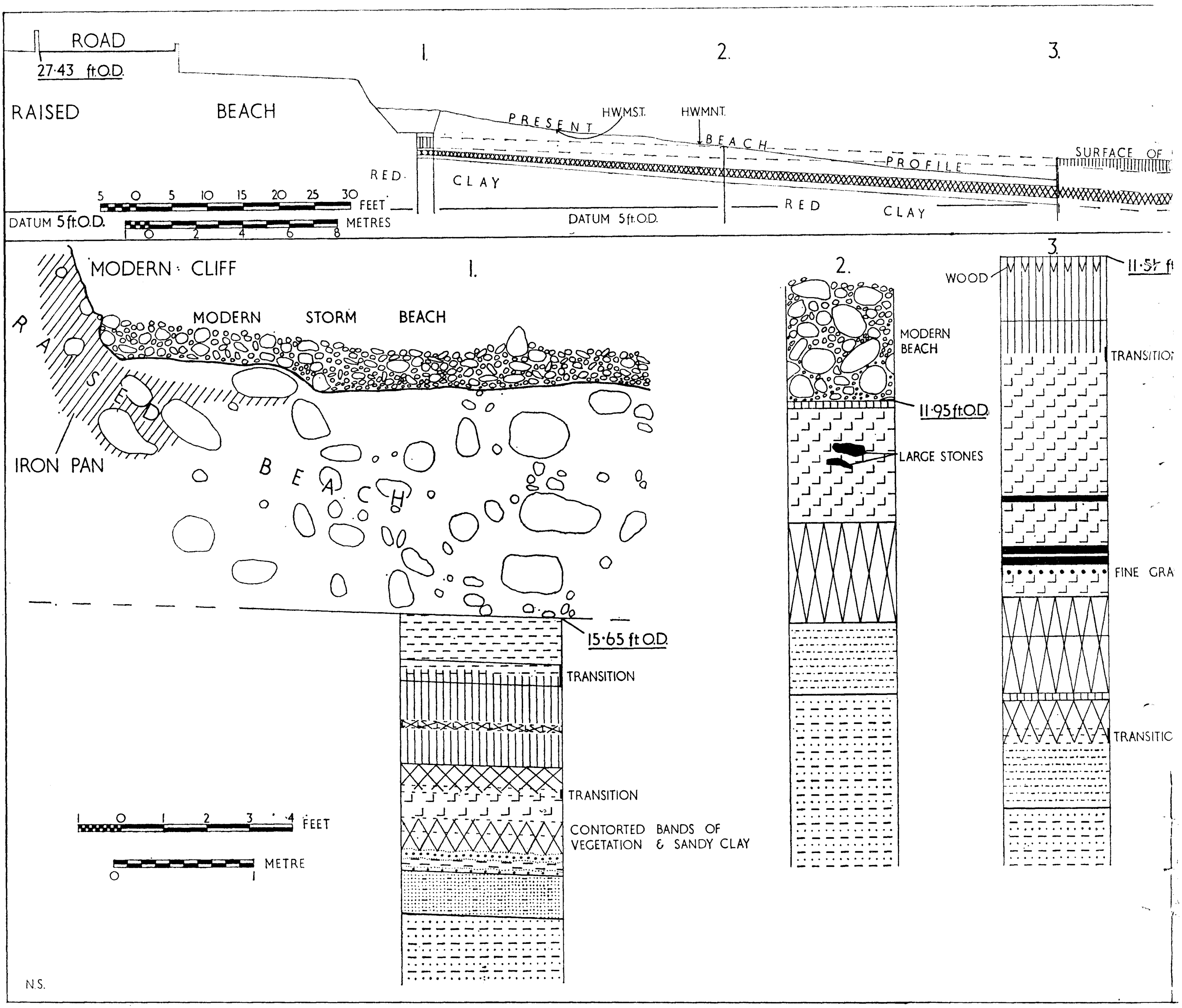
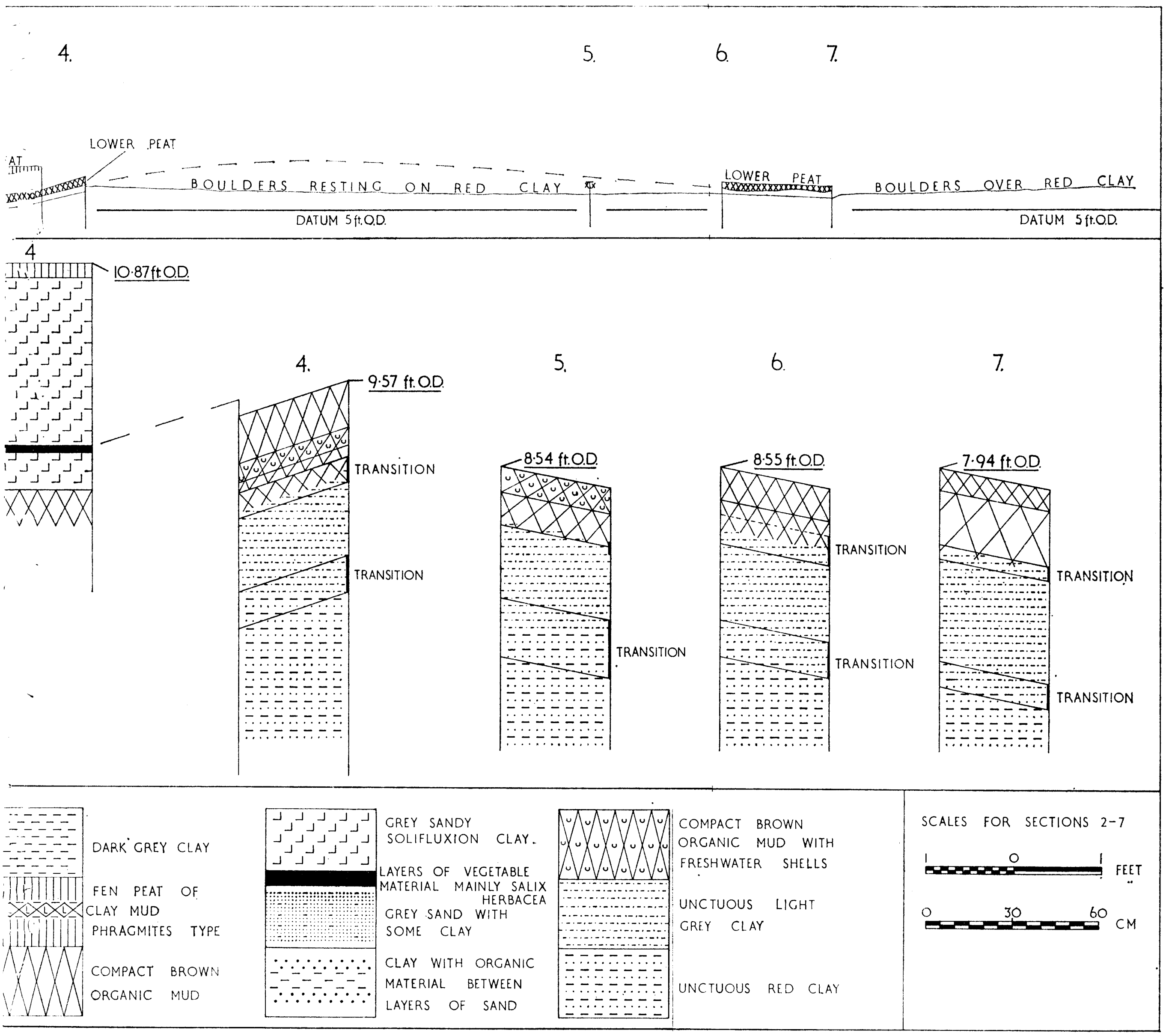


FIGURE 4. The line of section surveyed at Roddans Port between the coast road and low-water mark. The stratigr

The highest zone of the post-glacial beds here exposed consists of a few inches of bluish clay, running in under the steep shingle beach some feet above high-water mark. . . . Below this zone was a bed about six inches thick of solid peat. It contains numerous stumps of trees with roots spreading horizontally in all directions, and trunks and branches of trees. I measured one trunk 27 ft. in length. The stumps appeared to belong to the Scotch Fir, though I found no cones. The peat is seen only close to the edge of the shingle beach. Lower down it has been worn off the underlying beds, which consist of very fine pink and grey laminated clays. . . . They cover an area of perhaps an acre along the beach, and it is their horizontal beds that attract the eye from the road. These clays contained no fossils so far as I could see; and they looked identical with the clays which underlie the salt-marsh behind Killough in Co. Down, and out of which bricks are now made.'



vas investigated in a series of pits (1–7) along the line of section and is indicated in separate numbered columns.

There is evidence that the coast has receded inland by about 100 ft. (30 to 31 m) at Roddans Port since 1897. Where the capping of peat and tree trunks remains intact, the lower deposits (see figures 3 and 4) escape erosion; this is aided by the fact that at high water the uppermost peat lies below several feet of water. Nevertheless, undercutting and pothole action have been proceeding quickly since the protecting layer of raised beach was stripped back by wave action, and the plan in figure 3, drawn in June 1956, would undoubtedly show several changes if comparative measurements were now made. All heights are related to the Old Irish Ordnance Datum, which is approximately 8 ft. below the datum for Great Britain: thus the heights given are higher than if they were related to the datum in Great Britain (see Dixon 1949).

The vigorous destruction of the eastern coastline has reduced the opportunities of discovering dateable and pollen bearing deposits preserved between the two major marine submergences. Roddans Port is therefore an attractively informative site of exceptional importance for the history of the north-east coastline.

2. STRATIGRAPHY

The clays and peats now visible between tide marks at Roddans Port are shown in figure 3, and their stratigraphy is given in figure 4. The sequence was most clearly seen at point 3 (figure 4) and here a monolith of the deposit was collected so that close-lying samples could be obtained for the pollen diagrams. The stratigraphy of the monolith was as follows:

cm	
0–22·5	Dark brown, highly compacted *Phragmites* peat, with fragments of birch bark between 17·5 and 22·5 cm. Upper 8 cm of the peat burrowed by sea fauna and unsuitable for pollen samples.
22·5–35·5	Light brown, organic mud, rich in seeds of *Potamogeton* and *Myriophyllum*.
35·5–120·5	Grey, sandy solifluxion earth with numerous small, flat, and angular and slightly rolled fragments of shale. (A study of the orientation of the stones did not reveal any definite alinement.) Well-defined thin seams of organic detritus, in which leaves of *Salix herbacea* and *Polytrichum* were present, in the lower half of the clay at depths of 95, 103, 105 and 112 cm. There was not any sharp junction between the solifluxion clay and the underlying organic mud, but a transition spanning several centimetres.
120·5–167·5	Brown to grey-brown, highly compacted organic detritus mud. There was some variation in colour depending upon the amount of calcium in the mud. Some of this calcium came from disintegrated skeletons of *Chara*, and remains of freshwater shells.
167·5–172·5	Transition between detritus mud and the underlying clay.
172·5–195·4	Grey clay with very fine dark grey and black streaks. Stoneless and markedly unctuous. The lower 5 cm with thin laminations, clearly visible only when the clay was dry and its surface scraped smooth. These laminations continued down into the underlying reddish-brown clay, which was also markedly unctuous and contained a few stones. The total depth of this clay was not discovered but it was pierced to a depth of 4·6 m; at this depth there was a seam of gravel.

The peats and muds in this section are very compressed and this is due to the overburden of lagoon silt and beach deposit with which they were formerly capped, though evidence of these two last-mentioned deposits can now be found only under the raised beach (point 1, figure 4). The lagoon clay and beach deposit not only compressed the underlying sediments but protected them from erosion by waves as changes of sea-level occurred. Originally, the greater part of the Roddans Port peats lay below the zone of maximum wave activity and was therefore protected. However, as a result of isostatic readjustment,

FIGURE 12. General view taken from the coast road of the site at Roddans Port between high and low-water marks. The line of section (figure 3 and 4) is indicated by the surveying poles and level tripod, and excavation is in progress at point 3.

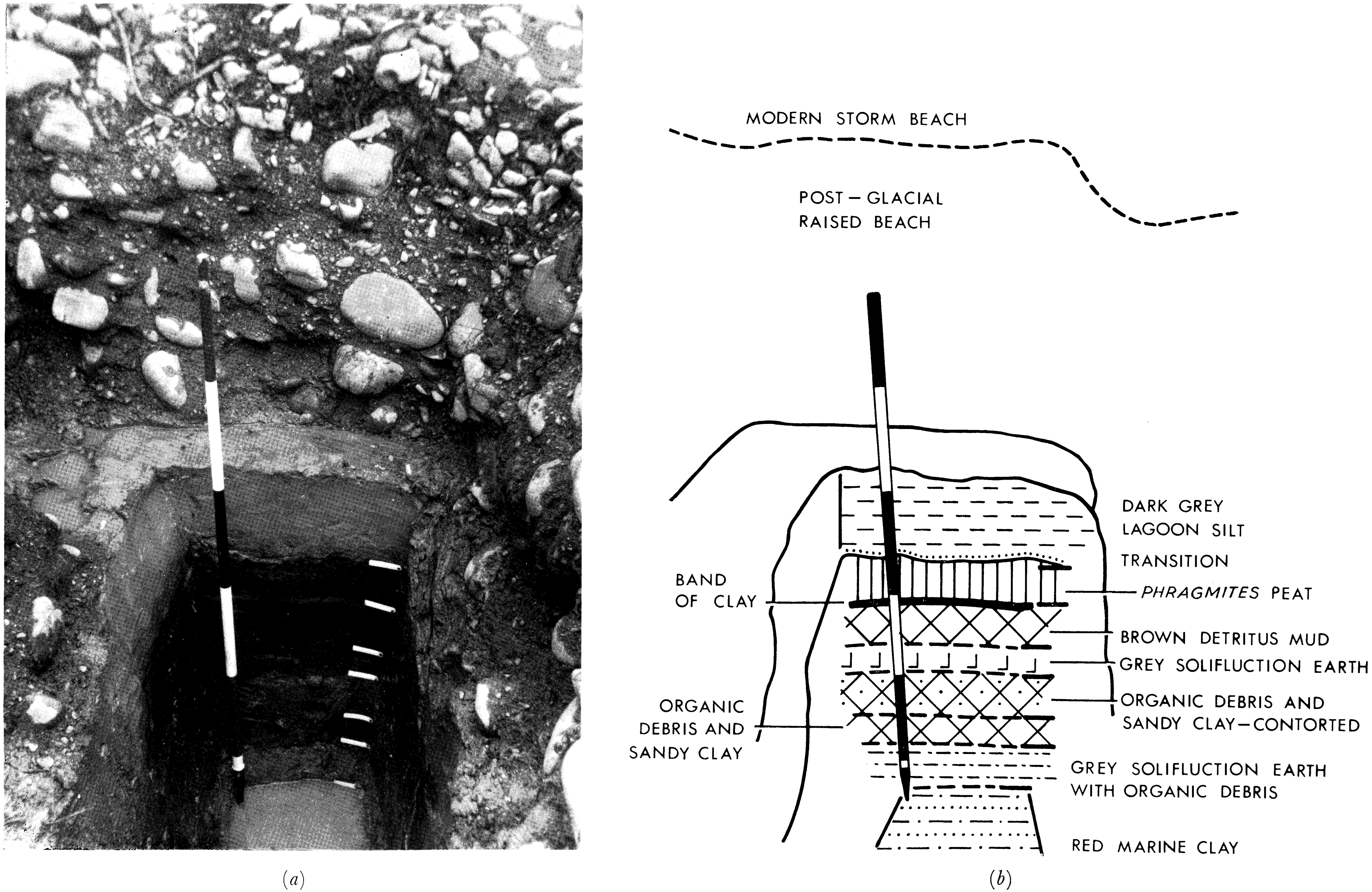


FIGURE 13. The section excavated at point 1 on the line of section (figure 3 and 4).

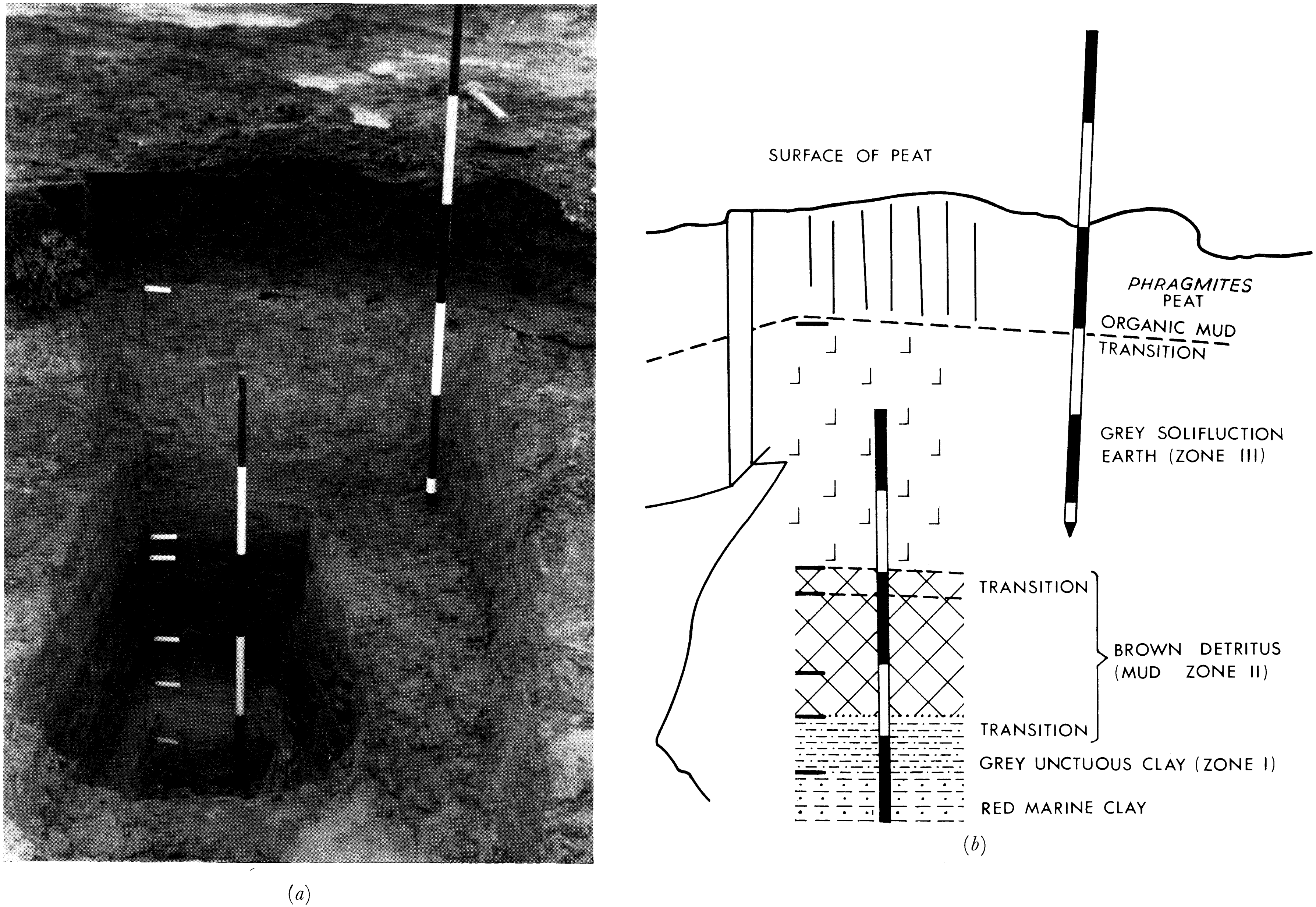


FIGURE 14. The section excavated at point 3 on the line of section (figure 3 and 4).

which raised the Post-glacial shoreline to its present level, the deposits were brought within the inter-tide zone and they are now subjected to greater wave attack.

Although the grey solifluxion earth between 35·5 and 120·5 cm was not stratified internally, there were thin, almost horizontal, seams of organic debris, in which twigs and leaves of *Salix herbacea*, leaves of *Polytrichum* species and seeds and fruits of water plants were identified (see table 1). The horizontal bedding suggests a periodic deposition of the solifluxion earth, with pools forming on temporary surfaces, the pools being colonized by the waterplants and the surface by the *Salix* and *Polytrichum*. It is unlikely that this plant debris was caught up by the deposit sludging into position *en masse* for that would have caused it to be brecciated throughout the clay.

Table 1. List of macroscopic plant remains from Roddans Port

The first four columns refer to Zones, I, II, III, and IV of the monolith from point 3 (see figure 4). Zones I and II embraced by the fifth column refer to the contorted Late-glacial beds beneath the raised beach at point 1 (see figure 4). Abbreviations: *a*, achene; *c*, calyx; *fr*, fruit; *h*, hair; *l*, leaf; *n*, nut; *o*, oospore; *s*, seed; *spr*, sporangium; *sp*, spore; *st*, fruit stone.

species	type of remain	I	II	III	IV	I and II
Armeria maritima (Mill.) Willd.	*c*	—	—	×	—	—
Betula pubescens Ehrh.	*fr*	—	—	×	—	—
C. cf. *flacca* Schreb.	*n*	—	×	×	×	×
C. cf. *hostiana* D.C.	*n*	—	×	—	—	—
Carex cf. *rostrata* Stokes	*n*	—	×	×	—	×
Eleocharis multicaulis (Sm.) Sm.	*n*	—	—	×	—	×
Empetrum nigrum agg.	*s*	—	×	×	×	×
Hippophae rhamnoides L.	*h*	×	×	—	—	—
Hippuris vulgaris L.	*st*	—	—	×	—	—
Lychnis flos-cuculi L.	*s*	—	—	—	—	×
Lycopus europaeus L.	*n*	—	—	×	×	—
Menyanthes trifoliata L.	*s*	—	—	×	×	—
Myriophyllum alternifolium D.C.	*n*	—	×	×	—	×
M. spicatum or *verticillatum* L.	*n*	—	—	—	×	×
Nymphaea sp.	*s*	—	—	—	×	×
Potamogeton cf. *alpinus* Balb.	*st*	—	—	×	—	—
P. cf. *densus*	*st*	—	—	×	—	×
P. filiformis Pers.	*st*	—	×	×	×	—
P. natans L.	*st*	—	×	×	×	×
P. pectinatus L.	*st*	×	—	—	—	×
P. perfoliatus L.	*st*	—	×	—	—	—
P. palustris (L.) Scop.	*s*	—	×	—	—	—
Ranunculus ‘A’	*a*	—	—	×	—	—
Ranunculus ‘B’	*a*	—	—	—	×	—
Ranunculus–Batrachium spp.	*a*	—	×	×	×	×
Rumex acetosella L.	*n*	—	×	—	×	—
Salix herbacea L.	*l, fr*	—	—	×	—	—
Scirpus tabernaemontani (C. C. Gmel) Palla	*n*	—	—	×	—	—
Viola palustris L.	*s*	—	—	×	×	×
Zanichellia palustris L.	*a*	—	×	—	—	—
Polypodium vulgaris L.	*spr*	—	—	×	—	×
Selaginella selaginoides (L.) Link.	*sp*	—	—	×	—	×
Characeae	*o*	—	×	×	—	×

The organic mud, underlying the last-mentioned grey solifluxion earth, was not obviously stratified internally though it was found to be easily cleaved with a knife into thin horizontal slabs. The surfaces of these slabs were threaded through in all directions with cyperaceous and graminaceous fragments and there was also a network of skeletons

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

of *Characeae*. Further, in some sections, as at points 5, 6 and 7 (see figure 4), there were well marked thin seams of freshwater shells, sometimes in great numbers (see appendix I).

The organic mud is underlain by a fine, laminated grey clay which changes in colour to red on passing downwards. The change in colour from grey to red is known from other Late-glacial clays (Pennington 1947) and might be associated with a change in particle size, and such a change is indicated for the Roddans Port clays since the red clay separated out above the grey clay when they were centrifuged together. The difference between the clays, however, goes further than this for it was found that the red clay contained marine foraminifera and ostracods, while the grey clay was entirely free of such fossils. It is probable that the grey clay is a freshwater clay although the presence in it of fruit stones of *Potamogeton pectinatus* could be evidence of brackish conditions.

The extensive coastal distribution of the red clay (see figure 1) and its absence inland suggests a marine deposit. The fossil content alone does not present firm evidence of marine origin because marine shells and foraminifera have been reported from northern Irish boulder clays (Stewart 1879); but taken in conjunction with the extensive coastal distribution there is sound reason to conclude that the hypothesis is correct. It should be emphasized that none of the fossils common to the red clay occurs in the tills of the drumlins immediately behind Roddans Port; these were examined with great care.

At Roddans Port the surface of the red clay is at +6 ft. (1·83 m) O.D. and extends downwards to at least −9 ft. (2·79 m) O.D. At that depth further drilling was prevented by gravel, but this was probably only a thin horizon of gravel. Such lines of gravel are seen in deposits of red clay at Killough brick works, which are about 1 mile in from the sea (figure 1). There some 30 ft. (9 m.) of the clay are exposed, and in places are in direct contact with grey till; the thin stringers of gravel in the red clay probably represent washing from such till.

The distribution of the red clay on the eastern Co. Down coast, and of related geomorphological features such as raised beaches above 40 ft. (12 m) O.D., show that the clay was distributed by a Late-glacial sea when the land was still depressed isostatically or just beginning to recover following the withdrawal and decay of the Irish ice from the coastal lands. Further evidence for this statement and a fuller discussion of this sea level are given in part 4.

Roddans Port deposits disappear beneath the raised beach to the sea side of the coast road and the stratigraphy there was revealed by digging a large trench at point 1 (figure 4). The beach, of large boulders and compact shingle, was a metre in thickness and rested, with a sharp junction, on a greyish-blue silt. This silt resembled the silt found below the raised beach at Ringneill Quay (Stephens & Collins 1960; Morrison 1961) at the northern end of Strangford Lough.

The stratigraphy at point 1 was as follows:

cm	
0–12·6	Loose shingle of the modern storm beach, with a few large boulders on its surface.
12·6–88·2	Very compact storm beach; probably part of the original raised beach. Large boulders and compact sand and fine shingle. The amount of sand increases with depth.

88·2–105·0	Dark grey silt. When this was seen on the shore in 1897, Praeger reported having found in it remains of *Zostera*. Although large samples of the present material were carefully sieved and examined, no fossils were observed, aside from a few unidentifiable worn fragments of mollusc shells.
105·0–112·6	Transition from the clay to the underlying *Phragmites* peat. It was still easy to trace the upright shoots of *Phragmites* which had been surrounded and buried by the clay.
112·6–126·0	Dark brown, highly compressed *Phragmites* peat.
126·0–129·4	A clearly defined band of clay mud.
129·4–142·0	A brown detritus mud with small pockets of sand here and there.
142·0–154·8	Grey, sandy solifluxion earth with a few small stones and some interwoven organic debris.
154·8–163·8	Contorted and rolled organic debris and grey, sandy clay. A few small stones.
163·8–170·0	Grey, sandy clay surrounding a seam of an olive-green clay, with organic debris threaded throughout the whole.
170·0–187·5	Grey solifluxion earth, stony in the upper half, but otherwise very sandy and penetrated densely with threads of organic debris.
187·5	Red laminated clay with a few small slaty pebbles; the largest found was 2·5 cm in length. Using an auger, 2 m of this clay were recorded, and below a depth of 1·5 m sandy and gritty layers were prominent.

The stratigraphy suggests, and it will be seen that later evidence of various kinds confirms, that the two solifluxion layers with an intermediate organic layer represent the familiar Late-glacial sequence of the Upper and Lower Dryas clays separated by organic deposits of the mild Allerød interstadial period.

It is interesting that the Late-glacial part of this section, extending downwards from 142 cm, is greatly contorted and brecciated so that the threefold sequence, so clearly observed at point 3, can hardly be recognized. It could be inferred from this that the section under the raised beach has exposed the marginal deposits of the inter-drumlin hollow, and the contortion of these marginal sediments occurred when the upper solifluction earth accumulated. The absence of lagoon sediments in the flat meadow lying inland of the beach is further confirmation that the raised beach overlies approximately the inner edge of the old lagoon.

3. PALAEOBOTANY

(i) *Introduction*

The pollen history is covered by three series of samples. The first series was taken at 2 cm intervals from a cleaned face of the trench dug into the raised beach at point 1 (see figure 4). The results are shown in pollen diagrams, figures 7 and 8. The discussion of these diagrams has been placed in the succeeding section where it is relevant to the dating of the Post-glacial land- and sea-level changes. The second series of samples, taken at 1 cm intervals from the monolith at point 3, has provided two diagrams, figures 5 and 6. These two figures give us a detailed picture of vegetational changes in the Allerød period and the early part of the Post-glacial period.

In calculating the percentages for the Late-glacial diagrams not less than 500 land pollen have been used in each sample, and for the Post-glacial diagrams not less than 500 tree pollen. Further details of the construction of the diagrams are given on the diagram pages. The zonation has followed Jessen's (1939) system for Ireland. Late-glacial time embraces three stratigraphical Zones I–III (I: Older *Salix herbacea* period, II: Allerød period, III: Younger *S. herbacea* period) and Post-glacial time begins with pollen zone IV and continues, in these diagrams, into pollen zone VI.

It is not possible at present to provide a wholly acceptable zonation of the Irish Late- and early Post-glacial periods. Watts (1963) has suggested that the stratigraphical definition of the Irish Late-glacial zones should be discontinued in favour of zones defined by pollen changes. He argues against stratigraphy because in Ireland the basal clays—which are now classified as Zone I—are nearly always barren of all but secondary pollen and, perhaps, are glacial. Hence he believes it will be of value to explore the possibility of distinguishing, on the basis of pollen, a Zone I within the lower part of what we now classify stratigraphically as Allerød or Zone II. This is a valuable suggestion, though an immediate change over to a pollen zonation would seem to be unwise considering how little evidence is available. Until recently much research on Irish Late-glacial sites focused on macroscopic remains, which are abundantly represented and well preserved, and very little detailed pollen work has been published. Smith, only in 1961, produced the first comprehensive pollen diagram for an Irish Late-glacial site, and the present deposit has allowed, for the first time, comprehensive identification of pollen to be coupled with close-sampling and radiocarbon dating. Another reason for recommending a cautious approach is that the Late-glacial pollen boundaries in Ireland probably cannot be defined by absolute characters such as the presence or absence of individual pollen types which are present probably from the beginning of the Later-glacial period. And the relative abundance of Late-glacial pollen could, presumably, have been much influenced by unimportant changes in very local conditions, such as drainage or erosion. For all these reasons zone boundaries in figure 5 have been drawn using stratigraphical evidence, though the Zone I/II boundary has been moved upwards slightly so that it coincides with the greatest indication of pollen changes in the region of the diagram.

A further region of difficulty in the present Irish zonation lies between the end of Zone III and the beginning of Zone IV. Smith (1961) has used a Zone III–IV, which is not in Jessen's original scheme, and he regards this as representing, at one site, a transitional period between the open vegetation of the Late-glacial and the, perhaps, closed birch vegetation of Zone IV. A similar transition may be identified in figure 6 where the same notation has been used. But Watts (1963) suggests that the fundamental event to distinguish is the replacement of birch by forests of pine, and deciduous trees at the beginning of Zone VI, and for this reason he considers the possibility of a Zone IV–V.

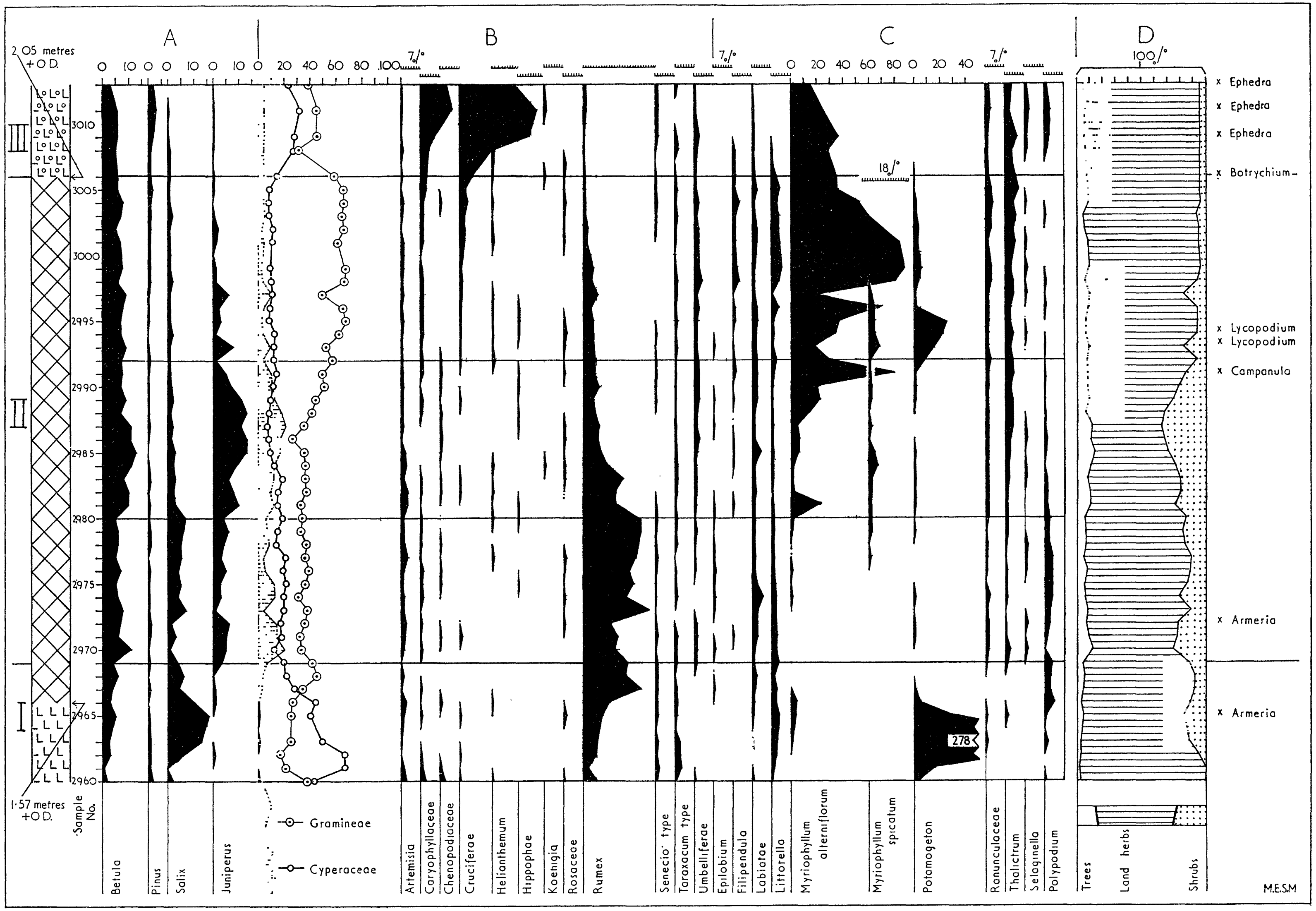


Figure 5. Pollen diagram from the lower part of the monolith taken from point 3 (see figure 4) Roddans Port. The sampling interval was 1 cm. The results of the analyses are expressed as percentages of the total pollen, excluding pollen of aquatics and spores of Pteridophytes.

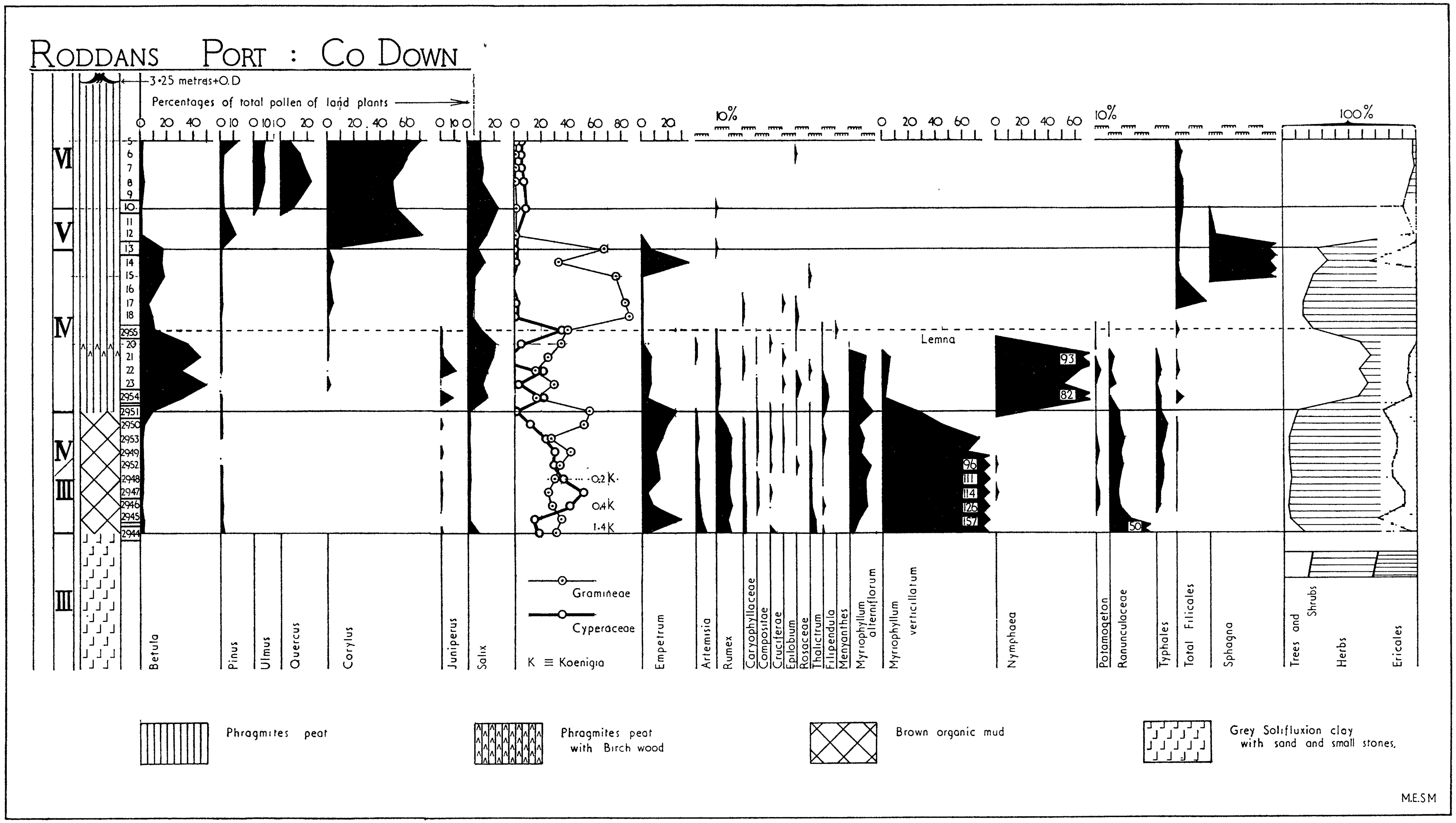


FIGURE 6. Pollen diagram from the upper part of the monolith taken from point 3 (see figure 4) Roddans Port. The sampling interval was 1 cm. The results of the analyses are expressed as percentages of the total pollen excluding pollen of aquatics and spores of Pteridophytes.

(ii) *Discussion*

Zone I

Pollen analyses could be carried only a short way into the Zone I clay although the few pollen types it contained were perfectly preserved. While the dominance of clay in the sediment and the paucity of pollen might be interpreted in terms of conditions inimical to plant growth, we should remember that other readings of the evidence are possible. The clay presumably was carried to the basin by solifluxion, but we know that floristically rich, herbaceous communities can grow on solifluxion soils, for instance, in Iceland. The relative absence of vegetation in this zone could just as well indicate that there had not been time, except for a few plants, for migration into the areas left free by the retreating ice.

Zone II

The change of sediment marking the shift towards warmer conditions is accompanied by rising curves of *Betula*, *Juniperus*, and *Empetrum*. Climatically this change might not have been so abrupt as the stratigraphy alone suggests. Thus, an initial phase with high values of *Rumex* pollen—presumably *Rumex acetosella* because fruits of this occured in the mud—suggests the continuance of conditions not very different from those in Zone I, and this has added significance in the context of Watts's (1963) suggestion that it may be possible to distinguish a vegetational unit which might in future be defined as Zone I within what we now call Zone II.

In the middle of the zone the decline of *Rumex* is accompanied by increasing values of *Juniperus* and *Empetrum*, and the similar behaviour of the curves of *Juniperus* and *Empetrum* suggests that they may have been together in some form of association. If it were possible to interpret the environment of the succeeding phase from its pollen, it might be possible to treat this central phase as a kind of hypsithermal interval. But there is no firm evidence of distinctly thermophilous species, and we note instead the occurrence of oceanic plants such as *Artemisia*, *Eleocharis*, *Helianthemum*, *Litorella*, *Potamogeton pectinatus*, and *Zanichellia palustris*.

A final, third phase of Zone II is marked out by increasing values of Gramineae and diminishing values of *Juniperus* and *Empetrum*. *Myriophyllum alternifolium* becomes very prominent.

Although it has been convenient to subdivide the Zone II pollen profile into three phases, undue significance should not be attached to these divisions. When further data are available they may emerge with wider significance but at present it is conceivable that the features characterizing each may have been very local, perhaps depending upon small and largely insignificant changes of the drainage into the basin in which the sediments accumulated.

Zone III

Unfortunately—and it is frequently so in Ireland—the Zone III solifluxion earth was almost devoid of pollen and the results at the top of figure 5 were obtained with difficulty. The pollen, however, provide the interesting *Ephedra distachya* which has a wide distribution now in southern Europe.

Although solifluxion earths occur in both Zones I and III these two periods appear vegetationally to have been very different. The list of water-plants from Zone III listed in table 1 does not indicate a barren landscape, and the identifications suggest floristic similarity between Zones II and III; many plants which presumably flourished in Zone II survived throughout Zone III, and were able to spread again in the Zone III–IV transition before the spread of the Post-glacial forests in Zone IV eliminated many suitable habitats. This floral history has been amply expounded and documented by Godwin (1956)

Specific identification has not been possible for the achenes of *Ranunculus* found in the organic seams of the Zone III solifluction earth. These have been listed in table 1 as *Ranunculus* 'A', and another unidentified *Ranunculus* achene from Zone IV mud is listed as 'B'. *Ranunculus* 'A' is 1·5 mm in length, and therefore much the size of *R. sceleratus*. Its surface is pitted all over with tiny hexagonal pits, so that it approaches the appearance of *R. hyperboreus*. *Ranunculus* 'B' has a smooth surface and in size and general appearance resembles *R. reptans*. However, with neither achene is the match with the suspect satisfactory because of differences in the position of the style and the point of its attachment. Mitchell (1953) likewise has found Late-glacial achenes of *Ranunculus* cf. *reptans*; he says... 'Three localities in Ireland...produce very small *Ranunculus* achenes, about 1·2 × 0·9 mm, brown in colour. They are too small to belong to any species growing in Ireland today. There are a number of northern *Ranunculus* species which have small achenes but it would be very difficult to separate them on the achenes alone. So if I refer these Irish achenes to *reptans*, it is merely to indicate that achenes of that size do occur; as *reptans* is the only northern form to occur in Britain, its name is used as a label.'

From the seams of organic debris in Zone III we have many telsons of the freshwater notostracan *Lepidurus arcticus*. Mitchell (1957) noted the occurrence of this species in several Irish and English Late-glacial sites. He believes that this *Lepidurus* was widely distributed in the British Isles in Late-glacial times. Of its distribution today he had said 'there is a relic population in deep lakes in the Scandinavian mountains, where it descends to 58° N; it descends to 57° N in the Pribyloff Islands. But the main distribution is circum-polar between 65 and 80° N, where it occurs in ponds and around shallow lake margins, and is often very abundant.'

Zone III–IV transition

A Zone III–IV transitional period is recognized by Iversen (1954) in the Danish pollen sequence. Perhaps, a similar period will be required in the Irish sequence. Smith (1961) identified such a phase at Kilrea and here at Roddans Port between the end of solifluxion at sample 2944 and the expansion of *Betula* woodland at sample 2951 there is an intervening period characterized by the open habitat genera, *Koenigia*, *Artemisia*, and *Rumex*. We could regard this as a transitional period with the extension of Late-glacial species into what is stratigraphically, and presumably climatically, Post-glacial. Iversen has suggested that in Denmark a transitional period appeared because the temperature rise was so rapid at the end of Zone III that forest development was unable to keep pace with climatic improvement. In Denmark the evidence for temperature rise is the end of solifluction and the expansion of thermophilous waterplants. Thus, together with *Scirpus lacustris* and *Typha latifolia*, which had been present in Zone II, Iversen has found *Ceratophyllum*, *Utricularia intermedia*, and *Myriophyllum verticillatum* in the Zone III–IV sediments.

But the homologous sediments at Roddans Port provide no comparable evidence for a rise of temperature and indeed the presence of pollen of *Koenigia* suggests that solifluxion may not have ceased entirely, although we observe no evidence of it in the stratigraphy.

Koenigia is certainly a good index to open habitat and possibly also to solifluxion conditions. It has been recorded living in a variety of habitats but it is most at home on the Icelandic mud flats, which are wet, unstable soils much affected by solifluxion. On these it forms a *Koenigia-Sedetum villosi* community, which is floristically one of the richest of the mud flat communities, and includes *Sagina intermedia*, *Juncus biglumis*, *J. triglumis*, *Sedum villosum*, *Cerastium cerastoides*, *Sagina nodosa*, *Agrostis stolonifera*, *Triglochin palustris*, *Polygonum viviparum*, *Luzula spicata*, *Poa alpina*, and *Equisetum arvense*. Many of these species have not yet been identified in the Irish Late-glacial, so that it would be worth watching for them during future work.

4. Late- and Post-glacial land and sea-level changes

The Late-glacial submergence

The red marine clay is one of the most important features of the deposits at Roddans Port. Stephens (1958, 1963) has presented the geomorphological evidence for regarding this clay, and other features along the Co. Down coast, as the result of a Late-glacial submergence following the withdrawal and decay of the Irish ice, which had covered the northern as well as the eastern coastlands. The sea was envisaged as flooding across the isostatically depressed landmass, cutting a shoreline and depositing the red clay, at a time when world sea-level had not recovered to its present-day level (Fairbridge 1961). Subsequent land recovery elevated the shoreline and the red clay to their present positions. There is no trace of this high shoreline to the south of Ballyness Bay in Co. Donegal, nor as far south as Dublin on the east coast of Ireland (Stephens & Synge 1965 *a*, *b*, in press). It is confined to that part of northern and north-eastern Ireland where the combined weight of the Irish and Scottish ice (not necessarily always in contact with each other) brought about the greatest isostatic depression.

Precise dating cannot yet be given to the submergence in Co. Down for the total age of the red clay is not yet known. At Roddans Port it is overlaid conformably by a grey Zone I clay, but it is possible that the red clay, because of its considerable depth, dates back beyond Zone I. However, it should be emphasized that precise correlation of shoreline features cannot be made between Co. Down and the north coast of Ireland (e.g. Inishowen). Thus, it is not yet known whether the deposits of red clay, and the raised beaches, found at widely separated places (figure 1) are strictly synchronous, even though these features may occur within the same range of height above datum.

Since this paper is concerned principally with Roddans Port, and our present knowledge of this Late-glacial submergence is far from complete, it is considered unwise to attempt a discussion of possible stratigraphical and chronological correlations with the rest of the British Isles. It is important, however, to say that recent work in south-west Scotland (Stephens & Synge 1965 *a*, *b*, in press), together with the investigations of Donner (1957, 1959, 1965), indicates that a series of non-synchronous Late-glacial shorelines are present which can be related to the stages of ice retreat. It seems likely that the Scottish system of beaches and shorelines differ in age from the Irish system, as Donner suggested.

The Post-glacial submergence

The Late-glacial strata at Roddans Port are succeeded by Post-glacial muds and peats which terminate in a grey marine silt, which is capped by beach deposits; these last two deposits belong to the Post-glacial submergence. The pollen analyses of these later deposits are recorded in figure 7 and 8. Detailed discussion of these is unnecessary here because interpretations of very similar records from nearby Ballyhalbert (Morrison & Stephens 1960) and Ringneill Quay (Morrison 1961) have already been published. But it was not possible to make a precise pollen zonation of the upper part of the pollen profile in any of these; it may be subzone VI*b* or VI*c*, but it seems there is nothing to indicate which subzone and thus to give a more precise maximal date for the overlying beach deposits. Too much importance should not be attached to the slight change in the run of the curves at 4·42 m O.D. (figures 7 and 8) for this change is caused probably by the interruption of the peat by a band of clay. How this clay originated is not known. While it had no marine fossils we should not overlook the coinciding peak of pollen of *Chenopodiaceae* in figure 8. The continuing curve of these *Chenopodiaceous* pollen might be evidence of an approaching shoreline.

Some guidance to age is given by the ^{14}C assay of wood from the top of the very similar pollen profile which was obtained from a deposit of freshwater peat (15 ft. O.D.) immediately below the raised beach at Ballyhalbert, and only two miles south of Roddans Port. It gave an age of 8160 ± 135 B.P., and using the Scaleby Moss dated-zone-sequence (Godwin, Walker & Willis 1957) as a standard, this corresponds to mid-zone VI. Similarly, at Ringneill Quay lagoon silts were placed in Zone VI*c*, and the ^{14}C age obtained for them was 7345 ± 150 B.P. (Stephens & Collins 1960). Ballyhalbert, on the outer coast of the Ards peninsula, may represent a freshwater phase before the marine transgression reached the level recorded by the marine silts at Ringneill (Godwin 1960). But there may also have been a time lag between the transgression on the outer coast and that inside Strangford Lough.

A zoning of the pre-beach deposits at Ballyhalbert, Ringneill and Roddans Port to mid-Zone VI makes the actual beach a little younger, and this would fit with the widely held belief that the Post-glacial marine submergence culminated towards the end of the Atlantic period. But it must be stressed that, as yet, no precise date can be given for the duration of beach construction and the end of the eustatic rise of sea-level against the Irish coast. However, at Ringneill charcoal obtained from an occupation layer at 22 to 23 ft. O.D., resting upon the raised beach shingle, gave a date of 3680 ± 120 B.P., and shells from a midden, at approximately the same height and in the same stratigraphic position, gave a date of 2660 ± 110 B.P. (Godwin & Willis 1962). These dates clearly set a limit to beach construction at this level, although the time-range which this allows for the beach at Ringneill is still too great.

Mitchell (1956) has provided more evidence from sections at Sutton, Co. Dublin, where a kitchen-midden containing a Neolithic polished stone axe was shown to be contemporaneous with the maximum of the marine transgression on this segment of coast. A peat layer at 12 ft. O.D., which according to Mitchell (1965) formed in a lagoon between storm ridges at Sutton has provided a date of 3730 ± 130 B.P. Shingle forming the raised beach and the wave-cut notch reach a height of 21 to 25 ft. O.D., at Sutton and on that part of the coast (Stephens 1957). If these storm ridges were formed during the retreat then the maximum of the transgression may be older than 3730 ± 130 B.P. However, peats occurring above or below marine silts or beaches can give only an approximate date for the marine sediments because of erosion, or a possible time-lag between the

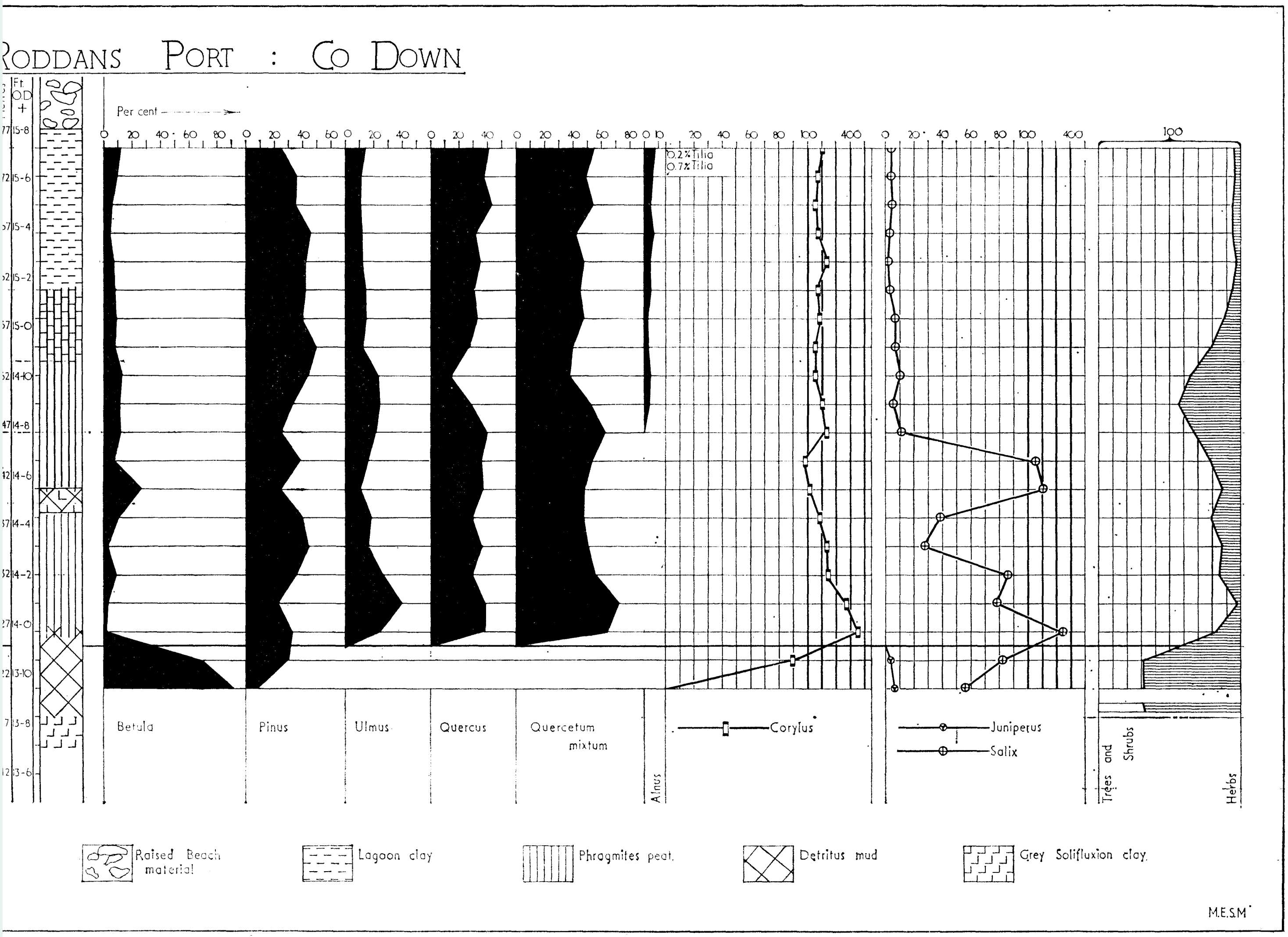


FIGURE 7. The tree pollen diagram from the deposits underlying the raised beach at point 1 (see figure 4) Roddans Port. The results of the analyses are expressed as percentages of the total tree pollen excluding *Corylus*.

two sets of deposits. Thus, although the maximum of the marine transgression at Sutton may be slightly older than 3730 ± 130 B.P., it is possible that there is a considerable discrepancy in time between the maximum of the transgression at Sutton as compared with Ringneill and other north-eastern sites. The dates suggest that the Post-glacial marine transgression is distinctly older in the north than in the south, and that we are, in fact, dealing with beaches of different age on the Co. Down coast as compared with Sutton. This site is very near the southern limit of the Irish Post-glacial raised beach, and it is also nearer the southern limit of the last ice-sheets than Co. Down. Sutton was therefore much nearer the periphery of the area affected by isostatic depression, whereas in Co. Down the sea was able to transgress at an earlier stage an area which had been more deeply depressed by the ice.

It is therefore in keeping with our understanding of these land- and sea-level movements to suggest that the Post-glacial raised beach is not a single synchronous feature on the east coast of Ireland, but is made up of a number of synchronous beaches which, if considered as a whole, form a metachronous feature from north to south. This would account satisfactorily for a Sub-Boreal date for the maximum of the transgression at Sutton, whereas an Atlantic date would seem to be more correct on the Co. Down coast. More informative and critical evidence for Irish land- and sea-level movements should now be sought in the interbedded peats and marine silts of the estuaries of the Foyle, Lagan and Quoile, and at other sites around the Irish Sea Basin.

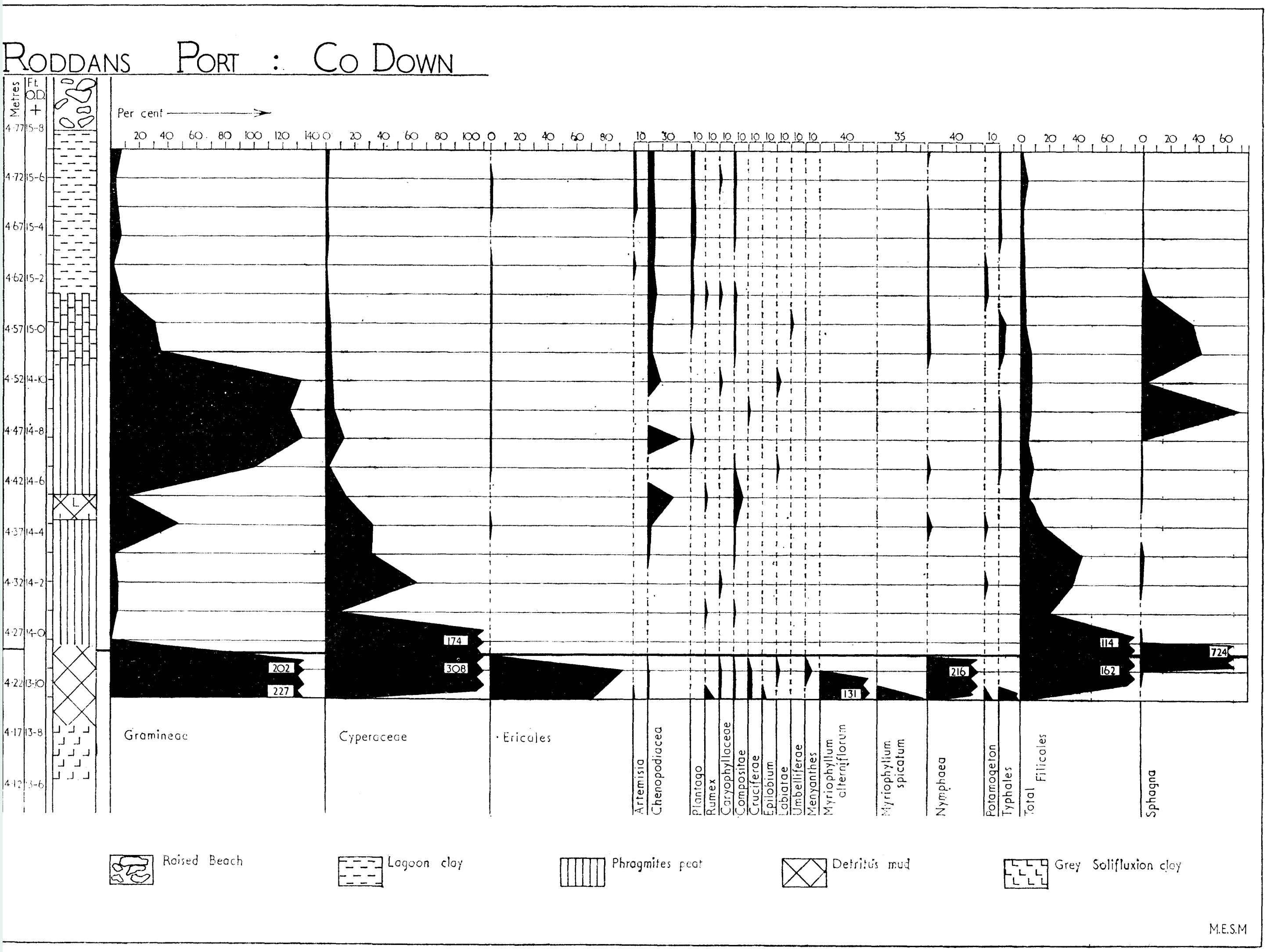


Figure 8. The non-tree pollen diagram from the deposits underlying the raised beach at point 1 (see figure 4) Roddan Port. The results of the analyses are expressed as percentages of the total tree pollen excluding *Corylus*.

Appendix I. Mollusca from Zone II Roddans Port, Northern Ireland

By Mrs Margaret Jope
Queen's University, Belfast

and S. P. Dance
British Museum, Natural History

The Roddans Port grey, Zone II clay was laminated, some interfaces being crowded with freshwater shells, chiefly *Lymnaea peregra* and several species of *Pisidium*. The only other shells identified were four specimens of *Planorbis*. The following species were recorded:

Lymnaea peregra (Müller). Common. Ubiquitous in the British Isles in any moist environment.

Planorbis crista (L.). One mature specimen and one juvenile. Widespread in the British Isles in still and running water.

P. laevis Alder. One specimen and one fragment. Common on the west coast of Ireland and some localities in Scotland and the north of England, in shallow lakes near the sea.

Pisidium spp. Identified by A. W. Stelfox and by S. P. Dance, the latter contributing the ecological notes.

P. casertanum (Poli). Common. Probably the commonest British freshwater mollusc. Found in all types of habitat.

P. obtusale lapponicum Clessin. Moderately common. A well-marked Arctic subspecies of *obtusale* Pfeiffer. Known in the Recent from northern Sweden; Klin, Russia; and Arctic north America. Specimens dredged in Lough Neagh have been referred to this form. Recorded as a fossil from several localities in England, and Stelfox records it from the early Post-glacial marls (?Zones IV or V) of the White Bog, Killough, Co. Down. Dance (1961) gives further notes and localities for this subspecies.

P. hibernicum Westerlund. Moderately common. In all types of habitat except those liable to be dry for long periods. Rather more common in the north of the British Isles than in the south.

P. milium Held. Moderately common. In all types of habitat except stagnant ditches.

P. nitidum Jenyns. Very common. In all types of habitat except stagnant places or places liable to dry up for long periods.

P. subtruncatum Malm. Moderately common. In most types of habitat but prefers running water.

This concurrence of *Pisidium* species suggests a stream fauna and, with the exception of *lapponicum*, all have been found living close together in a stream in the south of England (Dance 1957). The stream may have run through low-lying marshy land.

APPENDIX II. OSTRACODA FROM LATE-GLACIAL CLAYS AT RODDANS PORT AND OTHER SITES IN CO. DOWN, NORTHERN IRELAND

By F. W. ANDERSON
Geological Survey, London

The Ostracoda are all living North Atlantic species, but the prominence of *Cypridea punctillata* is rather typical of the older Post-glacial raised beaches.

Roddans Port Red Clay	
Cypridea punctillata Brady	Very common
'*Cythere*' *globulifera* Brady	Three specimens
Cytherura concentrica Brady, Crosskey and Robertson	One specimen
Roddans Port, Zone II shell layer	
Cytheridea elongata Brady	One specimen
Roddans Port, junction between Red Clay and Zone I clay	
?*C. elongata* Brady	One specimen
Portaferry Red Clay	
C. punctillata Brady	Four specimens
Ballyquintin Point Red Clay	
'*Cythere*' *globulifera* Brady	Five specimens
Ilyocypris gibba Ramdohr	Two specimens; freshwater species
Cytherura concentrica Brady, Crosskey and Robertson	One specimen
Cytheridea punctillata Brady	Two adult and fourteen juveniles

APPENDIX III. THE ALGAE OF THE LATE-GLACIAL SEDIMENTS FROM RODDANS PORT, NORTHERN IRELAND

By F. E. ROUND
Botany Department, Bristol University

During the investigation of pollen and plant remains in Late-glacial and Post-glacial sediments from Roddans Port, Morrison found many coenobia of *Pediastrum* in material of Zones I and II. Six samples of sediment from this material were examined. Part of each sample was prepared as for pollen analysis and in this the remains of *Pediastrum*, *Botryococcus* and desmids were examined. A second series was prepared for diatom analysis (see Round 1957). The principal features of the samples are given in table 2.

The samples were strikingly different in physical composition, but these differences were not correlated with the floristic variation. The presence of *Pediastrum*, *Botryococcus*, and among the diatoms *Cyclotella comta*, *Anomoeoneis serians* var. *brachysira*, *Navicula oblonga*,

TABLE 2. SUMMARY OF MAIN FEATURES OF THE SAMPLES

sample	nature of sediment	reaction to hydrochloric acid	*Pediastrum*	desmids	*Botryococcus*	diatoms
Zone I						
2962/63	grey clay	gas evolved	abundant	rare	present	rare
2967/68	laminated mud	—	abundant	frequent	frequent	occasional
Zone II						
2969/70	laminated mud	gas evolved	frequent	frequent	present	rare
2980/82	laminated mud	gas evolved	rare	abundant	frequent	absent
2982/83	clayey silt	—	present	rare	present	abundant
2991	laminated mud	—	present	rare	frequent	abundant

N. reinhardtii, *Diploneis* spp., *Cymbella* spp., and *Nitzschia angustata* var. *acuta*, suggests that at times during this period, there was sufficient water for a lake-like flora to develop. However, the majority of the species could also live on the surface of waterlogged soil (see discussion). *Pediastrum* is most abundant in Zone I, desmids in mid-Zone II, *Botryococcus* alternates from rare to frequent throughout the samples, and diatoms are most abundant in the uppermost samples of Zone II.

Pediastrum

This genus has often been found in Late-glacial material, but rarely in later zones which suggests that the conditions immediately after the disappearance of the ice were particularly favourable for its preservation. It is likely that such a common and cosmopolitan genus grew throughout the Post-glacial period and the reasons for its absence from the later zones are unknown. In a sample from Penkridge (Round 1956) and in samples from Neasham (Blackburn 1952), numerous taxa of *Pediastrum* were found, but in the Roddans Port samples only two forms (figure 9) of *P. boryanum* have been recorded. The coenobium illustrated in figure 9/1 is similar to the *P. boryanum* v. *boryanum* of Round (1956), but in the Northern Ireland samples the cells are punctate. The other type (figure 9/2) corresponds to figure 6 in Round (1956) but is only a seventeen-celled coenobium (10+6+1); this is referred to the var. *integriforme* Hansgirg. These two taxa are probably both benthic forms of the genus. The distribution suggests a progressive change in conditions from the early to the later part of the core, when *Pediastrum* became less frequent; this was probably related to the decreasing eutrophy of the waters.

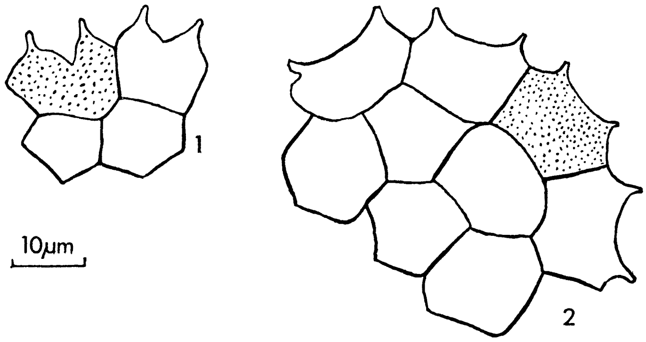


FIGURE 9. The common forms of *Pediastrum* in the Roddans Port material.
1. *P. boryanum* v. *boryanum*. 2. *P. boryanum* v. *integriforme*.

Botryococcus

The genus is not well enough preserved to enable an identification to a species. Presence of this genus suggests a moderately eutrophic, base-rich status of the waters; this is amply borne out by the diatom analysis. In the present-day Irish loughs it is of fairly wide distribution but commoner in the eutrophic series (Round & Brook 1959).

Desmids

The desmids listed in table 3 and figure 10 usually live amongst the littoral vegetation and no conspicuous planktonic forms are present (cf. the diatoms). Several species of the genus *Cosmarium* were also recorded from Zone II at Neasham (Blackburn 1952). They were frequent in upper Zone I and mid-Zone II but rare in later Zone II at Roddans Port. According to the pollen diagram of Morrison (F. 5), sample 2967/68 is situated just below the boundary of Zone I; from the algal analysis it is obvious that the change from Zones I to II conditions was taking place and affecting the algal flora soon after the change from clay to peat deposition. In fact the angiosperm flora altered as the sedimentation changed from clay to peat (e.g. *Salix* and *Potamogeton* declined and *Rumex* increased). The diatom flora also showed a great change from sample 2962/63 to 2967/68; in the first there is an absence of diatoms and in the second a typical Zone II flora is present. The changes in the desmid flora follow fairly closely certain changes in the angiosperm flora; during the period of early Zone II when desmids were most conspicuous in the flora, the water plants *Myriophyllum* and *Potamogeton* were hardly represented in the pollen. These plants, especially the former, need a fair depth of water and their absence from this zone suggests a period of low water level (cf. the absence of planktonic species).

TABLE 3. THE DISTRIBUTION OF DESMIDS IN THE SAMPLES

desmids	samples					
	2962/63	2967/68	2969/70	2980/82	2982/83	2991
Actinodesmium curtum v. *obtusum*	.	.	.	.	.	*
A. diplosporum v. *americanum* f. *minor*	.	.	*	.	.	.
Euastrum binale	.	.	.	*	*	.
Cosmarium blytii	.	.	.	*	.	.
C. botrytis	.	.	.	*	.	.
C. contractum v. *ellipsoideum*	.	*	.	*	.	.
C. granatum	*	*	*	*	*	*
C. humile v. *striatum*	.	*	*	.	*	*
C. impressulum	*	*	*	.	.	.
C. obtusatum	.	.	.	*	.	.
C. pseudatlanthoideum	.	.	.	*	.	.
C. punctulatum	.	*	*	.	.	.
C. subtumidum	.	.	*	.	.	.
C. venustum v. *minor*	*	.	.	*	*	*
Staurastrum boreale	.	*	.	.	.	.

Sample 2980/82 was the richest in desmids. This sample was completely devoid of diatoms.

Cosmarium granatum was the only desmid occurring in all the samples; it is a cosmopolitan species. The other desmids are widespread, occurring either in boggy places, often amongst *Sphagnum*, or in the weedy margins of lakes.

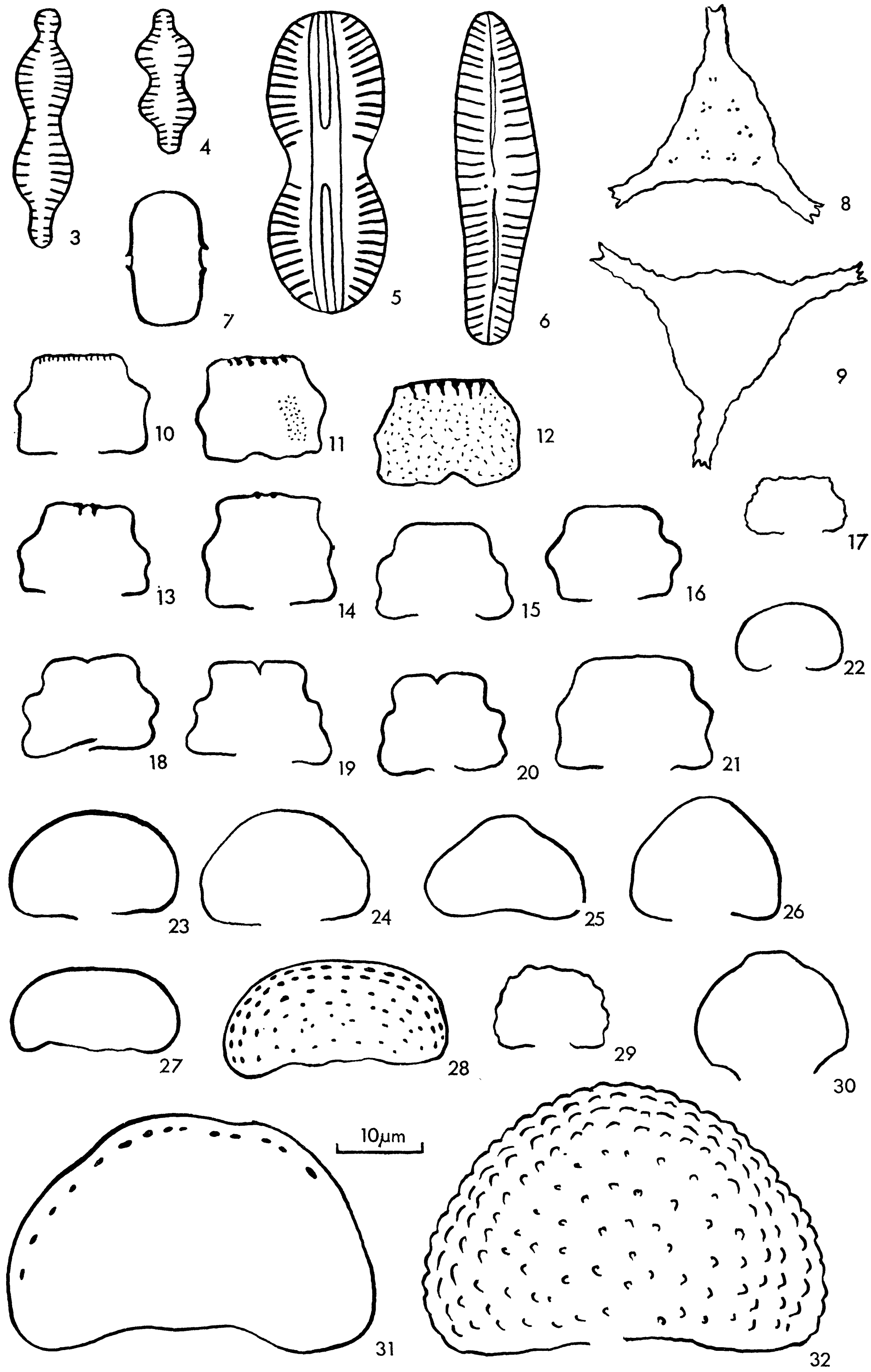


FIGURE 10. Some characteristic diatoms and desmids from the Roddans Port Late-glacial material. The desmids were badly preserved and they are all illustrated since assigning them to species proved difficult and the names are only tentative. 3, 4. Forms of *Fragilaria construens* v. *binodis*. 5. *Diploneis domblitensis* v. *subconstricta*. 6. *Comphocymbella ancyli*. 7. *Actinodesmium diplosporum* v. *americanum* f. *minor*. 8, 9. *Staurastrum boreale*. 10–14. Forms of *Cosmarium humile* v. *striatum*. 15, 16, 21. Forms close to *Cosmarium venustum* v. *minor*. 17. *Cosmarium blyttii*. 18–20. Forms of *Euastrum binale*. 22, 23, 27. Forms of *Cosmarium contractum* v. *ellipsoideum*. 24. *C. subtumidum*. 25. *C. pseudatlanthoideum*. 26. *C. granatum*. 28. *C. punctulatum*. 29. *C. impressulum*. 30. *Actinodesmium curtum* v. *obtusum*. 31. *Cosmarium obtusatum?* 32. *C. botrytis*.

Diatoms

Diatoms (see table 4 and figure 10) were scarce except in the last samples from Zone II (sample no. 2991 was in fact just above mid-Zone II). The relatively small number of species is characteristic of this period (Round 1957). The early part of Zone II was not a favourable period of diatom growth. However, cores from the English Lake District have shown that there may be marked variation in diatom content between different levels in the same zone during this early period of deposition.

The dominant species are from the attached or motile communities of the littoral zone of the lake. The only planktonic species present are those of the genus *Cyclotella*. The dominance of the non-planktonic communities in the early zones is characteristic of other cores (e.g. Kentmere (Round 1957) and Esthwaite Water (Round 1961)) and is an indication that the waters were highly turbid and unable to support a planktonic population. However, planktonic diatoms are on the whole less silicified than benthic species and therefore may have been present but not preserved. The presence of distinct epiphytic species, e.g. *Cocconeis placentula*, *Cymbella* spp., *Gomphonema* spp., *Epithemia* spp., and *Rhopalodia* spp., is evidence of a considerable growth of macrophytic plants. Morrison records a large population of *Potamogeton* in Zone II and *Myriophyllum* and *Littorella* were present in Zone II. The remaining species of diatoms almost certainly grew on the silts of the littoral zone.

The diatoms illustrate two features of the Late-glacial period which have been recorded elsewhere (Round 1957). The first is the occurrence of indicator species, e.g. *Cyclotella antiqua* and *Gomphocymbella ancyli*. The latter species is recorded by Hustedt (1930) as an indicator of the Ancylus period in Scandinavia, whilst the former is found in the Late-glacial period in Kentmere and Esthwaite Water and elsewhere in quaternary deposits and in Boreal regions. Surprisingly, the more striking indicators of Late-glacial time are missing, e.g. *Melosira arenaria*. The second feature indicated by this flora, is the presence of calcareous waters (cf. Kentmere and Esthwaite). The occurrence of species of the genera *Fragilaria*, *Mastogloia*, *Epithemia* and *Rhopalodia* and the scarcity of species of the genera *Eunotia*, *Frustulia*, *Pinnularia*, and *Stenopterobia*, is indicative of a high base status. The genus *Mastogloia* has not been recorded from Late-glacial material in the English Lake District, but was found by Ross (1952) in Zone II at Neasham; it is an indicator of fairly extreme calcareous conditions. The Neasham deposit contained many species common to the Roddans Port samples and it was also considered by Ross to have been laid down under calcareous conditions. Species of the genus *Mastogloia* occur on sediments of some of the present day Irish loughs and are almost entirely confined to the most calcareous series (Round 1959). This suggests that the Late-glacial lake at Roddans Port was of an extremely calcareous nature. This is further emphasized by the occurrence of species such as *Navicula reinhardtii*, *N. oblonga*, *Cymbella sinuata*, *C. ehrenbergii*, *Denticula tenuis*, *Nitzschia denticula*, *N. sinuata* v. *tabellaria*, and *N. angustata* v. *acuta*. All these have been shown to favour base rich habitats either in Ireland (1959) or in England (e.g.Malham Tarn (Round 1953 and unpublished)). Some of them, e.g. *N. sinuata* and *N. sinuata* v. *tabellaria*, are common on calcareous dune slacks in a subaerial habitat (Round 1958). There are, however, one or two apparently anomalous species, e.g. *Anomoeoneis exilis*, *A. serians*, and *Cymbella cesatii*, which are usually more abundant in acid habitats (cf. their distribution in the Irish loughs (Round 1959)). Their presence in this Late-glacial material suggests that under certain conditions they may be more widespread.

The only species which are present in these Late-glacial deposits and absent from the present-day Irish loughs samples in 1953 (Round 1959) are *Cyclotella antiqua*, *Fragilaria brevistriata*, *Mastogloia lanceolata*, *Navicula baccilliformis*, *Diploneis interrupta*, *Gomphonema gracilis*, *Gomphocymbella ancyli*, and *Nitzschia sinuata* v. *tabellaria*.

Of these, only *Cyclotella* and *Gomphocymbella* are likely to be absent from the present-day lake flora, due to their extinction in the Post-glacial period (cf. the distribution of the former in Windermere (Pennington 1943), and in Kentmere (Round 1957)). The others are possibly associated with subaerial habitats. The converse, i.e. species present in existing Irish loughs but absent from these Late-glacial samples, are exceedingly numerous and include a large number of acidophilic species. The absence of the genera *Tabellaria*, *Opephora*, *Peronia*, *Neidium*, *Stauroneis*, *Frustulia*, *Amphipleura*, *Pinnularia*, *Stenopterobia*, and *Surirella* is striking. All these genera are common in acidic habitats and their complete absence from these Zone I and Zone II samples is the most conclusive evidence of the calcareous nature of the deposits. On the other hand, genera such as *Gyrosigma* and *Cymatopleura* were not recorded, although they are usually frequent in calcareous lakes in Ireland and elsewhere, and have also been recorded from Zones I and II at Kentmere (Round 1957).

Gomphocymbella ancyli, which according to Hustedt (1930) and Cleve-Euler (1951) is an indicator of the Ancylus stage and earlier horizons in the Baltic, has not previously been recorded from Late-glacial deposits in the British Isles. Some other indicators of the Ancylus flora are given in figure 1 of Florin (1946) but only a few of these occur in the present samples, though more have been recorded from similar zones of Kentmere and Esthwaite Water. *G. ancyli* is also recorded as a present-day form only in alpine lakes (Hustedt 1930, 1943); its presence in such habitats today and in habitats that may have been similar in the Late-glacial period suggests that this may be one of the few diatoms which are useful indicators of glacial conditions. Hustedt (1948) considered that this species was one of the few stenothermal cold water forms; its present day distribution in central Alpine lakes of alkaline reaction is further confirmation of the base rich status of the Roddans Port Late-glacial sediments. Hustedt (1922) also comments on its ecology in the Lunzer Untersee where it is found in shallow water of the littoral zone on sediments near underwater springs; here the upwelling water maintains a constant low temperature throughout the year. In samples from Inter-glacial sediments in Denmark, Foged (1954) recorded many of the diatoms listed in table 4 but there the two indicator species, *Cyclotella antiqua* and *Gomphocymbella ancyli*, were absent, but others such as *Melosira arenaria*, *Stephanodiscus niagarae*, *Navicula hasta* and *N. interglacialis*, were present. A somewhat similar diatom assemblage was recorded from inter-glacial sediments at Oberohe in the Lüneburger Heide in north Germany (Hustedt 1954), although here as in Denmark a few so-called Nordic species were recorded, e.g. *Tetracyclus emarginatus*; these are absent from Roddans Port. However, comparison of the diatom lists suggests that the ecological conditions were similar in both the Inter-glacial and Late-glacial periods.

Table 4. The distribution of diatoms in the Roddans Port samples

Presence is indicated by + and in the three richest samples, 100 fustules were also counted. Sample 2980–82 was devoid of diatoms.

	samples				
diatoms	2962/63	2967/68	2969/70	2982/83	2991
Cyclotella comta	.	+	.	1	3
C. meneghiniana	.	+	.	+	+
C. kutzingiana	.	.	.	11	.
C. antiqua	.	+	.	+	+
Fragilaria intermidia	.	.	.	.	+
F. construens	.	6	.	.	+
F. construens v. *venter*	.	.	.	8	+
F. construens v. *binodis*	.	18	.	.	15
F. brevistriata	.	.	.	+	+
F. pinnata	.	.	.	+	.
Synedra ulna	.	.	.	.	+
Eunotia arcus	.	+	.	+	+
E. arcus v. *fallax*	.	.	.	.	1
Cocconeis placentula	.	12	+	+	14
Achnanthes microcephala	.	.	.	+	+
A. trinodis	.	.	.	+	.
A. flexella	.	.	.	+	+
Caloneis silicula	.	.	.	+	.
C. latiuscula	.	.	.	+	.
Mastogloia lanceolata	.	+	.	+	+
M. smithii v. *lacustris*	.	.	.	9	1
Anomoeoneis exilis	.	.	.	+	+
A. serians v. *brachysira*	.	.	.	1	+
A. serians v. *brachysira* f. *thermalis*	.	.	.	+	.
A. sphaerophora	.	+	.	.	.
Navicula bacilliformis	.	.	.	.	+
N. radiosa	.	.	.	9	1
N. cryptocephala	.	.	.	+	.
N. cincta	.	.	.	.	+
N. reinhardtii	.	.	.	+	.
N. oblonga	.	+	.	2	+
Diploneis ovalis	.	.	.	3	.
D. interrupta	.	1	.	.	.
D. domblitensis v. *subconstricta*	.	+	.	+	.
Amphora ovalis	.	+	.	.	+
A. ovalis v. *pediculus*	.	.	.	.	+
Pinnularia mesolepta	.	.	.	.	+
P. maior	.	.	.	.	+
Cymbella microcephala	.	.	.	6	+
C. leptoceros	.	.	.	+	+
C. aequalis	.	.	.	2	+
C. cesatii	.	.	.	+	2
C. cistula	.	.	.	.	+
C. affinis	.	.	.	1	+
C. parva	.	.	.	+	.
C. ventricosa	.	.	.	6	2
C. ehrenbergii	.	+	.	+	+
C. prostrata	.	.	.	1	+
C. sinuata	.	+	.	.	.
Gomphonema intricatum	.	+	.	4	8
G. gracile	.	.	.	.	+
G. acuminatum v. *coronata*	.	.	.	.	+
G. constrictum	.	.	.	.	+
Gomphocymbella ancyli	.	.	.	.	+
Denticula tenuis	.	.	.	+	+
Epithemia sorex	.	+ }63	+	+ }29	+ }49
E. turgida	.	.	.	+	.
E. muelleri	.	.	.	.	+
E. zebra v. *porcellus*	+	+	+	.	+
E. zebra v. *saxonica*	+	+	+	+	+
Rhopalodia paralella	.	.	.	.	4
R. gibba	.	.	+	+	.
Nitzschia denticula	.	+	+	+	+
N. sinuata	.	.	.	.	+
N. sinuata v. *tabellaria*	.	.	.	+	.
N. angustata v. *acuta*	.	.	.	3	.
N. amphibia	.	.	.	+	.

Summary

The algal remains in Late-glacial sediments from Roddans Port, N. Ireland, have been identified and their abundance estimated. The occurrence of indicator species and, in particular, of the uncommon taxon *Gomphocymbella ancyli* is noted. The flora has been compared with recent algal floras in Ireland and with Late-glacial and Inter-glacial sediments elsewhere. There is a preponderance of species from the littoral zone and from base-rich habitats.

The author wishes to thank Dr M. E. S. Morrison for making the material available and for providing information about the region and the pollen sequence. Dr A. J. Brook kindly checked the desmid identifications and made some helpful suggestions.

Appendix IV. Radiocarbon dates from Roddans Port, Northern Ireland

By H. Godwin, F.R.S., and E. H. Willis
University Sub-department of Quaternary Research, Botany School, Cambridge

When preliminary work on the Roddans Port site had shown its considerable promise for research into Late-glacial and early Post-glacial conditions, Dr Morrison boxed up and transferred to the Botany Department at Queen's University, Belfast, a substantial monolith through the deposits. During 1957 and 1958 careful pollen-analyses were made at close intervals from samples throughout the monolith, and during Easter 1958 one of us (H.G.) visited Belfast, and with the pollen diagrams at hand, and in consultation with Dr Morrison and Dr A. G. Smith, the horizons were decided upon from which samples were secured for radiocarbon dating. Each sample consisted of a slice sometimes 1 cm and sometimes 2 cm thick, through the monolith at the selected level. They were labelled and sealed in Polythene bags and conveyed to the Cambridge radiocarbon dating laboratory, where they were dried and where the assays were made by the other author (E.H.W.) in the first half of 1963.

The results are given below in tabular form and in stratigraphic order from below upwards: the numbers prefixed by 'R' in each case permit reference of the radiocarbon sample to the level in the pollen sequence (figures 5 and 6). A separate diagram (figure 11) has been constructed to display the results of the age determinations in relation to the pollen zonation and stratigraphy.

		years B.P.
Q-360	(R 2962 + 2963) grey clay with some organic content, near top of Zone I, *Salix* pollen maximum	12110 ± 150
Q-358	(R 2967 + 2968) bottom 2 cm of compressed detritus mud over grey clay, top of pollen-zone I, rise of *Juniperus* and *Empetrum* curves	11950 ± 150
Q-359	(R 2969 + 2970) organic mud at base of Zone II	11845 ± 150 11830 ± 150

		years B.P.
Q-361	(R 2980+2981) organic mud in lower half of Zone II	12090±150
Q-362	(R 2982+2983) organic mud, immediately above Q-361	11390±150
Q-363	(R 2991) organic mud, middle of Zone II, decrease of *Juniperus* curve	11450±150
Q-364	(R 3004) organic mud, top of Zone II, rise of Cruciferae and Caryophyllaceae	11770±150
Q-365	(R 3006) transition of organic mud to solifluxion clay at Zone II/III boundary	11480±150
Q-369	(R 2944) transition from solifluxion clay to organic mud, base of Morrison's transition Zone III/IV	11660±170 11370±170
Q-370	(R 2945+2946) basal part of organic mud over solifluxion clay, base of Morrison's transition Zone III/IV	10070±150
Q-371	(R 2954) *Phragmites* peat, base of Morrison's Zone IV, rise of *Salix* and *Juniperus* curves	10130±170
Q-368	(R 2955) *Phragmites* peat, middle of Zone IV, fall of *Betula* and rise of *Gramineae* curves	10210±150
Q-366	(R 13) *Phragmites* peat, Zone IV/V transition, beginning of *Corylus* curve	9430±150
Q-367	(R 10) *Phragmites* peat, Zone V/VI transition, *Ulmus* and *Quercus* curves begin	9090±150

It has to be noted that Dr Morrison chose boundaries for the Late-glacial pollen zones which do not correspond altogether with the main lithological transitions. At the Zone I/II transition this is only a matter of 3 cm difference in level, but at the Zone III/IV transition Morrison has interjected a transition zone 7 cm thick into the usual sequence, its base corresponding with the lithological transition, and its top with the pollen transition taken to mark the onset of Zone IV. It will be seen that in the event the errors of the radiocarbon assay are too large for the dating to be applied to distinctions of this fineness.

It was hoped that the radiocarbon dates of sample secured throughout the Roddans Port series of deposits would provide evidence of the date and length of the mild Allerød period to set against the relatively few determinations until now available for this episode elsewhere in north-west Europe, results jointly suggesting an age between 12000 and 10800 B.P. In the event this objective has only partially been achieved.

The group of dates (Q-360, Q-358, Q-359) that cover the clay/mud boundary and the closely approximating pollen-zone boundary I/II are very close to 12000 B.P. (figure 11), a result agreeing fully with determinations from Ruds Vedby, Wallensen and Meiendorf on the continental mainland and from Lunds in this country (Godwin & Willis 1959).

The dates of Q-362 (11390±150) and Q-363 (11450±150) from the middle of Zone II are conformable with dates from other sites, but that for Q-361 (12090±150) is older than one would have expected and is out of conformity with samples above and below it.

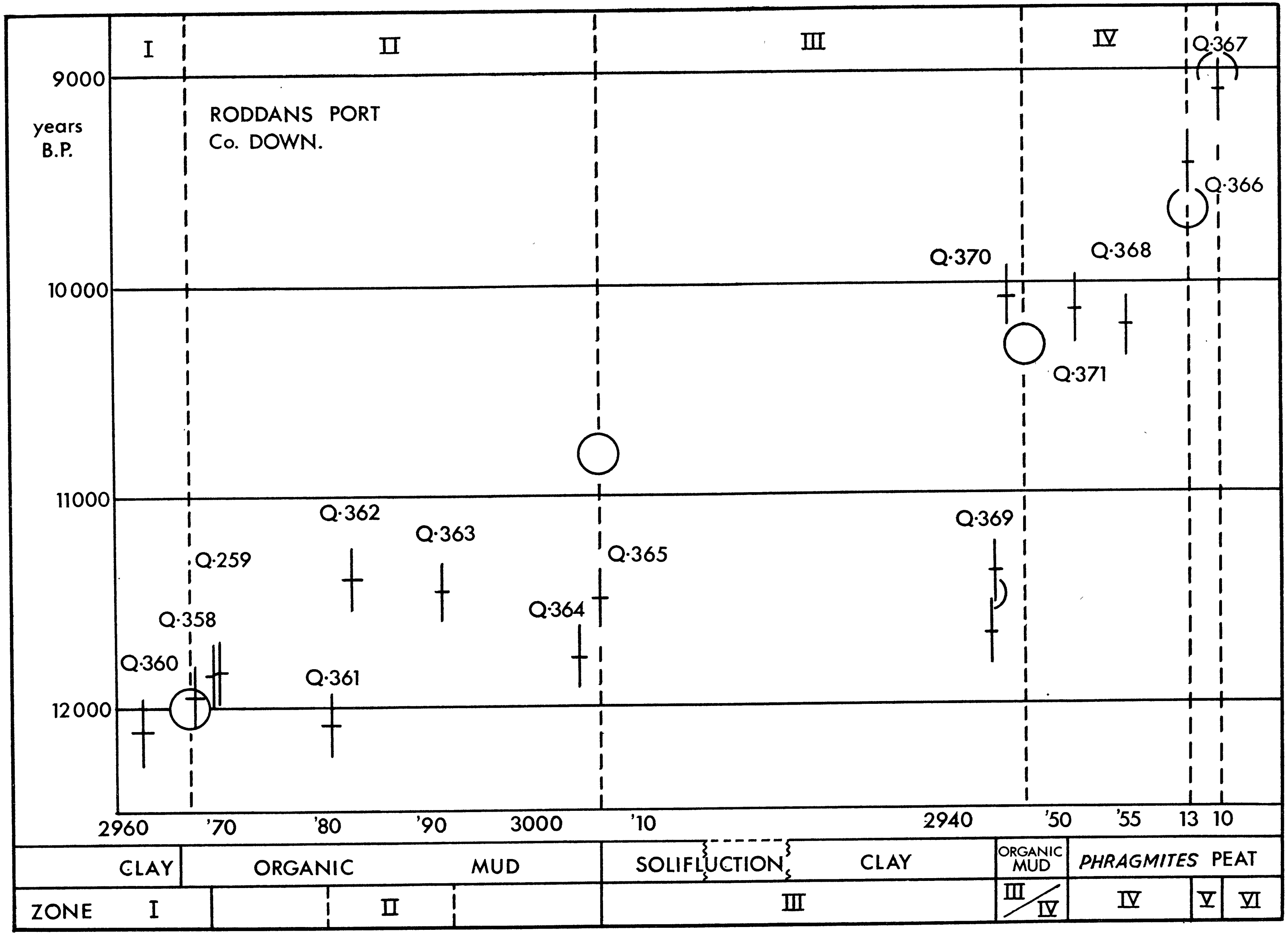


Figure 11. Radiocarbon ages of Late-glacial and Post-glacial samples from Roddans Port, Northern Ireland. Along the horizontal axis are shown Morrison's sampling index numbers, stratigraphy, and Morrison's pollen zone boundaries. The horizontal line for each dating represents the thickness of the sample slice (1 or 2 cm): the vertical line is the probable error (1 s.d.) of the count. The large open circles give the values to be expected on present knowledge of other British sites for the appropriate zone boundaries.

The samples Q-364 (11770 ± 150) and Q-365 (11480 ± 150) at the top of Zone II appear to be older than the samples below them in the middle of that zone. This makes them untrustworthy as index to the age of the concluding stages of Zone II, and possibly reflects the incorporation of inactive carbon in the upper layers of the organic mud. This suggestion is borne out by the presence of *Chara* and freshwater Mollusca, and by the positive reaction of the mud to hydrochloric acid. The mud samples were leached by acid before combustion so as to remove carbonate, but the hard-water error is due to assimilation by submerged water-plants of carbon from bicarbonate in solution at the time of formation of the deposits. Sometimes lake muds are free from this error, as apparently in the case of Ruds Vedby, but in other instances an error as large as 2000 years can be demonstrated (Godwin 1951; Deevey, Gross, Hutchinson & Kraybill 1954). It might be reasonable to conjecture that in this instance the muds first laid down in the pool between the drumlins would have been fairly free from dissolved bicarbonate, whilst the upper layers would have been progressively enriched in carbonate by continued drainage into the basin.

It will be apparent that the results for the Zone II samples (Q-358 to 365) as a whole fall within the accepted age range for the Allerød period in Britain and north-western Europe, that they confirm the results hitherto obtained as to the date of the commencement of the period, but do not suffice to date its conclusion.

Samples Q-369 and 370 were taken from the transition at the surface of the upper solifluxion clay to organic mud, and at the bottom of Morrison's transition III/IV zone. They must generally represent the Late-glacial/Post-glacial boundary, the age of which is taken to be about 10300 B.P. For no presently explicable reason our two age determinations (Q-369 $\left\{\begin{matrix}11370\pm170\\11660\pm170\end{matrix}\right\}$ B.P. and Q-370, 10070 ± 150 B.P.) although bracketing this date, are very much out of agreement with each other, despite repeated determinations.

Samples Q-366, 367, 368 and 371 are from *Phragmites* peat, material not susceptible to the hard-water error. Their particular importance lies in their relation to the Post-glacial pollen-zone boundaries, and the light they may shed upon the synchroneity or lack of it of such boundaries between different regions.

The most obvious comparison lies with the zone-boundary dates from Scaleby Moss, near Carlisle, some 110 miles eastwards on the English mainland, and at similar low elevation (Godwin *et al.* 1957). Leaving aside the two organic mud samples, Q-370 and 369, already referred to and of which Q-369 is particularly suspect, the agreement between the zone-boundary ages at the two sites is satisfactory. How far these ages for the zone-boundaries will be consistent at sites further apart is a matter for further research (Godwin 1960).

	Scaleby Moss		Roddans Port	
Zone V/VI transition	Q-161	9009 ± 194	Q-367	9090 ± 150
	Q-162	8816 ± 192		
Zone IV/V transition	Q-155	9747 ± 183	Q-366	9430 ± 150
	Q-154	9564 ± 209		
mid-Zone IV	.		Q-368	10210 ± 150
early Zone IV	.		Q-371	10130 ± 170
Zone III/IV transition	Q-152	10160 ± 193	Q-370	10070 ± 150
	Q-151	10264 ± *c.* 350	Q-369	$\left\{\begin{matrix}11660\pm170\\11370\pm170\end{matrix}\right.$
	Q-153	10325 ± 215		

Considering the fourteen samples from the site, ten have given radiocarbon dates conforming to expectation, but four (Q-361, 364, 365 and 369) are questionable. What is specially disquieting is that these four show little in common (except that they are from organic muds), come from levels of quite different ages and stratigraphic situation and in two cases the results differ greatly from those of immediately adjacent samples. If one attributes the error to the 'hard water effect', one must acknowledge that it still has to be associated with a most sharply erratic distribution of affected samples among the unaffected.

The authors wish to thank all those who helped to make these investigations possible: Dr F. W. Anderson, Dr S. P. Dance, Professor E. E. Evans, Professor J. Heslop-Harrison, Professor M. Jope, Mrs Margaret Jope, Dr V. B. Proudfoot, Dr F. E. Round, Dr A. G. Smith; Professor H. Godwin, F.R.S. and Dr E. H. Willis not only gave much invaluable advice, but also carried out the ^{14}C dating of samples. Acknowledgement is also due to the Nuffield Foundation and to the Queen's University of Belfast Research Committee for providing generous funds.

References

Blackburn, K. B. 1952 The dating of a deposit containing an elk skeleton found at Neasham, near Darlington. *New Phyt.* 51, 364.

Cleve-Euler, A. 1951 Die Diatomeen von Schweden und Finnland. Teil I. *K. Svenska VetenskAkad. Handl.* (4 Ser.) **2**, no. 1.

Dance, S. P. 1957 Notes on the *Pisidium* fauna of the Pevensey Levels district with special reference to *P. pseudosphaerium* Favre. *J. Conch.* **24**, 195.

Dance, S. P. 1961 On the genus *Pisidium* at Upton Warren. *Phil. Trans.* B, **244**, 418.

Deevey, E. S., Gross, M. S., Hutchinson, G. E. & Kraybill, H. L. 1954 The natural radiocarbon contents of materials from hard water lakes. *Proc. Nat. Acad. Sci., Wash.*, **40**, 285.

Dixon, F. E. 1949 Irish mean sea-level. *Sci. Proc. Roy. Dublin Soc.* **25**, (NS), 1.

Donner, J. 1957 The geology and vegetation of Late-glacial retreat stages in Scotland. *Trans. Roy. Soc. Edinb.* **57**, 221.

Donner, J. J. 1959 The Late- and Post-glacial raised beaches in Scotland. *Ann. Acad. Sci. Fenn.* **53**, 1.

Donner, J. J. 1963 The Late- and Post-glacial raised beaches in Scotland. II. *Ann. Acad. Sci. Fenn.* **68**, 1.

Fairbridge, R. W. 1961 Eustatic changes in sea-level. *Physics and Chemistry of the Earth*, **4**, 99.

Firbas, F. 1950 The Late-glacial vegetation of central Europe. *New Phyt.* **49**, 163.

Florin, M. B. 1946 Clypeusfloran i postglaciala fernsjölagerföljder i östra mellansverige. *Geol. Fören. Förhandl.* **68**, 429.

Foged, N. 1954 En interglacial diatomejordaflejring i Ost-Fyn. *Medd. dansk. geol. Foren.* 12, 541.

Godwin, H. 1951 Comments on radiocarbon dating for samples from the British Isles. *Amer. J. Sci.* **249**, 301.

Godwin, H. 1956 *The History of the British flora.* Cambridge University Press.

Godwin, H. 1960 Radiocarbon dating and Quaternary history in Britain. *Proc. Roy Soc.* B, **153**, 287.

Godwin, H., Walker, D. & Willis, E. H. 1957 Radiocarbon dating and post-glacial vegetational history: Scaleby Moss. *Proc. Roy Soc.* B, **147**, 352.

Godwin, H. & Willis, E. H. 1959 Radiocarbon dating of the Late-glacial Period in Britain. *Proc. Roy. Soc.* B, **150**, 199.

Godwin, H. & Willis, E. H. 1962 Cambridge University natural radiocarbon measurements V. *Radiocarbon*, **4**, 57.

Hulten, E. 1958 The Amphi-Atlantic plants. *K. Svenska VetenskAkad. Handl.* (4 ser.) **7**, no. 1.

Husted, Fr. 1922 Die Bacillariophyceen Vegetation des Lunzer Seengebiets. *Int. Rev. Hydrobiol.* **10**, 40.

Husted, Fr. 1930 Bacillariophyceae in Rabenhorst, *Die Kiesalgen Deutschlands, Österreichs und der Schweiz.*

Husted, Fr. 1948 Die Diatomeenflora diluvialer Sedimente bei dem Dorfe Gaj bei Konin im Warthegebiet. *Schweiz. Z. Hydrol.* **11**, 181.

Husted, Fr. 1943 Die Diatomeen flora einiger Hochgebirgseen der Landschaft Davos in der Schweizer Alpen. *Int. Rev. Hydrobiol.* **43**, 225.

Husted, Fr. 1954 Die Diatomeenflora des Interglazials von Oberohe in der Luneburger Heide. *Abh. naturw. Ver. Bremen*, **33**, 431.

Iversen, J. 1954 The Late-glacial flora of Denmark and its relation to climate and soil. *Danm. geol. Unders.* II R, Nr. 80, 87.

Mitchell, G. F. 1953 Further identifications of macroscopic plant fossils from Irish Quaternary deposits, especially from a late-glacial deposit at Mapastown, Co. Lough. *Proc. Roy. Irish Acad.* **53**B, 12, 225.

Mitchell, G. F. 1954 The Late-glacial flora of Ireland. *Danm. geol. Unders.* II R, Nr. 80, 73.

Mitchell, G. F. 1956 An early kitchen-midden at Sutton, Co. Dublin. *J. Roy. Soc. Antiq. Ireland*, **86**, 1.

Mitchell, G. F. 1957 Late-glacial finds of *Lepidurus arcticus* (Pallas) in the British Isles. *Nature, Lond.* **180**, 513.

Mitchell, G. F. 1965 In correspondence with N. Stephens.

Morrison, M. E. S. 1958 Palynological and ecological studies in northern Irish bog sites. Ph.D. thesis. Belfast.

Morrison, M. E. S. 1959 *Lepidurus arcticus* in the Irish Late-glacial. *Nature, Lond.* **184**, 739.

Morrison, M. E. S. 1961 The palynology of Ringneill Quay, a new Mesolithic site in Co. Down, Northern Ireland. *Proc. Roy. Irish Acad.* **61** C, 6, 171.

Morrison, M. E. S. & Stephens, N. 1960 Stratigraphy and pollen analysis of the beach deposits at Ballyhalbert, Co. Down, Northern Ireland. *New Phyt.* **59**, 153.

Pennington, W. 1943 Lake sediments; the bottom deposits of the north basin of Windermere, with special reference to the diatom succession. *New Phyt.* **42**, 1.

Pennington, W. 1947 Lake sediments; pollen diagrams from the bottom deposits of the north basin of Windermere. *Phil. Trans.* B, **233**, 137.

Praeger, R. L. 1897 Post-Tertiary beds at Ballyhalbert, Co. Down. *Irish Nat.* **6**, 306.

Ross, R. 1952 Diatoms from Neasham Late-glacial deposits. *New Phyt.* **51**, 378.

Round, F. E. 1953 An investigation of two benthic algal communities in Malham Tarn, Yorkshire, *J. Ecol.* **41**, 174.

Round, F. E. 1956 A note on some *Pediastrum* species found in an immediate post-glacial peat deposit. *Naturalist*, no. 858, 85.

Round, F. E. 1957 The Late-glacial and Post-glacial diatom succession in the Kentmere valley deposit. *New Phyt.* **56**, 98.

Round, F. E. 1958 Observations on the diatom flora of Braunton Burrows, N. Devon. *Hydrobiologia*, **11**, 119.

Round, F. E. 1959 A comparative survey of the epipelic diatom flora of some Irish loughs. *Proc. Roy. Irish Acad.* **60** B, 193.

Round, F. E. 1961 The diatoms of a core from Esthwaite water. *New Phyt.* **60**, 43.

Round, F. E. & Brook, A. J. 1959 The phytoplankton of some Irish loughs and an assessment of their trophic status. *Proc. Roy. Irish Acad.* **60** B, 167.

Smith, A. 1961 Cannons Lough, Kilrea, Co. Derry: stratigraphy and pollen analysis. *Proc. Roy. Irish Acad.* **61** B, 369.

Singh, G. 1963 Pollen analysis of a deposit at Roddans Port, Co. Down, N. Ireland, bearing reindeer antler fragments. *Grana Palynologica*, **4**, 466.

Stephens, N. 1957 Some observations on the 'Interglacial' platform and the early post-glacial raised beach on the north-east coast of Ireland. *Proc. Roy. Irish Acad.* **58** B, 129.

Stephens, N. 1963 Late-glacial sea-levels in North-East Ireland. *Irish Geog.* **4**, 345–359.

Stephens, N. & Collins, A. E. P. 1960 The Quaternary deposits at Ringneill Quay and Ardmillan, Co. Down. *Proc. Roy. Irish Acad.* **61** C, 41.

Stephens, N. & Farrington, A. 1964 Pleistocene geomorphology in Ireland. *Field studies in the British Isles.* Edited by J. A. Steers. Nelson.

Stephens, N. & Synge, F. M. 1965 *a* Late-Pleistocene shorelines and drift limits in North Donegal. *Proc. Roy. Irish Acad.* (In press).

Stephens, N. & Synge, F. M. 1965 *b* Pleistocene shorelines. *Geomorphological essays*; edited by G. H. Drury. (In press).

Stewart, S. A. 1879–80 The Mollusca of the boulder clay of the north-east of Ireland. *Proc. Belfast. Nat. F. C. Appendix V*, pp. 165–176.

Watts, W. A. 1963 Late-glacial pollen zones in western Ireland. *Irish Geog.* **4**, 367–376.

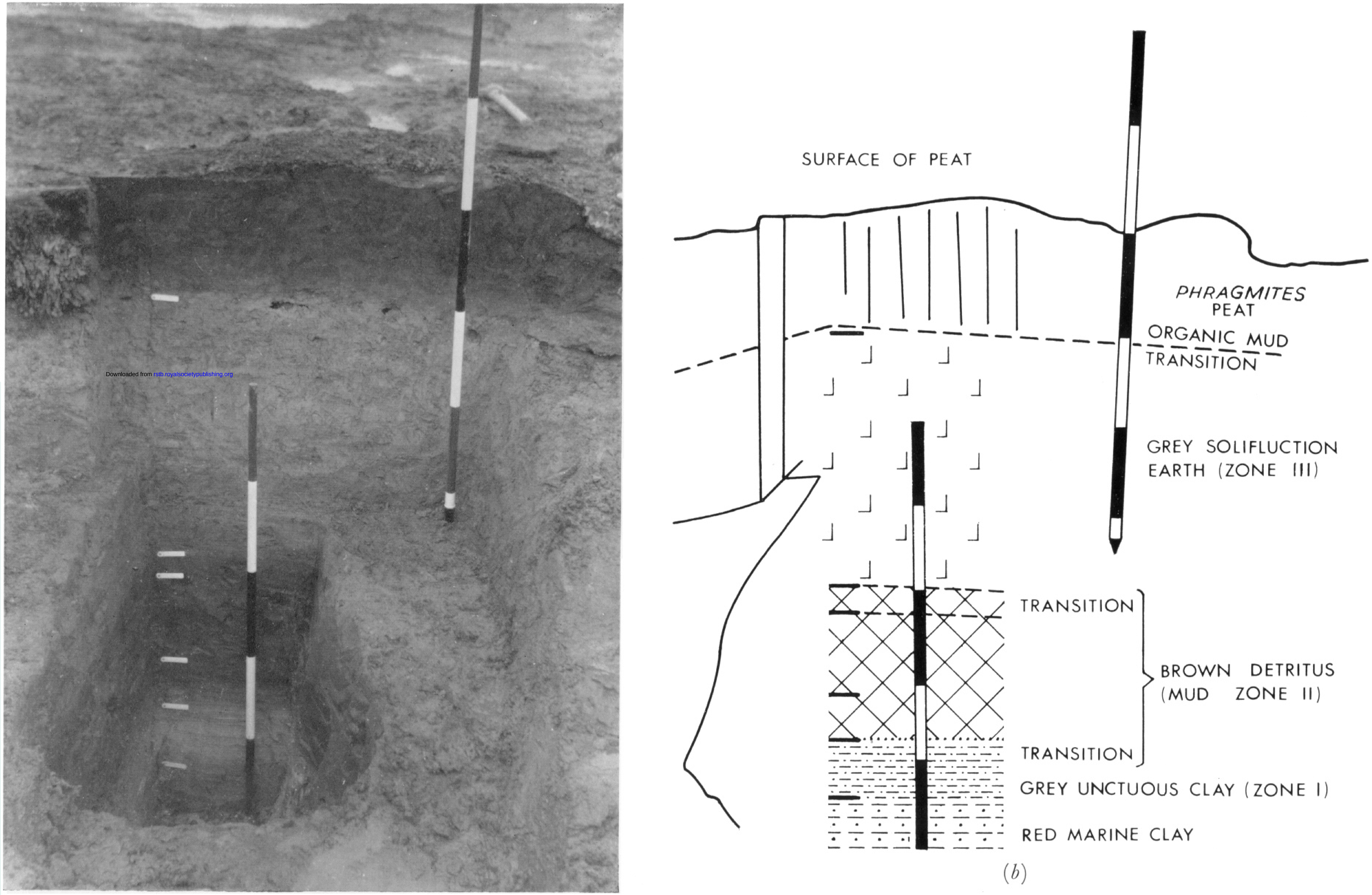
Welten, M. 1957 Über das glaziale und spatzglaziale Vorkommen von *Ephedra* am nordwestlichen Alpenrand. *Ber. Schweiz. Bot. Ges.* **67**, 33.

Wright, J. 1902–03 The micro-fauna of the boulder clay with some remarks on the movement of glaciers. *Proc. Belfast Nat. Hist. Soc.*, pp. 47–50.

FIGURE 12. General view taken from the coast road of the site at Roddans Port between high and low-water marks. The line of section (figure 3 and 4) is indicated by the surveying poles and level tripod, and excavation is in progress at point 3.

(*a*) (*b*)

FIGURE 13. The section excavated at point 1 on the line of section (figure 3 and 4).



(*a*)

(*b*)

FIGURE 14. The section excavated at point 3 on the line of section (figure 3 and 4).