FORAMINIFERA IN HOLOCENE MARSH CYCLES AT BORTH, CARDIGANSHIRE (WALES)

CONTRIBUTION—CARDIGAN BAY RESEARCH PROJECT

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ABSTRACT. The exposed Holocene deposits at Borth include two well-marked marsh cycles. The dominant foraminifera in these sediments are marsh and estuarine forms such as *Jadammina macrescens*, *Protelphidium depressulum*, *Elphidium orbiculare*, *Elphidium excavatum*, and *Ammonia beccarii* var. *batavus*. The distribution of these species reflects the different stages of the cycles and thus the late post-glacial history of Borth Bog.

BORTH Bog and the tidal flats and estuary of the Dovey valley are situated in the north-west of Cardiganshire (text-fig. 1). They form a roughly triangular area of low-lying marshy land and open sand flats extending from Borth in the south to Aberdovey in the north, with Glandovey at the eastern apex of the triangle (O.S. 1″ Map No. 127, grid ref. 92/63). The surrounding hills are formed of lower Palaeozoic grits and mudstones which have been sharply folded and faulted on a NNE. to SSW. strike. It is noteworthy from the ecologic viewpoint that limestones are absent in the drainage area and that mineralized veins with lead and zinc occur. The markedly straight northern shore of the estuary probably coincides with the Llyfnant fault of Jones and Pugh (1935). During the last Pleistocene glaciation the area was occupied by outflow ice from the Aran Mawddwy volcanic range and afterwards, during the Holocene, the open valley became infilled with estuarine and salt marsh sediments and peat.

The full stratigraphic details of this Holocene sequence are unknown, the unconsolidated deposits being for the most part of indeterminate thickness. Nevertheless, two records of borings given by Yapp, Johns and Jones (1916, 1917) place the solid Palaeozoic basement at 80 to 90 feet below the surface at Glandovey and 150 feet below the surface at Dovey Junction. In this early work may also be found details of the geology and of the plant communities recognizable on the present marshes and raised bog.

On the foreshore, to the west of Ynyslas and Borth, a submerged fossil forest is seen at low water, resting on blue silty clays, which are the oldest Holocene sediments exposed. These *Scrobicularia* clays are laminated deposits, pale blue to grey in colour, with occasional brown staining due to bacterial action, a feature which has been noted in the present marshes by Chapman (1960). There is considerable included silt, as well as sand at some horizons, and concentrations of plant remains occur at certain sites immediately beneath the overlying peats. The clays contain a poorly developed molluscan fauna, dominated by *Scrobicularia piperata* Gmelin, as well as extremely rich foraminiferal assemblages. These deposits appear to be equivalent to the Downholland silts (also named Formby and Leasowe Marine Beds) of Lancashire and Cheshire (Neaverson 1947).

The clays disappear eastwards beneath the fossil forest and the succeeding peats of Borth Bog. Godwin (1943) ran a line of borings from north to south across the region,

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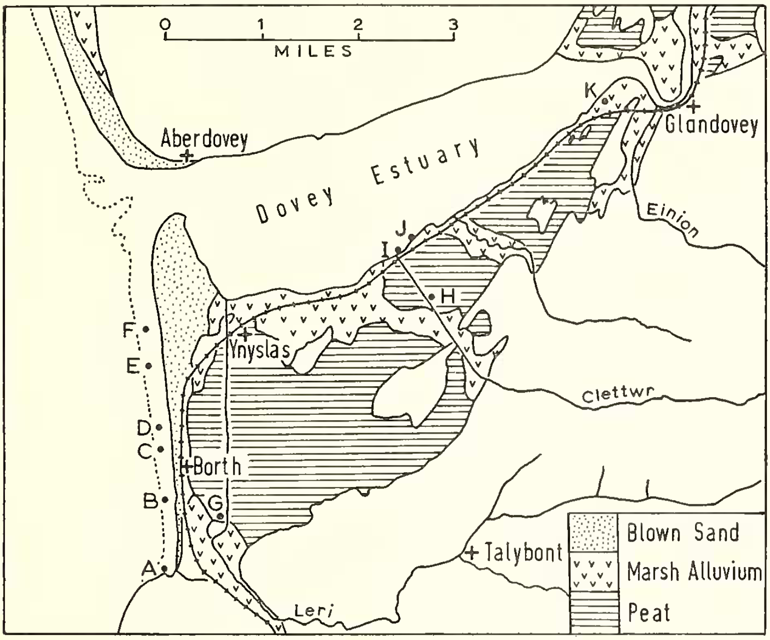
as well as a line extending from east to west linking the first section to the beach exposures of the Ynyslas foreshore. They revealed that the fossil forest and the succeeding raised bog rest upon a flat surface of *Scrobicularia* clay at minus 2 feet O.D. The sequence of pollen has been studied by Godwin and Newton (1938) and Godwin (1943), and evidence found for a late marine transgression bringing in a 'clay intercalation' from the Dovey Estuary, extending southwards into Borth Bog below the surface peats. To the west, the eroded seaward edge of the forest peats has now been over-ridden by a prominent, north to south, pebble storm beach, which is succeeded at its northern end by the blown sands of Ynyslas. To the north, the *Scrobicularia* clays and later peats are truncated by, or disappear beneath, the fine sands and muddy silts of the estuary and marine marsh of the river Dovey.

Absolute age determination and pollen analyses give what appears to be a reasonably accurate date for the formation of these Holocene deposits at Borth. Radiocarbon dating of the fossil forest peat layer, which immediately overlies the *Scrobicularia* clays, places its formation at 4000 B.C. (Godwin and Willis 1961). The pollen content of the immediately overlying peats shows that the forest layer falls within British Quaternary florizone VIIA and thus accumulated during the early Atlantic climatic phase. Pollen dating also shows that the late marine transgression occurred during the early sub-Atlantic phase, florizone VIII, and is thus comparable to the Romano-British transgression of the Fens (Godwin 1943), which began about 500 B.C. and apparently reached a maximum before 200 A.D. This represents the last substantial rise in sea level around the British Isles and initiated a cycle of marsh development in the Dovey area which proceeded until freshwater fen was again established. This stage was apparently reached some hundreds of years ago and since then the area has been relatively stable with marsh growth balancing channel cutting and meander migration. The idea that the formation of Borth Bog required some 1,500 years is supported by accretion studies (Richards 1934; Chapman 1960). These suggest that about 550 years are required for the development of mud flats into high marsh by vertical accretion. Even though sedimentation rates may have differed in the past a long period (historically) is indicated for the vertical and lateral accretion that accompanied the latest marsh cycle.

SAMPLE MATERIAL

During the severe storms of October and November 1960, the foreshore at Borth and Ynyslas was stripped of its superficial cover of unconsolidated sands, to give a maximum exposure of the fossil forest layer and the underlying *Scrobicularia* clays. It enabled six one-inch diameter auger borings, varying in length from 6 to 12 feet, to be made along a traverse extending from north to south across the outcrop (text-fig. 1). Excepting Bore A, in which basement rock was reached at minus 10 feet O.D., the base of the clay was nowhere penetrated. Similar borings were made through the deposits of the latest marsh cycle, one adjacent to the river Leri, one adjacent to the river Clettwr, and three from the mudflats of the Dovey Estuary.

Samples were collected at 1 foot intervals, and labelled in progressive order down each bore. These samples were examined for foraminiferal content. The relative homogeneity of the sediments made selection of a standard weight preferable to that of standard volumes (Smith 1954). Consequently 50 grams of dried material from each sample were weighed, disintegrated by boiling, and then dried once more. The sediment was then passed through a nest of sieves and the total foraminiferal fauna picked from mesh sizes 500 microns, 251 microns and 152 microns. Foraminifera remaining in the sediment on the 74 micron mesh sieve were retrieved by means of simple carbon tetrachloride concentration. The species present were identified and the total numbers of specimens found within each 50-gram sample were plotted stratigraphically (text-figs. 2 and 3). Very large residues were split by the standard quartile technique of Twenhofel and Tyler (1941).



TEXT-FIG. 1. Map of Dovey Estuary and Borth Bog, with geology after Yapp, Johns and Jones (1916, 1917), showing location of boreholes. Land above the 50-foot contour and the open sand flats of the estuary left blank.

STRATIGRAPHICAL SEQUENCE OF FORAMINIFERA

Only the uppermost part of the Holocene sequence (from florizone VIc onwards) is exposed. These deposits have been studied in detail. The populations of foraminifera include:

iii. The present-day association in the Dovey Estuary. (The study of these forms is still continuing and the results will be published separately.)

ii. The foraminifera in the deposits of the latest marsh cycle.

i. The foraminifera in the uppermost *Scrobicularia* clays.

These associations are almost identical, with the same species dominant in each. There are, however, some minor differences.

Species found only in the *Scrobicularia* clays include:

Asterigerina sp.
Biorbulina bilobata
Bolivina malovensis
Cassidulinoides tenuis
Elphidium goesi
Patellina corrugata
Triloculina brongniartii

Species found only in the deposits of the latest marsh cycle include:

Acervulina inhaerens
Alveolophragmium jeffreysi
Bulimina mexicana
Dentalina neugeboreni
Guttulina lactea
Hyalinea balthica
Lenticulina suborbicularis
Oolina borealis
Protoschista findens
Pyrgo williamsoni
Spiroloculina subimpressa
Spirophthalmidium acutimargo
Textularia conica
Triloculina trihedra
Verneuilina media

Apart from this slight qualitative difference, which may be due to collection failure since all these species are rare, the total number of specimens is also higher in many of the samples from the deposits of the latest marsh cycle. This is related to distance from the present estuary.

Within these Holocene deposits as a whole, 25 species of foraminifera occur in considerable numbers. The dominant species, which form a very abundant population element at most horizons (often more than 200 specimens per sample and more than 500 in some), are:

Ammonia beccarii var. *batavus*
Elphidium excavatum
Elphidium orbiculare
Protelphidium depressulum

Occurring more rarely, but exclusively dominant at certain horizons, are *Jadammina macrescens* and *Trochammina inflata*.

Species which form a subsidiary population element at most horizons (often more than 20 specimens per sample and more than 50 in some) are:

Angulogerina angulosa var.
Buccella frigida
Bulimina aculeata var.
B. affinis
B. gibba
Cibicides lobatulus
Discorbis bradyi
D. williamsoni
Elphidium bartletti
E. crispum
E. discoidale
E. incertum
E. macellum
E. margaritaceum
Heminwayina manilla
Oolina williamsoni
Protelphidium barleeanum
P. pompilioides
Quinqueloculina seminulum

(A full species list is given at the end of the paper)

ECOLOGICAL SIGNIFICANCE OF THE FAUNA

Certain species are critical in the recognition of brackish water environments:

Trochammina inflata; see Brady 1870, Hedberg 1934, Phleger and Walton 1950, Van Voorthuysen 1951.

Jadammina macrescens; see Bartenstein and Brand 1938, Brady 1870, Van Voorthuysen 1951.

Miliammina fusca; see Hedberg 1934, Phleger and Walton 1950.
Protelphidium depressulum; see Van Voorthuysen 1947, 1951.
Ammonia beccarii; see Bandy 1953, Hedberg 1934, Le Calvez and Le Calvez 1951, Van Voorthuysen 1947, 1951.

When either one or more of these species are dominant in a fossil assemblage, brackish waters are considered to have existed. These are the species which live in the present estuary and which also dominate the sediments at Borth, and reflect, by their distribution, the gradually changing environmental conditions of the marsh cycles.

DETAILED ANALYSIS OF FAUNA FROM BORES

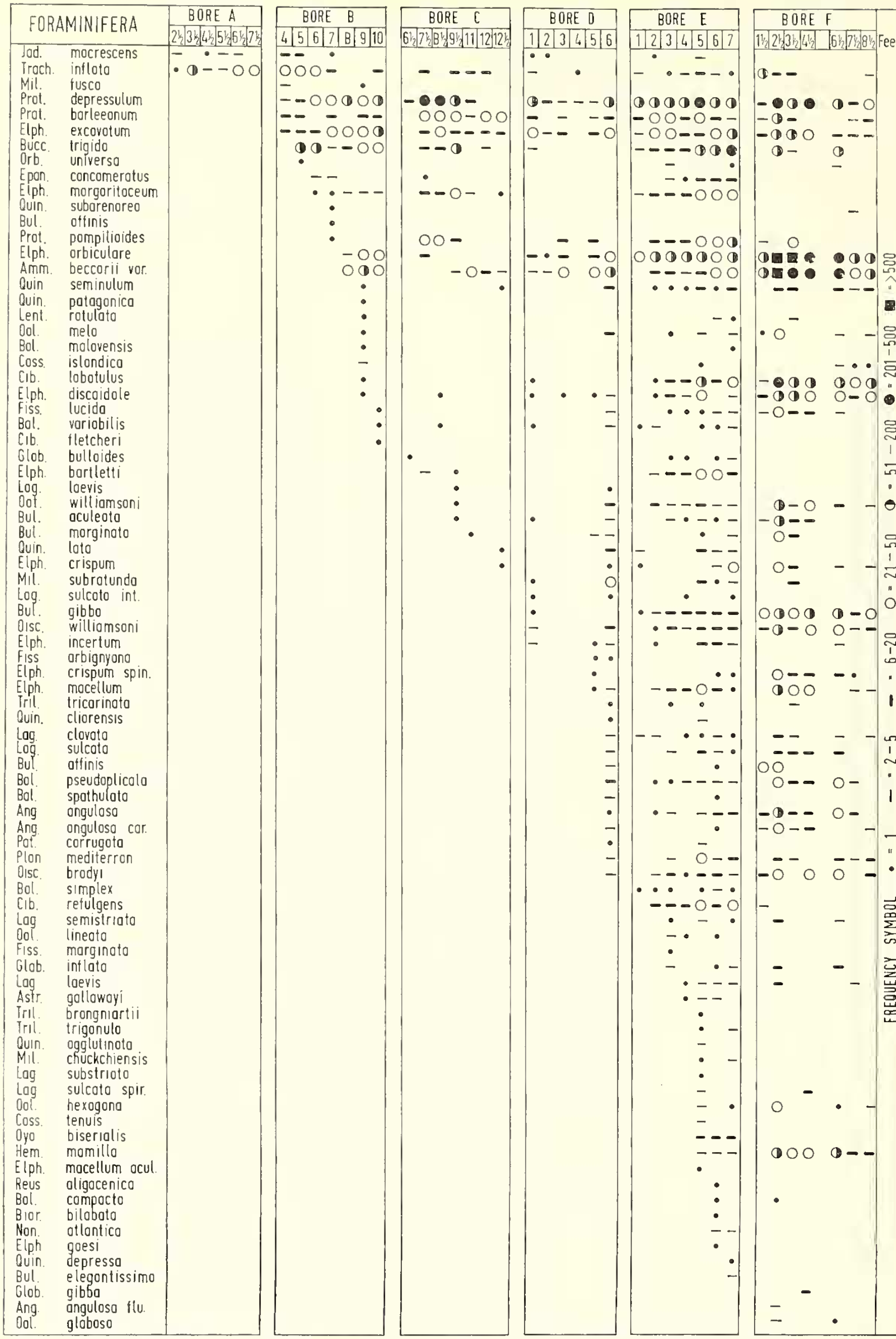
1. *The Foraminifera of the uppermost Scrobicularia clays.* The *Scrobicularia* clays were penetrated in the north–south line of borings A, B, C, D, E, F shown on the map (text-fig. 1). The first four were started in the lowest peats of the forest layer and, in the case of Bore B, penetrated 10 feet into the underlying clays. These bores thus provide an excellent opportunity for study of the included microfauna in relation to the palaeogeographical changes which eventually culminated in the growth of a forest cover with pines and birches. At the locations of Bores E and F the overlying forest layer has been eroded off. These bores therefore start lower in the sequence than the others and penetrate further into the clays (see text-fig. 2).

In Bore A, to the south, the fauna in the clays below the peat is dominated throughout by *Trochammina inflata* and *Jadammina macrescens*. In the present Dovey estuary these species characterize the high marsh zone, Juncetum, of Yapp, Johns and Jones (1917). Examination of the charts shows that the dominance of *T. inflata* becomes more marked upwards prior to the disappearance of the entire fauna in the peats. This certainly reflects the later stages of growth of a marine marsh and its passage into freshwater swamp.

The fauna in Bore B is more abundant and the marsh cycle is more completely shown. In the lowest clays penetrated the fauna is close to that of the present day mud flats and low marsh (Salicornietum) of the Dovey with *Elphidium excavatum*, *Elphidium orbiculare*, *Protelphidium depressulum* and *Ammonia beccarii* var. *batavus* as dominant forms. The fauna diminishes in number of individuals and species towards the top of the bore and six species only, three of them arenaceous, were retrieved from the clays about 2 feet below the peats. These include the high marsh species *Jadammina macrescens* and *Trochammina inflata*.

The charts for Bore C again illustrate the marsh cycle, with gradual change and diminution of the fauna accompanying the passage into the peats from a maximum at the 9-foot interval. Below this interval the fauna is again sparse. As in Bore B the uppermost *Scrobicularia* clays are unfossiliferous, with intercalated peat, wood fragments, and rootlets. Iron staining in these deposits resembles that seen in the present high marsh of the Dovey.

Bore D shows similar faunal trends, but here the lowest clays penetrated yield an abundant fauna dominated by *A. beccarii* var. *batavus* and including thirty-four other species, which suggests strong estuarine to marine influences. Again the fauna tends to diminish towards the top of the bore, the fauna at 1 foot depth being dominated by



TEXT-FIG. 2. Distribution of foraminifera in the *Scrobicularia* clays.

Protelphidium depressulum and *Elphidium excavatum*, together with *Trochammina inflata*, typical marsh species, although a number of other species occur rarely.

The top of Bore E is some 2 or 3 feet below the forest layer, which at this location has been eroded away, and older sediments are penetrated at the bottom than in the other borings. Nevertheless, clays with a marsh fauna are preserved at the top and the same general ecologic evolution can be seen. The fauna in the lowermost samples, 5–7 feet depth, is very abundant, dominated by *Buccella frigida* and *Ammonia beccarii*, with up to fifty-five other species, indicating strong estuarine to marine influences. This fauna diminishes rapidly upwards in the boring, above a *Scrobicularia* shell bank at 4½ feet, and the uppermost samples show the typical marsh fauna seen in the other cores.

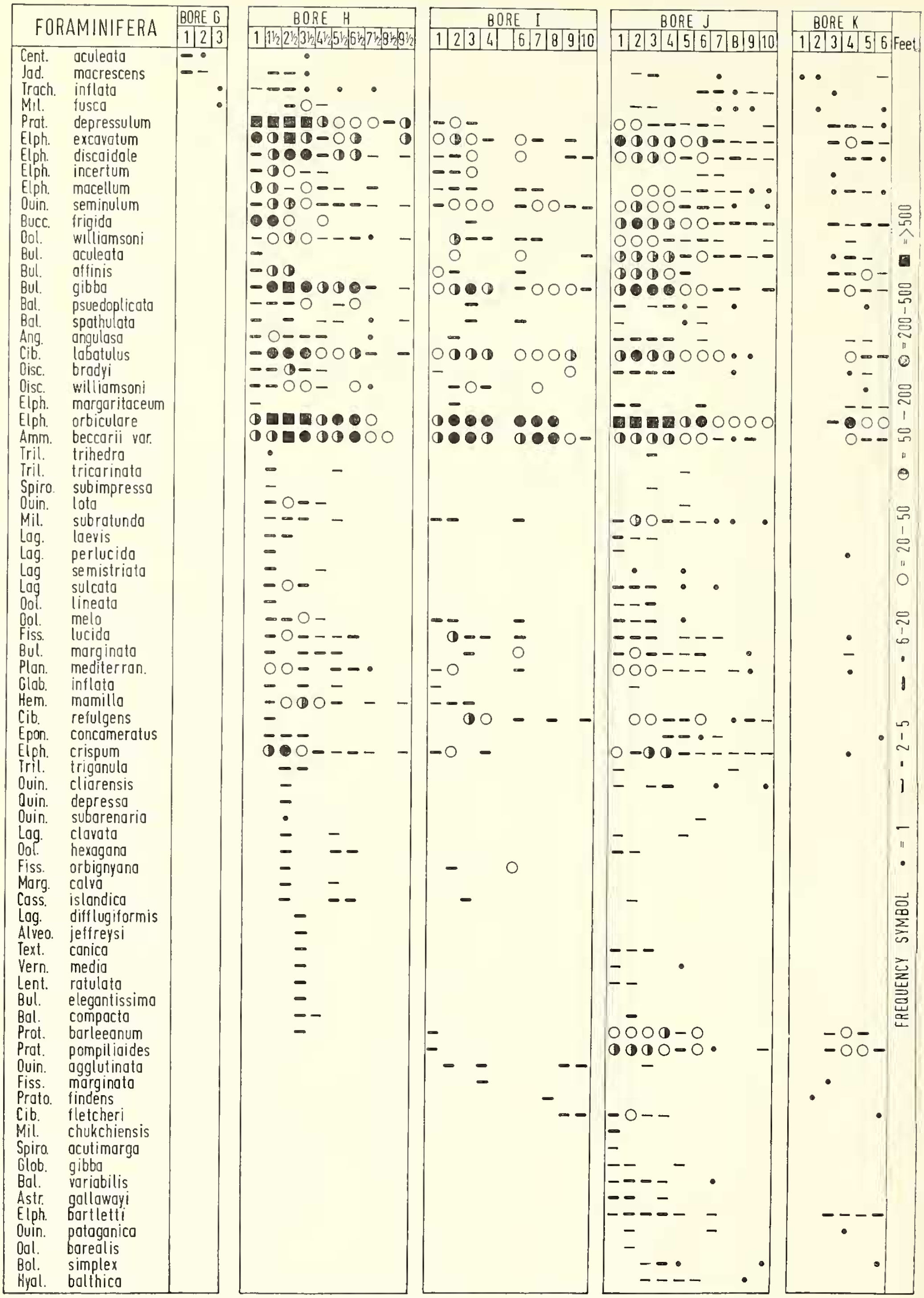
Bore F is similar to Bore E but with more of the uppermost *Scrobicularia* clays eroded off, so that less of the marsh phase is seen in the charts. The fauna is less abundant in species but more abundant in numbers of specimens than Bore E but shows a similar diminution at the top, illustrating the progress of the marsh cycle towards freshwater conditions.

Detailed study of the bores therefore supports the idea that the *Scrobicularia* clays of the Ynyslas foreshore are the deposits of a cycle of marsh deposition, the faunas indicating a passage upwards from estuarine deposition through an open intertidal flat and salt marsh stage to freshwater conditions. The faunal associations are essentially the same as those found in the present Dovey estuary. The sediments are more or less contemporaneous in age, although the most northern bores (E and F), because of removal by erosion of the highest clays, reached older beds.

Besides the marked vertical change seen in the *Scrobicularia* clays there is also a lateral change in the faunas from south to north. Bore A appears to represent the former limit of clay deposition at the edge of the existing marshes, its fauna being typical throughout of the present Dovey high marsh. Northwards through bores B, C, and D, the increasing estuarine and tidal influence of the Dovey is reflected in the gradual increase in number of foraminifera present, the faunas becoming more and more typical of the present day open tidal flat zone. Bores E and D, in close proximity to the main Dovey channel, show the best developed estuarine faunas. Thus palaeogeographic evidence suggests that the river Dovey has maintained its present location in post-glacial time from at least late *Scrobicularia* clay times (end of Boreal florizone VI).

2. *The Foraminifera in the deposits of the latest marsh cycle.* The deposits of the latest marsh cycle were penetrated in borings G, H, I, J, and K (text-fig. 1). Three of these borings (I, J, and K) were made on the present Dovey marshes; Bore H was made near the river Clettwr; and Bore G near the river Leri at its tidal limit.

The faunal changes which occur through these bores resemble those seen in the bores from the foreshore (text-fig. 3). As is well seen in Bores K and H, the total number of specimens and species reaches a maximum approximately half-way up each boring, then gradually falls. Although this is not so marked in Bores I and J the faunal changes in all four indicate a full physiographic cycle with a change from a marsh or open flat environment to estuarine conditions, then a return to high marsh. This is well shown by Bore K situated at the head of the estuary. The lowest samples yield a marsh fauna with *J. macrescens*, together with open tidal flat species such as *E. excavatum* and *E. orbiculare*. Such a fauna might be expected at the beginning of the transgression which undoubtedly



TEXT-FIG. 3. Distribution of foraminifera in the deposits of the latest marsh cycle.

caused both erosion and migration of the marsh zones landwards, probably with fairly rapid conversion of much of the former freshwater bog area into open tidal flat. The fauna at 4 feet shows the peak of the transgression with maximum estuarine to marine influence. The dominant species in this association is *E. orbiculare*, a dominant form in the present-day estuary. The succeeding samples show a marked diminution in the number of species, the fauna at the top of the boring representing a typical high marsh assemblage with *J. macrescens*, *Miliammina fusca*, and *Protoschista findens*, the same fauna as in the present high marsh. The lateral succession of present-day marsh zones is thus mirrored by the vertical succession in the upper part of the borings; the sharply defined estuarine, low marsh, and high marsh associations indicating steady accretion presumably accompanying a relatively stable sea level.

Bore J was located in the lower high marsh (lowest salt marsh sward, Glycerietum) near the mouth of the Clettwr, so that the full cycle is not seen, but as in Bore K a sparse marsh fauna with open flat elements is found in the lowest samples penetrated. The fauna towards the middle of the boring, dominated by *E. orbiculare*, indicates maximum estuarine influence, and that in the upper part of the boring shows the gradual passage to low marsh. The peak of the transgression is indicated by samples about 5 or 6 feet below the surface, which is near the top of the low marsh. This compares with a maximum of 2 feet total thickness for the same interval in Bore K. This strikingly confirms the observations made by Richards (1934), which suggested that the rate of accretion in the lower estuary was about twice that at the river end.

The charts for Bore I show very similar faunal trends except that fewer species were recovered. The marsh cycle is also very well shown in Bore H located well within the present freshwater area, near the east bank of the Clettwr. Here the period of maximum transgression is indicated by the total faunal maximum in samples between $2\frac{1}{2}$ and $5\frac{1}{2}$ feet. This boring begins in low marsh sediments and the full cycle to high marsh is not seen. Marsh sediments only were found in Bore G. Here the appearance of *Centropyxis* indicates the onset of freshwater conditions.

CONCLUSIONS

Fauna and climate. The oldest Holocene deposits studied at Borth are the *Scrobicularia* clays. These were laid down in late Boreal times, over 6,000 years ago, while the deposits above the clays represent almost continuous deposition down to the present day. The sediments thus span a period of great climatic vicissitudes from the late Boreal, through Atlantic and sub-Boreal, into the present sub-Atlantic phase. Although the fossil faunas differ little from those living today there is some evidence of change with climate in the faunal sequence. *Buccella frigida*, generally considered a cold-water form, is one of the most abundant species in the *Scrobicularia* clays but is relatively less significant in the succeeding assemblages. This trend is paralleled by a simultaneous increase in *Bulimina gibba*, both possibly related to the change from Boreal (Continental) to Atlantic (Oceanic) climatic conditions.

Faunal affinities. The distinctive foraminiferal associations in the Holocene beds at Borth may be compared with those distinguished in other parts of the British Isles, particularly by Macfadyen (1938, 1942, 1955). The two main areas are (i) Swansea Bay and the Somerset Levels, (ii) the Norfolk Broads and the Fens. Fifteen species of foraminifera are common to all areas, seventeen are restricted to the Fens and Broads, twenty-two to the Swansea area, fifty-six to the Borth beds. It is possible that the high figures for Borth merely reflect the more detailed work carried out; nevertheless, these figures provide some evidence of distinct sub-provinces in the British area.

Summary of palaeogeographic events. The lowest sediments studied, the *Scrobicularia* clays, are the final deposits of the main, post-glacial (Flandrian) transgression. The foraminifera in these deposits support the conception of a succession from estuarine conditions through salt marsh to fen carr and finally to pine and birch forest. This forest climax was reached by about 4000 B.C. These events were followed by a change in climate and during the wetter Atlantic phase the forest was overwhelmed by freshwater peats. At approximately 500 B.C. renewed marine transgression took place, reaching a peak during Romano-British times. Another cycle of marsh growth was thus initiated, to be completed some hundreds of years ago. The stages of this physiographic cycle can be interpreted from the foraminiferal faunas.

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SPECIES LIST

Full names of species plotted in text-fig. 2:

Jadammina macrescens (Brady)
Trochammina inflata (Montagu)
Miliammina fusca (Brady)
Protelphidium depressulum (Walker and Jacob)
Protelphidium barleeanum (Williamson)
Elphidium excavatum (Terquem)
Buccella frigida (Cushman)
Orbulina universa d'Orbigny
Eponides concameratus Montagu
Elphidium margaritaceum (Cushman)
Quinqueloculina subarenaria Cushman
Bulimina affinis d'Orbigny
Protelphidium pompilioides (Fichtel and Moll)
Elphidium orbiculare (Brady)
Ammonia beccarii (Linné) var. *batavus* Hofker
Quinqueloculina seminulum (Linné)
Quinqueloculina patagonica d'Orbigny
Lenticulina rotulata (Lamarck)
Oolina melo d'Orbigny
Bolivina malovensis Heron-Allen and Earland
Cassidulina islandica Norvang
Cibicides lobatulus (Walker and Jacob)
Elphidium discoidale (d'Orbigny)
Fissurina lucida (Williamson)
Bolivina variabilis (Williamson)
Cibicides fletcheri Galloway and Wissler
Globigerina bulloides d'Orbigny
Elphidium bartletti Cushman
Lagena laevis (Montagu)
Oolina williamsoni (Alcock)
Buliminа aculeata (d'Orbigny)
Buliminа marginata d'Orbigny
Quinqueloculina lata Terquem
Elphidium crispum (Linné)
Miliolinella subrotunda (Montagu)
Lagena sulcata (Walker and Jacob) var. *interrupta* (Williamson)
Bulimina gibba d'Orbigny
Discorbis williamsoni Cushman and Parr
Elphidium incertum (Williamson)
Fissurina orbignyana (Seguenza)
Elphidium crispum (Linné), spinose var.
Elphidium macellum (Fichtel and Moll)
Triloculina tricarinata d'Orbigny
Quinqueloculina cliarensis (Heron-Allen and Earland)
Lagena clavata (d'Orbigny)
Lagena sulcata (Walker and Jacob)
Buliminа affinis (d'Orbigny)
Bolivina pseudoplicata Heron-Allen and Earland
Bolivina spathulata (Williamson)
Angulogerina angulosa (Williamson)
Angulogerina angulosa (Williamson) var. *carinata* (Cushman)
Patellina corrugata Williamson
Planorbulina mediterreana d'Orbigny
Discorbis bradyi Cushman
Bolivina simplex Phleger and Parker
Cibicides refulgens (Montfort)
Lagena semistriata Williamson
Oolina lineata (Williamson)
Fissurina marginata (Montagu)
Globigerina inflata d'Orbigny
Lagena laevis (Montagu)
Astrononion gallowayi Loeblich and Tappan
Triloculina brongniartii d'Orbigny
Triloculina trigonula (Lamarck)
Quinqueloculina agglutinata Cushman
Miliolinella chukchiensis Loeblich and Tappan
Lagena substriata Williamson
Lagena sulcata (Walker and Jacob) var. *spirata* Bandy
Oolina hexagona (Williamson)
Cassidulina tenuis Phleger and Parker

Dyocibicides biserialis Cushman and Valentine
Heminwayina mamilla (Williamson)
Elphidium macellum (Fichtel and Moll) var. *aculeatum* Silvestri
Reussella cf. *R. oligocoenica* Cushman and Todd
Bolivina compacta (Sidebottom)
Biorbulina bilobata (d'Orbigny)
Nonionella atlantica Cushman
Elphidium goesi Stschedrina
Quinqueloculina depressa d'Orbigny
Buliminella elegantissima (d'Orbigny)
Globulina gibba (d'Orbigny)
Angulogerina angulosa (Williamson) *fluens* Todd
Oolina globosa (Montagu)

Additional species plotted in text-fig. 3:

Alveophragmium jeffreysi (Williamson)
Hyalinea balthica (Schroeter)
Lagena perlucida (Montagu)
Lagenammina difflugiformis (Brady)
Oolina borealis Loeblich and Tappan
Protoschista findens (Parker)
Spiroloculina subimpressa Parr
Spirophthalmidium acutimargo (Brady)
Textularia conica d'Orbigny
Triloculina trihedra Loeblich and Tappan
Verneuilina media Hoglund

Thecamoebinae

Centropyxis aculeata (Ehrenberg)

Rare species not plotted in Fig. 3:

Acervulina inhaerens Schultz	Bore J at 4′
Dentalina neugeboreni (Schwager)	Bore H at 1½′
Bulimina mexicana Cushman	Bore J at 3′
Lenticulina suborbicularis Parr	Bore J at 4′
Guttulina lactea (Walker & Jacob)	Bore J at 5′
Oolina globosa (Montagu)	Bore J at 3′
Pyrgo williamsoni (Silvestri)	Bore J at 5′

REFERENCES

BANDY, O. L. 1953. Ecology and paleoecology of some Californian Foraminifera. *J. Paleont.* **27**, 161–82, pl. 21–25.

BARTENSTEIN, H. and BRAND, E. 1938. Die foraminiferen Fauna des Jade-Gebietes. *Senckenbergiana*, **20**, 381–85.

BRADY, H. B. 1870. The ostracoda and foraminifera of tidal rivers. *Ann. Mag. nat. Hist.*, Ser. 4, 273–306, pl. 11, 12.

CHAPMAN, V. J. 1960. *Salt marshes and Salt Deserts of the World.* London.

GODWIN, H. 1943. Coastal peat beds of the British Isles and North Sea. *Journ. Ecol.* **31**, 199–247.

—— and NEWTON, L. 1938. The submerged forest at Borth and Ynyslas, Cardiganshire. *New Phytol.* **37**, 333–44.

—— and WILLIS, E. H. 1961. Natural radiocarbon measurements, III. *Radiocarbon*, **3**, 60–76.

HEDBERG, H. D. 1934. Some recent and fossil brackish to freshwater foraminifera. *J. Paleont.* **8**, 469–76.

JONES, O. T. and PUGH, W. J. 1935. The geology of the districts around Machynlleth and Aberystwyth. *Proc. Geol. Ass. Lond.* **46**, 247–300.

LE CALVEZ, J. and LE CALVEZ, I. 1951. Contribution à l'étude des foraminifères des eaux saumâtres. *Vie et Milieu.* **2**, 237.

MACFADYEN, W. A. 1938. Post-Glacial foraminifera from the English Fenlands. *Geol. Mag.* **75**, 409–17.

—— 1942. A Post-Glacial microfauna from Swansea docks. *Geol. Mag.* **79**, 133–46.

—— 1955. 'Foraminifera' *in* GODWIN, H. Studies on the post-Glacial history of British vegetation, XIII. The Meare Pool region of the Somerset Levels. *Phil. Trans., B*, **239**, No. 662, 161–90.

NEAVERSON, E. 1947. Coastal changes around Liverpool Bay since the Ice Age. *Proc. Lpool Geol. Soc.* **19**, 3–31.

PHLEGER, F. B. and WALTON, W. R. 1950. Ecology of marsh and bay Foraminifera, Barnstaple, Massachusetts. *Amer. J. Sci.* **248**, 274–94.

RICHARDS, F. J. 1934. The salt marshes of the Dovey Estuary, IV. The rates of vertical accretion, horizontal extension and scarp erosion. *Ann. Bot.* **48**, 225–59.

SMITH, M. L. 1954. A method of selecting sample sizes. *J. Paleont.* **28**, 116–17.

TWENHOFEL, W. H. and TYLER, S. A. 1941. *Methods of study of sediments.* New York.

VOORTHUYSEN, J. H. VAN. 1947. Holocene foraminifera from borings in tidal marshes. *The Micropaleontologist*, **1** (2), 5–6.

VOORTHUYSEN, J. H. VAN. 1951. The quantitative distribution of Holocene Foraminifera in the N. O. Polder. *Proc. 3rd Int. Cong. Sediment. Neth.*, 267–72.

YAPP, R. H., JOHNS, D., and JONES, O. T. 1916. The salt marshes of the Dovey Estuary, Pt. 1. *J. Ecol.* **4**, 27–42.

—— —— —— 1917. The salt marshes of the Dovey Estuary. Pt. 2. *J. Ecol.* **5**, 65–103.

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