Pollen Analyses of Late - and Post-glacial Deposits in the Western Forth Valley.

by

Clive L. Brooks

Thesis submitted to the University of Edinburgh for the degree of Doctor of Philosophy.

1976.

Acknowledgements.

In submitting this thesis the author is deeply aware of the considerable debt of gratitude he owes to his supervisors, Dr. J.B. Sissons and Dr. W.W. Newey of the Geography Department of the University of Edinburgh, for their advice and encouragement. He would also like to thank Professors T.W. Watson and J.T. Coppock and Dr. J.A.T. Young, of the same Department, for the support they have given.

The writer also thanks Dr. F. Bell of the Botany Department of Liverpool University, the staff of the Royal Botanic Gardens, Edinburgh and Forest Products Research Laboratories, Aylesbury, Buckinghamshire, for assistance in identifying macrofossils; Isotopes Inc. U.S.A., for radiocarbon dating facilities; Dr. M. Butterworth of the Department of Chemistry, University of Aston, Birmingham, for advice on Pre-Quaternary spores; the Ordnance Survey (Archaeological Division), Edinburgh Office, for historical data; Dr. J.M. Gray of the Geography Department, University of London, for geomorphological information presented in Fig. 6; Dr. J.B. Sissons, for permission to reproduce the shoreline gradients in Fig. 30; Dr. N.A. Mörner of the Geologiska Institut, Stockholm, for permission to reproduce the sea-level curves in Fig. 2; Miss B. Beattie and Mr. R. McKechnie of the Scottish Wildlife Trust for assistance in identifying plants; Mr. R. Morton of the School of Scottish Studies, University of Edinburgh, for photographic reduction of the diagrams presented in this thesis; the various proprietors and landowners who allowed access to their properties; Mrs. M. Pardington for typing this thesis.

Summary.

The objective of this thesis is the elucidation of the characteristics and chronology of vegetational sequences that have accompanied changes in sea-level and climate in the western Forth valley during the Late-Quaternary.

A major aim of the investigations was to construct a type diagram illustrative of regional Post-glacial vegetational development. In this diagram, from a site in the westernmost part of the Forth valley, eight pollen zones (Forth Valley Zones I - VIII) each characterised by, and named after, certain pollen assemblages are distinguished. These are correlated with pollen zones of the English zonation in diagrams from other sites in the research area. Broad trends of Post-glacial woodland development are indicated in the type diagram and are divided into three chronozones. The earliest of these covers the immigration of trees into the region during the Pre-Boreal and Boreal; the second relates to the Atlantic period, the time of the climatic optimum when mixed broad-leaf deciduous forests attained their maximum development and raised bogs developed in the western Forth valley; the third covers the period of probable anthropogenic influence upon forest development.

Radiocarbon dates from Post-glacial deposits in the western Forth valley fall within dated Post-glacial pollen zones at a site at Scaleby Moss in northern England, suggesting that the pollen zones at Scaleby may be synchronous with Forth valley zones. On this basis and until more C^{14}

dates of Forth valley pollen zones become available, the dated zonal divisions at Scaleby may be used as a temporary chronological index for dating major vegetational events during the Post-glacial. Until further radiocarbon evidence is forthcoming, the pollen assemblage zones and chronozones at the type site provide a broad chronological framework of major vegetational events with which other pollen diagrams from sites in the area can be compared and assessed.

At most of the sites investigated, some pollen spectra are from minerogenic deposits from buried raised beaches and marine clays laid down during former periods of high sea-level. Pollen frequencies from these deposits are indicative of regional vegetation that was contemporaneous with the formation of the buried beaches and carse clays. At one site, however, the deposition of river-borne pollens into the sea has resulted in the over-representation of alder in the carse clays in this locality. Other factors, such as pollen selectivity by moving water, especially by sea currents, and reworked pollen from older material (apart from Pre-Quaternary spores from Devonian and Carboniferous rocks in the region) are considered to be insignificant, as pollen frequencies from the buried beaches and carse clays are comparable to those from organic material at the type site and at other sites investigated. Thus pollen from ice-transported marine deposits of Zone II age in Zone III terminal moraines at Menteith in the western Forth valley and at Kinlochspelve in south-east Mull, are also considered to be representative of the vegetation in these areas around 11,800 B.P. and 11,300 B.P. respectively, when sea-level was high, and this type of vegetation is comparable to that which characterises Zone II at other Scottish sites.

Changes in relative levels of land and sea in the area gave rise to variations in soil conditions. These were associated with changes in plant assemblages that have been interpreted from pollen and stratigraphic data. Falling sea-levels produced local vegetation successions from the halophytic species characteristic of saltmarshes to fresh-water marsh and swamp communities; but this sequence was followed by retrogression as sea-level again rose.

Pollen evidence together with radiocarbon dates provides a chronological framework which supported by geomorphological evidence, can be used to date relative changes of sea-level in the western Forth valley during the Late-Quaternary.

During the earliest part of the period under consideration, namely the Late-glacial Interstadial (Zone II), sea-level was high in the westernmost part of the Forth valley by about 11,800 B.P. The height of this sea-level in relation to the land is unknown. Around 10,800 B.P., ice of the Loch Lomond Readvance moved down the Forth valley to Menteith where it culminated probably c. 10,300 B.P. This event corresponded with the culmination of the main Late-glacial marine transgression, represented by the Buried Gravel Shoreline in south-east Scotland and, farther west, by the High Buried Beach, when sea-level was between

10 - 12m OD.

Subsequently, ice disappeared from the Forth lowlands (and other parts of Scotland) as a result of climatic amelioration. Then during Zone F.V. 1 (the Pre-Boreal) the sea rose and the Main Buried Beach was formed. Pollen evidence indicates that the sea transgressed swiftly into the research area, reaching the western extremity of the Forth valley before the end of Zone F.V. 1, and that the influence of land uplift, consequent upon glacial unloading, upon the rise of this sea-level was insignificant.

Following the formation of the Main Buried Beach sea-level dropped to about 7m OD, when deposits of the Low Buried Beach accumulated. This event took place during Zone V (Zone F.V. 2). The level of the sea then fell further, reaching a minimal level c. 8,500 B.P. Shortly after this date, the sea began to rise rapidly in relation to the land and carse clays began to accumulate over the buried beaches and the peat deposits resting upon them. This marine transgression, the principal Post-glacial marine transgression in the Forth valley, was in response to a eustatic rise of sea-level resulting from the disintegration of the world's ice sheets.

Geomorphological data indicate that the land was rising as the main Post-glacial sea transgressed into the upper Forth valley. A major objective of the thesis was to determine whether the early rise of the sea at this time was retarded by land uplift. Pollen evidence signifies that the advance of the sea into the western Forth valley was relatively swift, beginning in Zone F.V.3 (VIa) and reaching the western margin of the Forth valley by the beginning of Zone F.V.4 (VIb). Thus the influence of isostatic recovery upon the early rise of the main Post-glacial sea in this region was insignificant.

However, the sea reached some sites at later times. This may be explained by local variables related to differences in site conditions and locations. These include the rapid development, in relation to the rising sea, of peat and the deposition of river-borne sands and gravels which resulted in the surfaces of these deposits being raised above sea-level until the sea rose and began to cover them with carse clays. At other locations carse clays, and possibly fine river-borne sediments, accumulated, resulting in the raising of the level of these clays above the sea. Subsequently, peat deposits were formed upon them until the sea rose and began to cover these minerogenic and organic layers with carse clay. At some sites sands and gravels were discharged into the sea by streams and were built up above sea-level. Later, these minerogenic deposits were buried beneath carse clays as the sea rose.

These local variables focus attention on some of the difficulties of attempting to correlate isolated fragments of relict marine features in the western Forth valley, but it is hoped that the data presented in this thesis may be of use as a basis for further research into problems relating to Post-glacial land and sea-level changes, particularly in the central Scottish lowlands.

Declarations.

In accordance with regulations 2.4.10 and 2.4.15 for Postgraduate study in the University of Edinburgh, I declare that parts of the research work in this thesis were published with the approval of my supervisors, Dr. J.B. Sissons and Dr. W.W. Newey, before the thesis was submitted for examination.

Results of pollen analyses of deposits at sites at Menteith and Kinlochspelve are published in a paper by J.M. Gray and the writer, and those from material at Woodend Farm Site 1, Easter Mye, Newburn, The Homesteads and Bield, are in a paper produced jointly by Dr. J.B. Sissons and the author. Stratigraphy and pollen at the latter two sites are described by the writer in a separate publication. These papers are included in the thesis as an appendix.

I declare that the body of this thesis was composed by me and is my own work.

C.L. BROOKS.

CONTENTS.

CONTENTS.

MAPS AND DIAGRAMS.

Maps and Diagrams.

TABLES.

Tables.

Introduction.

This thesis is concerned with the physical evolution of part of the Forth valley, especially the characteristics and chronology of the vegetational sequences that have accompanied changes in sea-level and climate in this part of Scotland in the Late-Quaternary.

The research area is situated in the Central Lowlands of Scotland and is located within a broad plain, locally referred to as carseland, in the western part of the Forth valley. The carse, drained by the River Forth and its tributaries, extends eastwards from the vicinity of the Highland margin to end between Grangemouth and Bo'ness, and its geomorphology reflects some of the principal events of the Late - and Post-glacial periods in this part of lowland Scotland. The western part of the plain is almost enclosed by a belt of morainic deposits, the Menteith moraine, produced by the last incursion of Highland ice, the Loch Lomond Readvance, into this area. The carse is associated with a major Post-glacial marine transgression which culminated about 6,500 B.P. and which laid down a widespread deposit of grey clay known locally as carse clay. With intermittent retreat of the sea extensive peat mires developed over the higher parts of the ill-drained carse surface, although in modern times man has removed much of the peat and the underlying carse has been transformed into valuable farmland. Concealed beneath the carse clay, numerous borings have revealed the existence of near-horizontal surfaces each with a covering of peat and each representing a much earlier position of the sea. These surfaces rise like a series of steps from the buried channel of the Forth and are known as the Low, Main and High Buried Beaches.

This thesis is an investigation of the chronology and related characteristics of these events in the physical geography of the western Forth valley and it attempts in particular to elucidate vegetational development which accompanied changes in sea-level. Additionally an attempt is made to interpret and correlate vegetational development which accompanied Late-glacial marine conditions in the western Forth valley and in a small area in south-east Mull, situated west of the Scottish mainland. The methods utilized in this research are those of pollen analysis, stratigraphical examination and radiocarbon assay.

The thesis is presented in six parts. In Part 1 the physical evolution of the western Forth valley is outlined. Part 2 deals with the choice of the pollen sites, followed in Part 3 by a description of the research methods and techniques used. In Part 4 the stratigraphic and pollen data from each site are presented, which are then discussed in Part 5. A summary of this discussion is given in Part 6.

PART 1.

The Evolution of the Research Area with Particular Reference to Geomorphology and Vegetation.

1.i. Outline of the Geography of the Research Area.

The research area is located within that part of the western Forth valley which extends from near Bo'ness westwards for about 43Km (Fig. 1). The western Forth valley is an extensive tract of lowland floored mainly by Old Red Sandstone and Carboniferous sedimentary rocks. It terminates near the edge of the Scottish Highlands and is bounded by various hill masses, notably the Menteith and Ochil Hills and the Campsie Fells. At Stirling the volcanic rocks of the Ochils and Campsie Fells are separated by a narrow gap which forms the major link between two parts of the Forth valley.

The region is drained by the River Forth, which rises in the south-west Grampians. The Forth flows eastwards across the Carse of Stirling and is joined by numerous tributaries, the most notable being the River Teith and the Allan water which enter the Forth just west of Stirling. After threading through the Stirling gap, the Forth meanders to become increasingly pronounced and the river widens to become the inner tidal Forth estuary into which flow the Carron and Avon rivers.

The hill areas mentioned above bound an extensive lowland plain whose surface is mostly below 15m OD. This plain is composed of estuarine deposits collectively known as the carse clays. From Grangemouth westwards to Stirling, a distance of about 17Km, the carse varies in width up to several kilometres, but is greatly constricted in the Stirling gap. West of Stirling the carse forms a broad flat plain

Map showing the location of the pollen sites in the western part of the Forth Valley

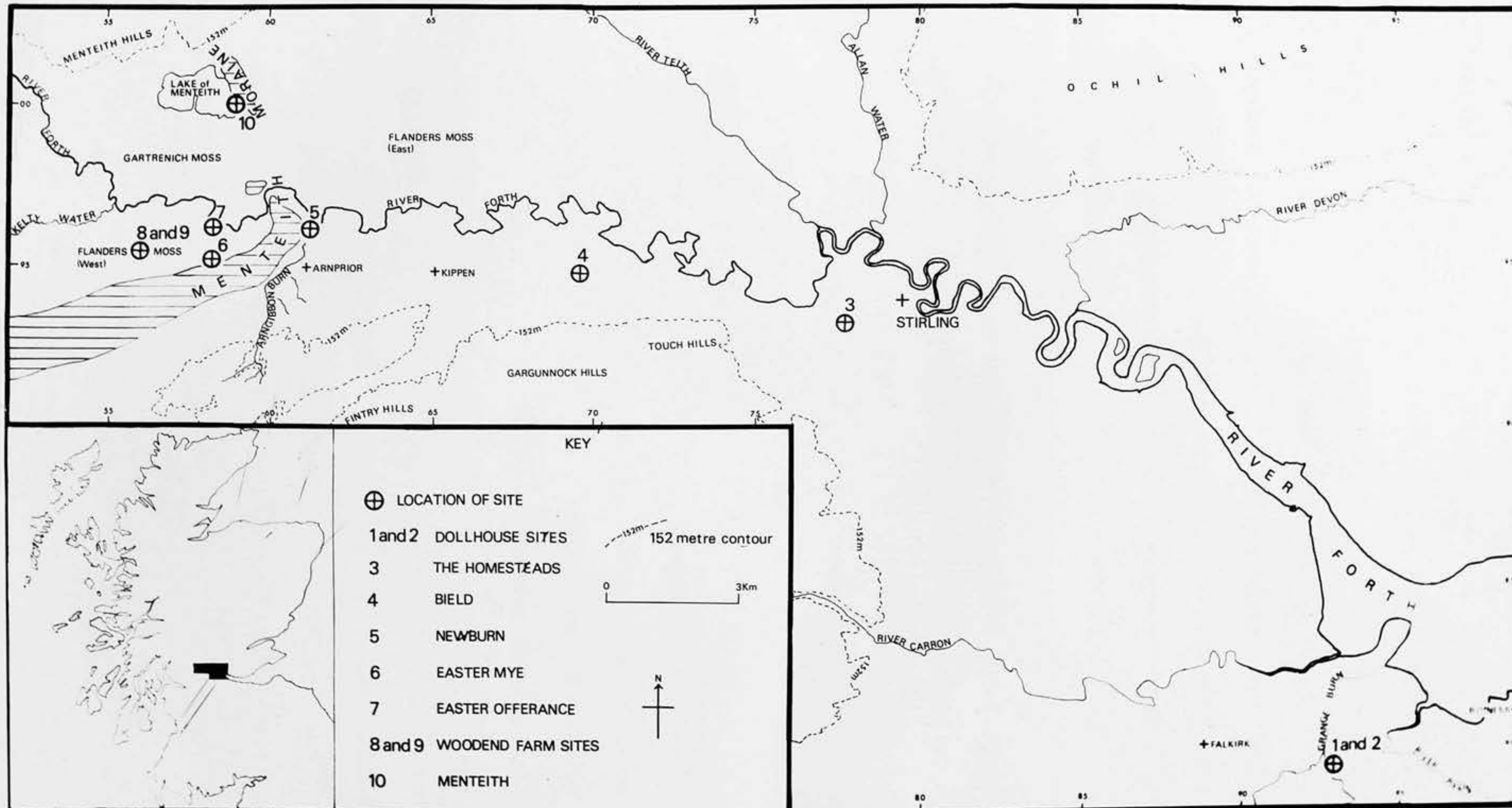


Fig 1

called the Carse of Stirling which is about 27Km long with a maximum width of approximately 6Km. In the west, this broad plain is interrupted and almost divided by the Menteith moraine.

In the westernmost part of the Carse of Stirling are extensive peat bogs, the largest of which are East Flanders Moss, West Flanders Moss and Gartrenich Moss. Parts of the latter Mosses, however, have already been afforested and other parts are in preparation for afforestation. East of these mosses the primeval vegetational landscape has been profoundly altered. The original forests have long been cleared as a result of agricultural and industrial exploitation while former large areas of peat moss have been removed and the ground brought under cultivation.

In the Forth lowlands are a variety of landforms associated with Late-Quaternary glaciation. The most outstanding glacially-deposited landform in the western Forth valley is the Menteith moraine. This feature is a complex arcuate ridge system, about 20Km long, which encloses the westernmost part of the Forth lowland. Immediately west of the moraine is the Lake of Menteith which occupies and defines a large kettlehole. At Stirling occur kames and kettleholes which eastwards merge into, and are replaced by, a spread of outwash sands and gravels, this in turn grading into raised beach flats. Yet farther east, outwash sand and gravels merge into deposits of the Main Perth Raised Beach which forms an important feature near Plean (NS 837864), while a similar relationship is seen around Larbert. In the easternmost part of the research area is the Polmont esker system, which forms a distinct series of ridges not far from the flat carseland of the Grangemouth area.

Compared with many other parts of Scotland, the Forth valley is favoured climatically, having less rain and cloud. Except on high ground rainfall is not excessive and is evenly distributed over the year with a tendency to a minimum in April and a maximum in August. Precipitation is mainly frontal rain associated with eastward moving depressions, hence there is a decrease from west to east. Thus Gartmore in the western extremity of the Forth valley receives an annual average rainfall of 1,800mm, while the Grangemouth area receives 900mm of rain per annum.

Temperatures reflect the mild oceanic climate of the Forth lowlands. Stirling has an average January mean of $3.4^{o}C$ and a July mean of $15.3^{o}C$. The early summer months are the sunniest, receiving an average maximum of 174 hours of sunshine in May. During the winter months, sunshine totals are low, reaching an average maximum of 29 hours in December. The length of the annual growing season for vegetation in that part of the lowland plain in the research area is about 8 months.

The region is divisible into climatic "sub-regions" on the basis of accumulated temperature data (Birse and Robertson, 1970). Thus the carseland from Grangemouth to Stirling is classified as moderately exposed, rather dry and warm lowland with fairly mild winters. West of Stirling to Kippen (NS 690948) the carse is classified as warm moist lowland; from Kippen westwards to the western edge of the Forth valley, as warm wet lowland.

1.ii. Outline of the Geomorphology of the Western Forth Valley.

The research presented in this thesis relates to events associated with the later stages of the decay of the Devensian ice sheet, and in particular to events that occurred after the ice finally disappeared from the westernmost part of the Forth valley, about 10,000 years ago.

During the last glaciation the whole of Scotland (and far beyond) was ice-covered, apart perhaps from the highest mountain peaks (Sissons, 1967b). The decay of this ice was interrupted by readvances. In the research area Simpson (1933) claimed to have recognised two readvances; the earlier one he named the Perth Readvance, the later (and less extensive) one, the Loch Lomond Readvance.

That the Perth Readvance was a major episode in Scottish Late-Quaternary history seems doubtful. Simpson could find no precise stratigraphic evidence for the readvance limit in the Forth valley, or elsewhere. Later, Francis _et al_ (1970) found no evidence of a major readvance in the Stirling area and considered that the features attributed to the so-called Perth Readvance, which have been described by other workers (Sissons, 1962a, 1963a; Sissons and Smith, 1965a; Sissons, Smith and Cullingford, 1966), could be explained by a standstill period during the melting of the last great ice sheet, possibly accompanied by a minor oscillation of the ice front. In the Perth district, Paterson (1973) found convincing evidence of a readvance only at Moneydie, where an oscillation is represented by two till layers separated by laminated sediments. He considered that this readvance was a local event as no second till layer was found elsewhere. According to Paterson, the evidence from the Perth and Forth areas does not support the concept of the Perth Readvance proposed by Simpson (1933), but indicates the probable occurrence of localised readvances of ice during the general retreat of a major ice sheet.

Widespread deglaciation is indicated by radiocarbon and stratigraphic evidence. Radiocarbon dates of between about 13,000 B.P. and 11,800 B.P. have been obtained from shells in Late-glacial marine clays in the Glasgow area (Bishop and Dickson, 1970; Peacock, 1971). These dates may be considered in relation to a date of 13,940 ± 250 B.P. from organic deposits between Late-glacial sands and silts near Lockerbie, Dumfriesshire (Bishop, 1963); a date of 12,810 ± 155 B.P. from silty organic material at Loch Droma (Kirk and Godwin, 1963) and dates of 11,800 ± 180 B.P. and 11,580 ± 180 B.P. from peat beneath clay at a site in south-western Scotland (Moar, 1969). In addition, dates of 11,800 ± 170 B.P. and 11,700 ± 170 B.P. have been obtained from ice-transported marine shells in morainic deposits at Menteith and Loch Lomond respectively (Sissons, 1967a). The Loch Droma date with pollen and iodine analyses of lake deposits at Lochs Sionascaig and Tarff in north-west Scotland, suggest that these locations became ice-free by about 13,000 B.P. (Pennington and Lishman, 1971). On the basis of this evidence it may well be that the whole of Scotland became free of ice before the Loch Lomond Readvance. Support is provided by evidence reviewed by Sissons (1974c), which suggests that total deglaciation of Scotland, and other parts of Britain, occurred by 12,500 B.P.

The shelly marine deposits in the Menteith moraine attest the presence of the sea in the Forth valley during this milder phase. These marine shells, along with those from the Loch Lomond moraine, consist predominantly of boreal and sub-arctic species, which include Arctica islandica, Buccinum undatum and species of Tridonta, Littorina, Mytilus, Chlamys and Nuculana (Jamieson, 1865; Jack, 1875; Simpson, 1933; Gray and Brooks, 1972). These shells and the radiocarbon dates of 11,700 B.P. and 11,800 B.P. obtained from them, indicate that they are related to one marine phase and further indicate lower sea temperatures than at present.

The location of these shelly marine deposits in morainic debris in the Loch Lomond and Menteith areas also furnishes proof of a readvance of ice following this mild phase. This forward movement of ice - the Loch Lomond Readvance - rarely extended beyond the margins of the uplands and no large ice sheet was formed; instead numerous valley glaciers existed in many parts of Scotland. The limit of the ice in the Forth valley is very clearly defined by the Menteith end-moraine complex and the absence of surface morainic deposits east of this feature, criteria which also define the limit of the Loch Lomond Readvance in the Teith valley adjacent to the Forth lowlands (Thompson, 1972).

The Menteith moraine extends for 20Km, forming an arcuate loop from 10Km west of Buchlyvie to the Port of Menteith, and almost encloses the western Forth lowlands. At its western extremity the moraine forms a low ridge at about 245m OD and largely consists of angular blocks of Highland erratics. The moraine declines in altitude to approximately 60m OD at Buchlyvie, where it is composed of mounds and terraces of sand and gravel. Eastwards, near Arnprior, the moraine turns northwards and forms a conspicuous ridge system immediately east of the Lake of Menteith. In this locality the moraine is breached by the River Forth. The deposits in this part of the moraine are exposed in a section by the shore of the Lake of Menteith. Here Simpson (1933) recorded 3m of dark grey clay containing marine shells which are overlain by about 9m of sands and gravels. From this evidence Simpson inferred that the ice flowed into the sea, which he decided stood at about 19m OD. This figure is no longer considered valid as it is now known that the grey clay was ice-transported and is not in situ.

The age of the Loch Lomond Readvance was established by Donner (1957) through pollen analysis. At Donner's Drymen site, situated outside and between the Loch Lomond and Menteith ice lobes, Late-glacial pollen Zones I, II and III are represented; at his Gartmore site, within the limit of the Menteith ice, these zones are not recorded, the pollen sequence beginning with the earliest Post-glacial zone, Zone IV. On this basis Donner concluded that the Loch Lomond Readvance occurred during Zone III between about 10,800 B.P.

and 10,300 B.P.

Sea-level at the maximal extent of the Zone III ice in the Forth valley was lower than Simpson (1933) envisaged (Sissons, Smith and Cullingford, 1966; Sissons, 1966). The relative height of the sea has been assessed from outwash fans of sand and gravel in the vicinity of the Menteith moraine. One such outwash area is located at Powis Mains near the south-east corner of the Lake of Menteith, approximately 2Km north of where the Forth has breached the moraine. At this location, kames and dead-ice hollows are succeeded eastwards by the outwash plain which declines down-valley from around 23m OD, through a breach in the moraine, to about 10m OD passing beneath peat and carse clay. Another outwash plain occurs near Arnprior. Here a valley excavated by meltwaters from the Zone III ice (Sissons, Cullingford and Smith, 1965) cuts deeply into the moraine. From this depression the buried outwash plain extends north-eastwards along the valley floor declining in altitude to about 11m OD. The outwash deposits must have been laid down during the time the ice stood at the moraine, for if the ice had retreated, the configuration of ground exposed would have disrupted the supply of meltwater, preventing the growth of these outwash deposits. Farther east a large buried outwash fan spreads out into the Forth valley from the mouth of the Teith valley. As this fan is buried beneath later formed buried beach and carse deposits, like those at Menteith, this outwash deposit was probably also initiated by meltwaters associated with Zone III ice (Kemp, 1971).

Subsequent to the maximum of Zone III ice, a sequence of three buried raised beaches were formed in the Forth valley. These features were first identified by Sissons (1966) in the western part of the Carse of Stirling, and subsequently east of Stirling (Sissons, 1969; Kemp, 1971). Before Sissons' detailed investigations, sub-carse morphology had received scant attention, Jamieson (1865) and Geikie (1894) suggesting that silty clay deposits underlying sub-carse peat may be buried beach deposits.

The buried beaches, referred to in descending and chronological order as the High, Main and Low Buried Raised Beaches, are distinctive features on both sides of the Forth river; each being differentiated by altitude and composition (although all are highly micaceous). The surface of each feature is overlain by a layer of peat of variable thickness. The beaches and associated peat deposits were subsequently buried beneath carse clay during a later transgression and have been isostatically uplifted.

The highest beach, the High Buried Raised Beach, is not found inside the Menteith moraine, but extends eastwards from it. South of the Forth this beach extends horizontally with a shoreline at about 12m OD for a distance of 3Km down-valley from the moraine. The southern margin of the beach ends abruptly against steeply-rising ground, which also limits the carse at a higher level. From its shoreline at approximately 12m OD, the High Buried Beach declines northwards to about 10m OD at its northern margin. North of the Forth this beach extends eastwards from the Menteith moraine for some 5Km, its shoreline declining from about 12m to approximately 10m OD; its slope perpendicular to the shoreline being as much as 2m.

Farther down-valley towards Stirling the High Buried Beach is missing along the northern side of the Forth lowland. Kemp (1971) has suggested that beach formation was prevented by outwash being discharged from the Teith, as deposits of the High Buried Beach do not overlie the Teith outwash fan. East of Stirling the High Buried Beach is poorly represented, a relatively small fragment being located beneath the carse between Abbey Craig and Menstrie north of the Forth. In this area the shoreline altitude of the feature is between roughly 10 and 8m OD, the buried beach declining to about 7m OD at its seaward margin.

The surface of the High Buried Beach is interrupted by small shallow valleys. In these minor depressions peat, which elsewhere overlies the beach surface, is missing. Kemp has suggested that these features are small river channels comparable to those which traverse present coastal mud-flats. Similar small river channels cross the surfaces of the lower beaches.

The upper few centimetres of the High Buried Beach consist of grey silty sand beneath which is coarse sand with a distinctive pink or pale brown colour. The grey layer is presumed to owe its colour to weathering or leaching, while the characteristic pink colour of the lower layer is derived from Old Red Sandstone bedrock in the western Forth valley, or from Old Red Sandstone drift which is abundant in the west-east part of the Menteith moraine (Sissons, 1966). The commonest heavy mineral constituent of the High Buried Beach is garnet, probably derived from the breakdown of schistose Highland rocks (Kemp, 1971).

The age of the High Buried Beach, has been determined on geomorphic evidence (Sissons, 1966), but awaits confirmation by C^{14} and pollen datings. As intimated above, sea-level was about 12m OD during part of the time decaying ice at the Menteith moraine discharged outwash into the sea. At this location the outwash passes beneath deposits of the High Buried Beach, the shoreline of which is between about 11 and 12m OD. This evidence, and the fact that the High Buried Beach is not represented west of the Menteith moraine, indicate that the beach was formed during the time ice was decaying at the moraine. As the latter event probably occurred around 10,300 B.P. it appears that the High Buried Beach ceased to form about this time. In addition, as the altitude of the High Buried shoreline is slightly higher than that of the outwash deposits, it also appears that sea-level rose after they were formed.

A sample of peat immediately overlying the High Buried Beach at Wester Kerse (NS 652000) on the north side of the Forth was analysed for pollen by Newey (see Kemp, 1971). Although the peat was poor in pollen, the predominance of Betula, with Corylus of secondary importance, and a few grains of Ulmus and Quercus, led Newey to conclude that this organic deposit was formed during the latter part of Zone V. This zone has been radiocarbon dated as between about 9,700 B.P.

and 8,800 B.P. (Godwin, Walker and Willis, 1957). Thus the peat overlying the High Buried Beach at Wester Kerse was formed much later than the beach, and is therefore of no use in dating this feature. In addition there was no pollen evidence of saltmarsh conditions which characterise the basal peats overlying the later buried beaches in the western Forth valley (Newey, 1966; Brooks, 1972).

At its northern margin the High Buried Beach falls quite sharply and is often separated from the Main Buried Beach by a small but distinct bluff about 0.5 to 1.5m high (Sissons, 1972). Unlike the High Buried Beach, the Main Buried Beach is represented and widely developed west of the Menteith moraine. In this area the beach extends for approximately 7Km and slopes in an eastward direction. On both sides of the Forth the Main Buried Shoreline is generally between 10 and 11m OD and slopes towards the Forth to between about 8 and 9m OD. East of the Menteith moraine the beach is extensively developed on both sides of the Forth. On the south side of the river it is traceable over a distance of approximately 28Km, extending past Stirling and ending near Falkirk. In this latter area the buried shoreline is at about 7m OD and the beach slopes northwards to nearly 5m OD at its northern margin. On the north side of the Forth, east of Stirling, the Main Buried Beach is not extensively developed, extending eastwards for about 4Km from Abbey Craig to Menstrie. The altitude of this beach in this area is between about 7 and 6m OD and slopes towards the Forth. Linear regression of the altitudes of the Main Buried

Shoreline south of the Forth gives this feature an overall down-valley gradient of 0.146m/Km. There are, however, distinct variations of gradient of this shoreline west of Stirling (Sissons, 1972). Within the Menteith moraine the shoreline has a calculated down-valley gradient of 0.092m/Km over 7Km. Immediately east of the moraine the shoreline is 1m lower than within it, and is essentially horizontal (the calculated up-valley gradient being 0.004m/Km over 4Km). Eastwards for approximately 8Km the shoreline gradient is 0.115m/Km down-valley. It then descends nearly 1.5m in a distance of about 1Km, thereafter becoming horizontal for about 5Km towards Stirling. It is suggested that these variations of gradient are reflective of dislocations caused by variable uplift (Sissons, 1972). The possibility that these gradients represent more than one shoreline of different ages was tested by Brooks (1972), whose pollen investigations at sites situated on both sides of a major dislocation a few kilometres west of Stirling indicated that the buried beach fragments examined were approximately synchronous and related to the Main Buried Beach.

The Main Buried Beach is composed of fine grey sediments. The top few centimetres of the beach usually consist of silt or clay with occasional thin bands of silty fine sand, the latter becoming more numerous downwards until they comprise the whole deposit, apart from occasional thin bands of silt and clay. The mineral constituents of this beach are similar to those of the High Buried Beach, with the exception that muscovite is a characteristic component. The mica is considered to be representative of the end product of the decomposition of Highland ice (Kemp, 1971).

The occurrence of small river channels on the surface of this beach has already been noted. In some of these minor channels on this beach marine shells are found, the commonest being species of Cardium, Mytilus and Ostrea, which were probably deposited during the later carse transgression. Pollen evidence, however, indicates that the Main Buried Beach accumulated under marine influence, during which time saltmarsh vegetation existed (Newey, 1966; Brooks, 1972).

Radiocarbon dating of the Main Buried Beach in the Forth valley has at present not been attempted, as this beach and its peat cover are buried beneath carse clay and are nowhere exposed, thus precluding the collection (with the equipment available) of uncontaminated samples for radiocarbon assay. Pollen evidence indicates, however, that this beach ceased to accumulate in the western Forth valley between about late Zone IV and the beginning of Zone V (Durno, 1956; Newey, 1966; Brooks, 1972). The IV/V boundary has been radiocarbon dated elsewhere at about 9,500 B.P. (Godwin, Walker and Willis, 1957), thus the Main Buried Beach ceased to accumulate at about this time. This date accords with a date of 9,640 ± 140 B.P. from basal peat beneath carse at a section near Perth (Callow and Hassall, 1970).

The above evidence shows that the Main Buried Beach was formed at a later date than the High Buried Beach. As the characteristic grey deposits of the former feature have a sharp upper limit, it appears that the Main Buried Beach was formed as a result of a marine transgression.

Towards the Forth the margin of the Main Buried Beach is fringed by the shoreline of the Low Buried Beach. The former beach generally slopes gently towards the latter but in places, for example near Arnprior, the Main and Low Beaches south of the Forth are separated by a sharp bluff of about 3m. The Low Buried Beach extends west of the Menteith moraine, but in this area it is not well developed, being a narrow feature, the surface of which is between about 7 and 8m OD. Eastwards from the moraine the Low Buried Beach is more widespread, in places forming a continuous feature a few hundred metres broad, sloping towards the Forth from approximately 7 to 6m OD. North of the Forth the altitude of the beach is rather higher, declining southwards from about 8 to 7m OD. East of Stirling the Low Buried Beach is poorly represented north of the Forth, extending for about 4Km between 6 and 7m OD from Abbey Craig to Menstrie. Like the Main Buried Beach in this area, the surface altitude of the Low Buried Beach increases slightly from west to east as a result of beach build-up by sediment from adjacent rivers. On the south side of the Forth, east of Stirling, the Low Beach is a very extensive feature, extending from Stirling down-valley to the Rosehill - Kersebrook - Blairs area, where its surface altitude is approximately 5m OD.

About the top metre of the Low Buried Beach is composed of sticky grey silt and clay which contain innumerable vertical stems of reeds that merge upwards into the overlying peat. Downwards, the grey clay merges by alternation into grey silty fine sand.

Pollen analysis at a site near Kippen shows that the Low Buried Beach ceased to accumulate during the upper part of Zone V. In northern England this zone lasted from approximately 9,500 B.P. to 9,000 B.P. (Godwin, Walker and Willis, 1957) and if these dates are applicable to the Forth area, the Low Buried Beach deposits probably ceased to be laid down shortly before 9,000 B.P. A radiocarbon date of 8,690 ± 140 B.P. from the base of the peat at this site, however, indicates a slightly younger age. The difference between the pollen and radiocarbon evidence may be due to the lack of synchroneity between the pollen zones in the Forth valley and those in England, while the peat must be younger than the beach on which it rests. An age of about 8,800 B.P. for the beach seems a reasonable compromise. The above evidence demonstrates that the Low Buried Beach is younger than the Main Buried Beach, but evidence that the former feature was formed as a result of a marine transgression is not clear; however, it is probable that such was the case rather than a relative halt or standstill of land and sea (Sissons and Brooks, 1971).

Taking into consideration the dates of the Main and Low Buried Beaches, it appears that these features were formed within about 1,500 years of the time the ice stood at the Menteith moraine. The distinctive composition of these beaches, which is quite different from the overlying carse deposits, may be related to the wasting away of the Zone III ice mass.

The Low Buried Beach and overlying peat slope gently towards the Forth. West of Stirling these deposits are missing in a central belt roughly 400m to 1Km wide, which broadly follows the present course of the Forth. Within this belt, carse clay is much thicker than elsewhere and downwards the clay alternates and is partly mixed with sand and marine shells. This evidence indicates that, following the formation of the Low Buried Beach, sea-level fell and was restricted to a relatively narrow estuarine channel. As mentioned above, the Low Buried Beach probably ceased to accumulate around 8,800 B.P.; thus the sea had probably become restricted to the now buried estuary a short time later, probably reaching its minimal level about 8,500 B.P. (Sissons, 1966).

Subsequent to the sea being restricted to the buried estuary, a major transgression occurred which resulted in the Low, Main and High Buried Beaches and associated peat deposits being buried beneath carse clay. Buist (1841) was the first to recognise this marine transgression in the Tay and Earn valleys, although it was Jamieson (1865) who first realised the broader significance of this event in Scottish Quaternary history.

The carse clay is the most extensive marine deposited feature in eastern Scotland, giving rise to widespread low-lying plains in sheltered coastal areas. The most well-developed carse areas are located in the Firths of Forth and Tay. In the former area the carse clay extends the whole length of the western part of the Forth valley and penetrates numerous tributary valleys. In the less sheltered parts of the lower Forth estuary carse clay is not extensively developed, being chiefly located in embayments such as Aberlady Bay and the Tyne estuary on the East Lothian coast.

In the western Forth valley Durno (1956) found no evidence of carse clay at a site at West Flanders Moss and considered that clay underlying peat at Blair Drummond Moss to the east was not related to the carse. On this basis Durno (1958) inferred that the maximum westerly extent of the carse clay was between West Flanders and East Flanders Mosses, despite earlier evidence to the contrary. This anomalous situation was resolved by Sissons and Smith (1965b) who showed that two roughly circular areas of peat in East and West Flanders Mosses rest on buried beach deposits and are surrounded, but not penetrated by, carse clay. From this evidence Sissons and Smith argued that on the withdrawal of the sea from the buried raised beach, peat developed over the beach surface and, probably assisted by isostatic recovery, was able to maintain itself during and after the main Post-glacial transgression which deposited the carse clay.

The carselands are elevated mudflats usually composed of silt and clay with a very small amount of sand and are generally free of stones, although sand and gravel layers in carse clay commonly occur at the mouths of former and present stream courses. About the top metre of the carse clay is often tougher than that underneath, which consists of very soft wet blue-grey mud often referred to as "sleech".

These deposits often contain abundant decaying vegetable matter resulting in the sleech having a foetid odour.

The marine origin of the carse deposits has long been recognised by the abundance of marine shells they contain in some places (Sibbald, 1707; Blackadder, 1824; Jamieson, 1865; Turner, 1869; Foord and Kidston, 1890; Geikie, 1894; Dinham, 1927; Smith, 1972), among the commonest being species of Cardium, Ostrea, Cyprina, Littorina, Trophon, Mytilus, Buccinum, Scrobicularia and Cerastoderma. In addition skeletons of whales embedded in the carse have been recorded (Bald, 1811; Drummond, 1824; Milne-Holme, 1871; Morris, 1892) as well as seal skeletons (Dinham, 1927) at various locations in the western Forth valley. More recently evidence of marine conditions has been supplemented by pollen analysis which indicates that saltmarsh vegetation existed as the carse clay was laid down (Newey, 1966; Brooks, 1972). In addition a seed of Suaeda maritima has been found in carse clay at Flanders Moss (Dickson, 1971). Yet further evidence of marine conditions is furnished by foraminifera such as Miliammina fusca and Jadammina macrescens, both characteristic species of inter-tidal marsh environments, in the carse clay at Tentsmuir in north-eastern Fife (Chisholm, 1971).

At its western extremity, the maximum altitude of the carse clay is almost 15m OD while in the east, at the mouth of the Tyne, it is about 6m OD. Linear regression of the altitudes of the carse clay south of the Forth gives this shoreline an overall eastward gradient of about 0.067m/Km

(Sissons, 1972).

After the culmination of the carse transgression, which is represented by the Main Post-glacial Beach (named PG1, Sissons, 1967b), sea-level began to fall to its present level. This retreat, however, was marked by halts, distinguished by breaks of slope in the surface of the carse clay (Geikie, 1881; Read, 1959). These breaks of slope were later recognised as a sequence of three beaches lower than PG1 and which were first identified in the carse surface in the Grangemouth - Stirling area. The beaches, named in descending order PG2, PG3, PG4, are sometimes differentiated by small but distinct bluffs, but are usually distinguished only by accurate and detailed levelling (Sissons, 1967b). These beaches are also present in the carse clay north of the Forth and with the exception of PG4 are represented west of Stirling (Smith, 1968). Measurements along these beaches show that all slope eastwards with decreasing gradients. South of the Forth PG2 and PG3 have very similar gradients close to 0.06m/Km; that of PG4 is about 0.003m/Km (Sissons, 1967b). North of the Forth the gradients of PG2 and PG3 are close to 0.04m/Km and that of PG4 is at about 0.01m/Km (Smith, 1968). Followed westwards each shoreline gradient increases and merges into the one above, suggesting sedimentation as sea-level was falling. The presence of an occasional thin band of peat beneath the carse clay of the lowest beach, PG4, is apparently indicative of a slight transgression, but as yet it is unknown whether PG3 and PG2 were similarly formed (Sissons, 1967b).

The age of the carse clay has and still does command great interest. A radiocarbon date of 8,270 ± 160 B.P. from peat immediately beneath carse clay at a site near Kippen (Sissons, 1966) indicates that by that date the eustatic rise of sea-level which initiated the carse transgression was already in progress. Near Airth, between Grangemouth and Stirling, a sample of peat immediately beneath carse clay gave a date of 8,421 ± 157 B.P. (Godwin and Willis, 1961) which is similar to the upper date from Kippen and confirms that the carse clay began to be deposited at this site after this date. In the light of the above evidence a radiocarbon date of 3,249 ± 160 B.P. from peat beneath carse clay at Littleward, near Kippen (Godwin and Switzur, 1966), appears anomalous.

Evidence relating to the termination of the carse transgression is more abundant. At a site at Ochtertyre Moss, pollen analysis shows that peat began to develop over carse clay at this location during sub-zone V11b (Erdtman, 1928), which according to radiocarbon dated zones elsewhere (Godwin, Walker and Willis, 1957) is between about 4,900 B.P. and 2,500 B.P. A pollen diagram from a site at West Flanders Moss (Turner, 1965) shows that peat at this location began to develop over the carse clay during sub-zone V11a. From the base of this peat a radiocarbon date of 5,492 ± 130 B.P. was obtained (Godwin and Willis, 1962) which was, until recently, accepted as the date for the end of the carse sea. This date accords with that of 5,535 ± 160 B.P. obtained from shells in the highest Post-glacial raised beach at Aberlady Bay (Smith, 1972). A radiocarbon date of 6,490 ± 125 B.P. was obtained from basal peat overlying the Main Post-glacial Raised Beach at a site in the southwestern part of West Flanders Moss (Sissons and Brooks, 1971). This date indicates that the carse clay ceased to accumulate much earlier than 5,500 B.P. The revised age of this feature accords with dates of 6,645 ± 120 B.P. and 6,150 ± 120 B.P. from deposits overlying stratigraphic equivalents of the carse clay at Lochar Moss and Newton Stewart, respectively, in south-west Scotland (Godwin and Willis, 1962). In addition, the date of 6,490 ± 125 B.P. accords with evidence from Tentsmuir, in northeastern Fife, where it has been shown that the carse transgression culminated between 7,605 ± 130 B.P. and 5,830 ± 110 B.P. (Chisholm, 1971).

As yet there is little available evidence of the age of the sequence of raised beaches associated with the regression of the carse sea. Sissons, (1967b) estimated that the third visible Post-glacial Raised Beach, PG3, was formed about 4,000 B.P., as peat overlying this feature gave a radiocarbon date of 4,120 ± 105 B.P. A sample of peat overlying a carse shoreline at Aberlady Bay, and tentatively correlated with Sissons' PG3 shoreline, gave a date of 2,505 ± 100 B.P. (Smith, 1972).

As there are four visible Post-glacial raised beaches in the Forth valley, it seems that some of the above evidence may relate to beaches formed at different times. In this context the date from south-west Flanders Moss (Sissons and

Brooks, 1971) relates to the Main Post-glacial Raised Beach (PG1). According to Smith (1968) the base of the peat at West Flanders Moss, dated by Godwin and Willis (1962) also rests upon PG1, whereas the peat at the base of Ochtertyre Moss, dated by Erdtman, partly overlies the surfaces of PG2 and PG3. As yet, however, the three lower visible Post-glacial beaches have not been investigated in detail to test this hypothesis, but the variance of the radiocarbon and pollen evidence indicates that dating the termination of the carse sea is not a simple matter as previously thought.

Summary of Events.

1. During the build up of the last great ice sheet most of Scotland was covered by ice. The decay of this ice sheet appeared to be a continuous process, accompanied by local advances of the ice front.

2. By about 13,000 B.P. Scotland was probably free of ice and the sea extended to the western extremity of the Forth valley.

3. Between approximately 10,800 B.P. and 10,300 B.P. a lobe of Loch Lomond ice advanced into the Forth valley; the limit of this readvance being defined by the Menteith moraine.

4. As the Loch Lomond ice decayed at the Menteith moraine, glacial meltwaters excavated minor valleys and deposited outwash sands and gravels into the Forth valley.

5. Within a very short period close to 10,300 B.P., after the main deposition of the outwash but before the ice retreated from the Menteith moraine, the High Buried Beach was formed during a slight rise of sea-level.

6. Subsequently sea-level fell but then rose again slightly and formed the Main Buried Beach which ceased to accumulate at approximately 9,500 B.P. This feature was later dislocated at the Menteith moraine and at a point a few kilometres west of Stirling by crustal movements.

7. The sea regressed from the Main Buried Beach but probably rose again to produce the Low Buried Beach which ceased to accumulate at around 8,800 B.P.

8. A further lowering of the sea caused it to be confined to a relatively narrow estuary, the sea reaching its lowest

level round about 8,500 B.P.

9. Thereafter sea-level rose rapidly as a result of world-wide deglaciation. It overtook the isostatically rising land, causing the earlier beaches to be buried beneath carse clay that now forms the present surface of much of the Forth valley. The transgression culminated at about 6,500 B.P.

10. After the maximum of the transgression, sea-level fell and produced the younger Post-glacial beaches, PG2, PG3 and PG4.

1.iii. The Altitudes and Gradients of the Shorelines of the Western Forth Valley.

The present elevation of the raised beaches described in the preceding section has commanded, and still does command, great interest. Until recently much attention was directed to explaining the altitude of the carse and its westward increase in height which Carmichael had noted in 1832. Among the earliest explanations for the slope of this feature was that it was caused by marine erosion (Chambers, 1848). Earlier, Buist (1841) had postulated that the carse in the Tay and Earn valleys had achieved its present position by "a general upheaving which brought about the present land and water into the relative positions they now occupy". Others (Milne-Holme, 1871; Morris, 1892) thought that the slope of the carse was partly a reflection of estuarine deposition, as the altitude of present mudflats generally increases towards the head of an estuary in common with tidal range. Jamieson (1906, 1908) however, believed that the westward rise of the carse was related to land uplift and corresponding melting of glacier ice, the centre of which he thought was west of the Forth lowlands. He had proposed this concept in 1865 and it had been supported by Wright (1914).

Jamieson's concept of shoreline displacement differs considerably from the interpretation initiated by the Geological Survey in 1879, which recognised three horizontal raised beaches named the 100, 50 and 25 foot raised beaches. This classification became widely accepted and persisted until recently. Donner (1959, 1963), for instance, claimed to have identified 100, 50 and 25 foot raised beaches at various coastal locations in Scotland, and Earp et al (1962) maintained that the carse in the Forth valley is horizontal. Not all workers accepted this scheme; Jamieson, for example, could find no evidence of the 100, 50 and 25 foot raised beaches and concluded that they did not exist. Jamieson's conclusions were later confirmed by Sissons (1967b), which led to the abandonment of the Geological Survey's classification and the reaffirmation of the westward rise in height of the raised beaches in the Forth valley.

Detailed investigations (Sissons, 1963a, 1966, 1967b, 1969, 1972; Sissons and Smith, 1965b; Smith 1965, 1968; Kemp, 1971; Sissons and Brooks, 1971) have shown that the sloping nature of the raised beaches, including those buried beneath the carse, is related to a combination of differential land uplift and world sea-level changes associated with glacial readvances and decay of the last ice sheet. In a broader context, these events are closely linked with the growth and decay of the world's glaciers which radiocarbon and other evidence indicate were approximately synchronous events.

It is now generally accepted that in response to climatic deterioration and consequent glacier build-up, land and ocean level dropped, minimal levels being reached when glacial ice was at its maximal extent. As the glaciers decayed, water was returned to the ocean which accordingly rose, while the land, relieved of its ice-load, readjusted. The decay of the last ice sheet was not continuous, however, being interrupted from time to time by major glacial readvances which resulted in reversal of eustatic (and perhaps in some areas of isostatic) rises.

The amount of land uplift is related to the thickness of the ice. In Scotland the centre of isostatic recovery is considered to lie in the south-west Grampians (Wright, 1914; Donner, 1959; Sissons, 1965, 1967b) as this area was the major source of ice accumulation during the build-up of the last Scottish ice sheet. Outwards from the ice centre the amount of land uplift diminishes. As the centre of isostatic uplift is situated west of the Forth lowlands, the eastward decline in altitude and gradient of the raised beaches in the Forth valley reflects the outward diminution of isostatic recovery. This pattern corresponds with that in north-west Europe, which shows that the rate of isostatic recovery increases towards the location of the centre of the former ice mass (West, 1968). In this context, it is common practice to cite a single gradient for the whole length of a shoreline, but this is inapplicable to at least some of the raised beaches in the Forth valley, owing to local variations of shoreline gradients caused by differential uplift and dislocations noted in the previous section.

Another factor that has influenced the slope and distribution of the raised beaches is the age of the features. During the formation of the earliest Late-glacial beaches in East Fife (Cullingford and Smith, 1966) most of Scotland was covered by ice. Thus these beaches are situated a considerable distance from the ice centre and, having experienced a longer period of uplift than their younger counterparts, are more steeply tilted. The latter point is illustrated by comparing the gradients of the oldest East Fife raised shoreline with that of the Main Perth Raised Shoreline, the former having a gradient of 1.26m/Km, the latter a gradient of 0.43m/Km. As a consequence of glacier decay, the younger Late-glacial beaches terminate nearer and nearer the ice source. The Post-glacial shorelines, unconstrained by ice, extend even farther towards the centre of isostatic recovery and are less warped. The Main Post-glacial Shoreline, for example, reaches to the western extremity of the Forth valley and has a low gradient of about 0.08m/Km.

Initially isostatic uplift at a particular location was rapid, occurring during or soon after ice decay, as indicated firstly, by the fact that the earliest East Fife shoreline is twice as steeply inclined as the last; secondly, by the location and lower altitude of the later formed Perth raised beaches.

Apart from isostasy, the second most important factor to have influenced the raised beaches is the eustatic changes of sea-level. As stated earlier, changes in ocean levels are closely associated with the growth and decay of the world's glaciers. Many attempts have been made to plot the variations of sea-level changes using radiocarbon, pollen, height measurements etc., in specific areas or in the world

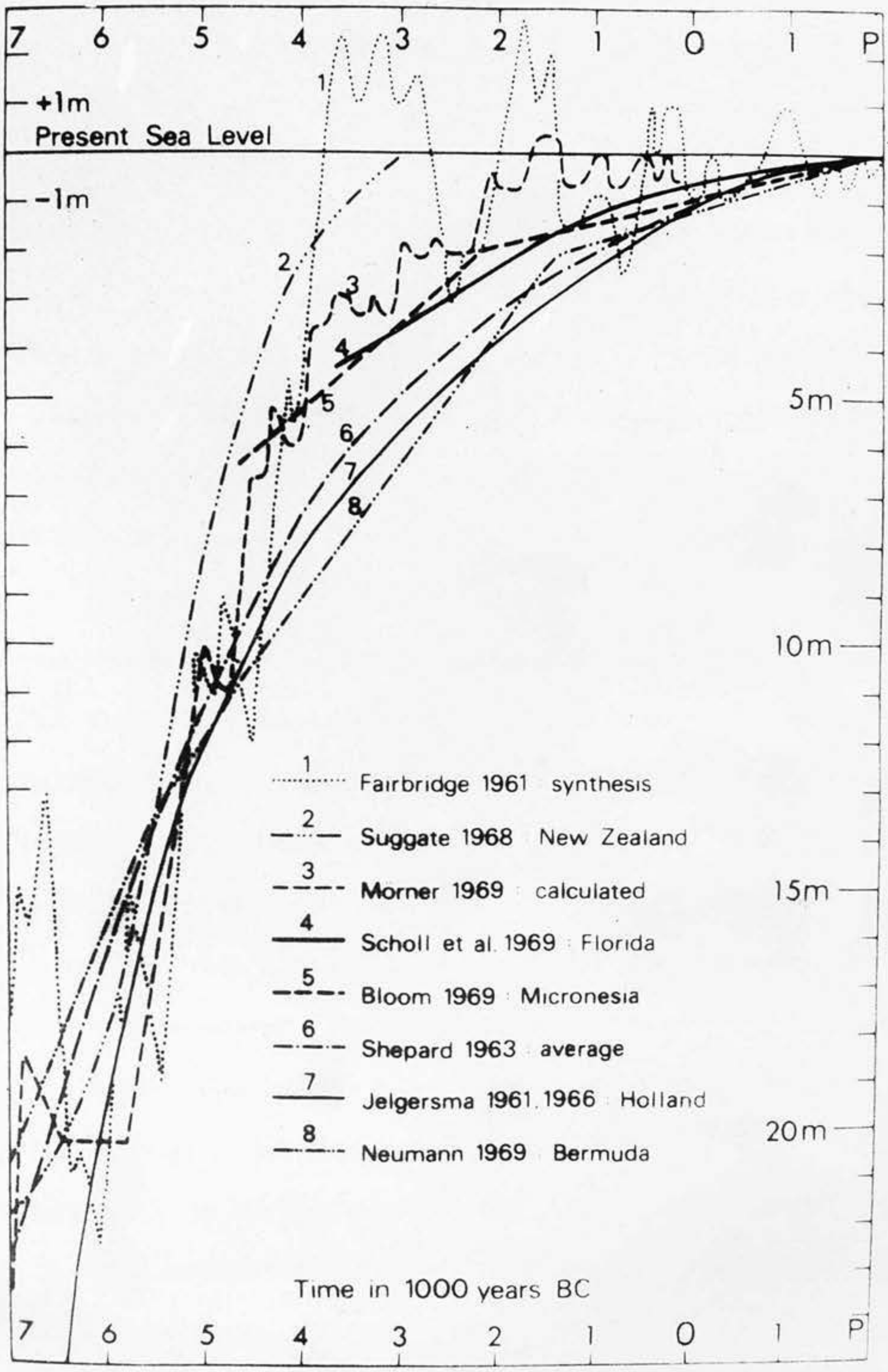


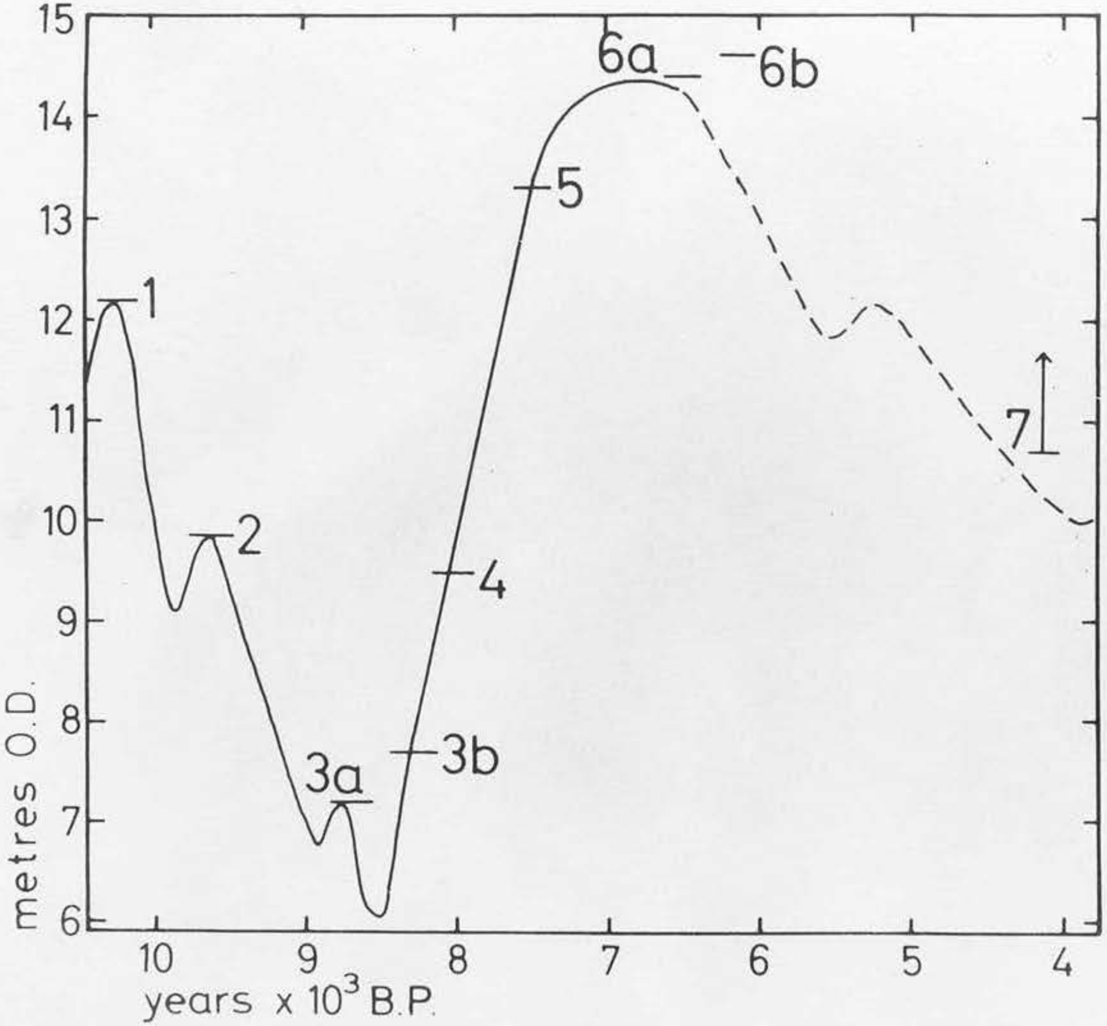
Fig 2 Sea-level curves of the Holocene period.
(produced by Mörner, 1971)

as a whole (Godwin, Suggate and Willis, 1958; Fairbridge, 1961; Shepard, 1963; Schofield, 1964; Curray, 1965; Jelgersma, 1961; Moran and Bryson, 1969; Mörner, 1969, 1971; Tooley, 1969, 1974). While there is broad agreement on eustatic fluctuations during the early part of the Holocene period, there is some serious disagreement on sea-level changes during the last 6,000 years or so, despite the application of similar methods to the same investigated areas. Many factors are considered to contribute to the diversity of the results obtained, among the most important being the influence of tectonic and isostatic effects on sea-level changes, and the sources, quality, quantity and individual interpretation of the data.

It has been suggested that in order to isolate eustatic sea-level changes from isostatic and tectonic influences, data must be obtained from relatively stable areas (Fairbridge, 1961). There is some doubt, however, as to whether such areas exist in the world, so that it may be impossible to construct an acceptable eustatic sea-level curve for the Post-glacial period (Jelgersma, 1966). Most writers, however, accept the inadequacy of present results and point to the need for improved measuring and dating techniques. Considering these points, it is apparent that there may be considerable imprecision in most, if not all, eustatic sea-level curves (Kemp, 1971) and this may account for the variety of positions and forms of the sea-level curves in Fig. 2. Thus in assessing isostatic and eustatic factors in order to relate variations of sea-level to the world wide pattern, much will depend upon the choice of eustatic curve.

Contrasting with the problems in determining eustatic and isostatic changes in comparatively large areas, is the relative accuracy possible in considering these changes from accurate levelling and detailed geomorphological evidence from a relatively small area such as the Forth valley. Thus on the basis of detailed height measurements and geomorphological evidence, supplemented by radiocarbon dates, two curves of relative land/sea-level changes have been constructed in relation to the raised beach sequence in the Forth valley (Sissons, 1967b; Kemp, 1971). These curves relate respectively to the Menteith moraine and a suite of buried beaches at a point near Abbey Craig, a short distance east of Stirling. A third curve based on the same methods, but including pollen evidence, has been constructed for the Menteith moraine (Sissons and Brooks, 1971). Between them the curves relate to relative land and sea-level changes from about 11,500 B.P. to the present; but because of the sloping nature of the raised shorelines, the graphs represent combined eustatic and isostatic changes at fixed points at the above mentioned locations.

Information relating to the earliest part of the time period under consideration is obtained from Kemp's (1971) curve at Abbey Craig, which shows a rise of sea-level relative to the land which began sometime before 11,500 B.P. and culminated at about 10,300 B.P. This sea-level rise is considered to have been due to more than one cause; the earlier stage being eustatic, resulting from the release of



Relative sea level changes at the Menteith moraine.

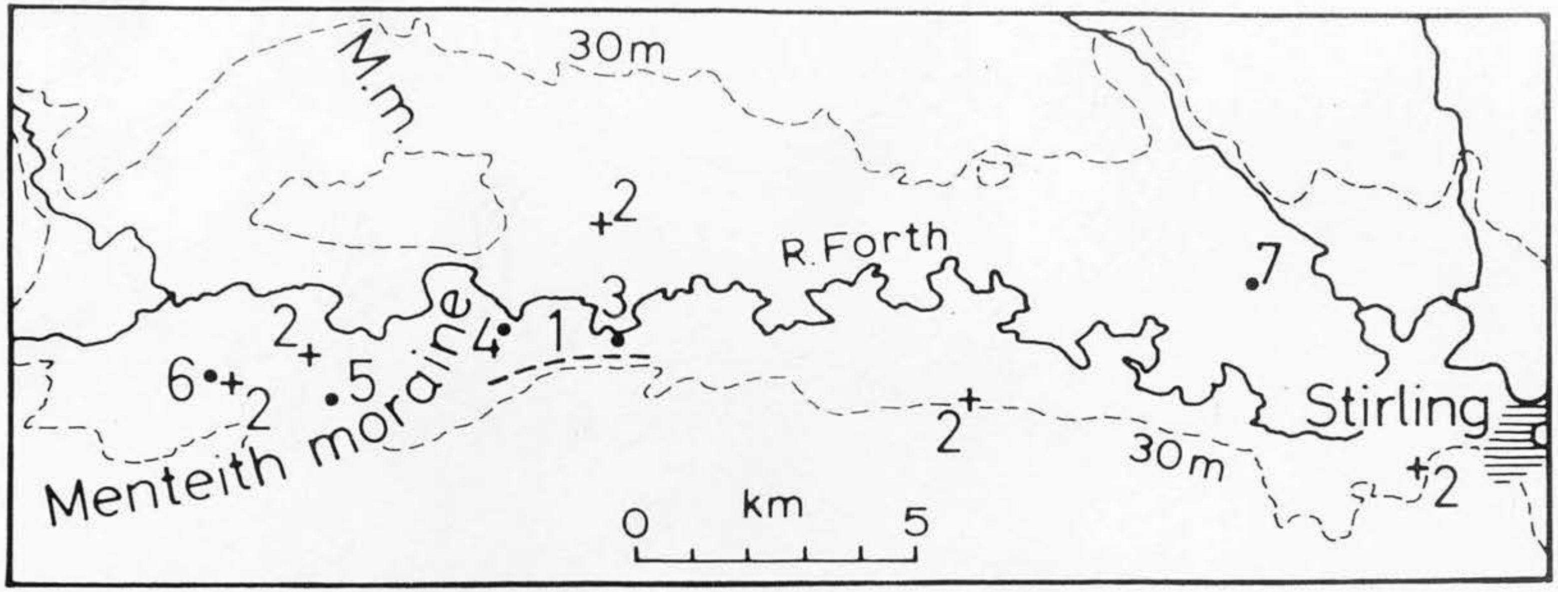
For sites 3a to 7 horizontal lines extend one standard error either side of radio-carbon dates. Sites 1 and 2 are based on other evidence and the length of the horizontal lines are arbitrary

As isostatic tilting in the Forth area is generally towards a direction south of east, the altitude of point 7 is too low in relation to the other points and the arrow indicates the probable amount of correction

(Sissons and Brooks, 1971)

Fig 3

Location of sites (Sissons and Brooks, 1971)



+, pollen sites ; •, pollen and radiocarbon sites.

1, High Buried Beach (heavy broken line)

2, Main ,, ,,

3, Low ,, ,,

4, 5, Base of carse clay

6a, 6b, 7, Surface of carse clay

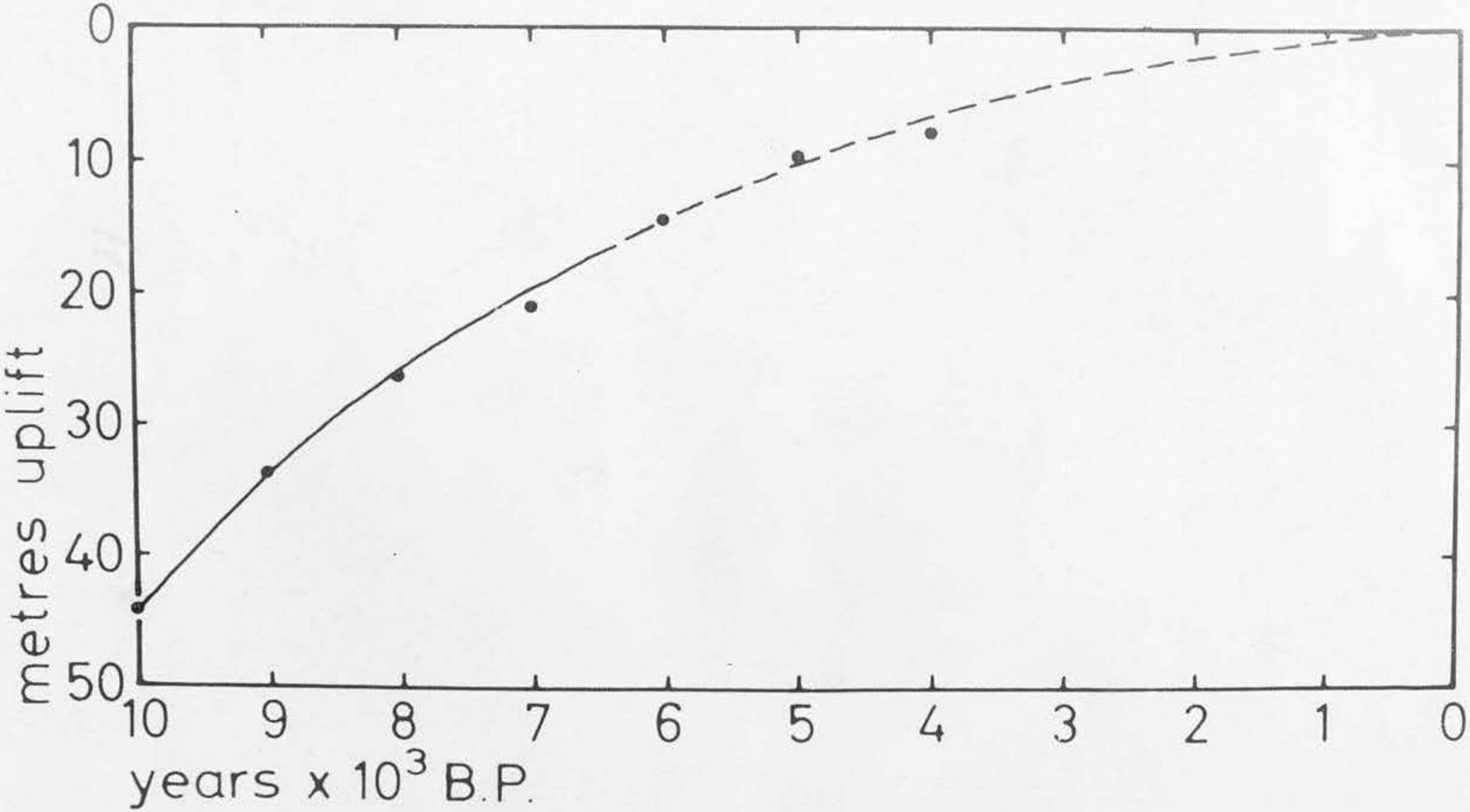
Fig 4

water from the decaying Scottish ice sheet (or its equivalent in the world), the later stage being related to downwarping of the land as the Loch Lomond ice advanced.

Subsequent interaction of eustatic and isostatic movements illustrative of the period from about 10,000 B.P. to 4,000 B.P. is reflected in the curve in Fig. 3. The data used to construct this curve were collected from seven sites, the locations of which are shown in Fig. 4. The curve shows that during the formation of the High Buried Beach, sea-level was relatively high, at approximately 12m OD. Then relative to the land, sea-level fell, a slight transgression occurring at c. 9,500 B.P., when sea-level was at about 10m OD and the Main Buried Beach was formed. The sea then regressed to almost 7m OD, reaching this level at around 8,700 B.P., during which time a minor transgression probably occurred and the Low Buried Beach was formed. Then sea-level fell to about 6m OD at approximately 8,500 B.P. during which time it was restricted to the buried estuary. Shortly afterwards, by about 8,500 B.P., the sea rose rapidly in relation to the land and carse clay was deposited. This marine transgression reached a maximum altitude of about 14m OD and culminated at c. 6,500 B.P., which is almost 1,000 years earlier than indicated by the earlier curves of Sissons (1967b) and Kemp (1971). After the maximum of the transgression, sea-level fell to below 11m OD by about 4,000 B.P., and according to Sissons' (1967b) curve, had dropped to nearly 6m OD as the younger Post-glacial beach, PG4, was formed at approximately 2,500 B.P.

Donner (1970) has constructed a curve of land and sea-level changes in central Scotland between 12,000 B.P. and 3,500 B.P. This curve shows a constant marine regression from 25m OD at about 12,000 B.P. to nearly 6m OD at approximately 6,500 B.P. Then sea-level steadily rose to a maximum of about 15m OD at 5,000 B.P. and subsequently fell to c. 14.6m OD by 3,500 B.P. Donner's curve, however, is partly based on estimation from evidence from five sites and thus does not record the full sequence of land and sea-level changes in the Forth lowlands as revealed by the detailed investigations described above.

Comparisons have been made between the varying positions of land and sea-level in the Forth valley with other curves of sea-level changes from other parts of the world, in order to estimate the relative importance of the isostatic and eustatic elements in the formation of the raised beaches (Sissons, 1967b; Kemp, 1971; Sissons and Brooks, 1971). On this basis the amount of uplift of the raised beaches has been calculated, which shows that isostatic recovery progressively diminished, as demonstrated by the estimated uplift of about 90m of the earliest Late-glacial beaches in East Fife compared with 10m of uplift of the Main Postglacial beach. Land uplift did not decrease at a constant rate, however, as mentioned earlier; isostatic recovery being initially rapid following ice decay associated with the East Fife and Perth shorelines. In addition, recent evidence indicates that rapid uplift also occurred at the Menteith moraine in association with the Loch Lomond ice



Land uplift at the Menteith moraine during the past 10,000 yrs. (Sissons and Brooks,1971)

Fig 5

(Kemp, 1971). After this ice had disappeared, isostatic recovery diminished at a fairly steady rate as indicated by the curve in Fig. 5.

During the formation of the Late-glacial beaches in East Fife world sea-level was low. Subsequently the sea rose during the Late-glacial and transgressed westwards along the Forth valley. Extensive gravel deposits were laid down during this marine transgression which apparently began sometime after 13,500 - 13,000 B.P. and ended probably about 10,300 B.P. During most of this time the sea stood at, or slightly above, its present level in relation to the land (Sissons, 1969).

From about 10,300 B.P. to approximately 8,500 B.P. land uplift usually exceeded world sea-level rise, although relatively minor transgressions were probably associated with the formation of the buried beaches as illustrated in Fig. 3. The pronounced rise in the curve in Fig. 3 from approximately 8,500 B.P. indicates a transgression of about 7m in 1,000 years. This marked rise implies rapid melting of the world's glaciers causing eustatic sea-level to rise steadily and overtake the isostatically rising land whose recovery, as noted above, was slowing down during this period. In this context it is significant to note that Bryson <u>et al</u> (1969) believe that in Canada "catastrophic ice disintegration" followed the Cockburn Readvance, which is considered to have culminated between 8,500 B.P. and 8,000 B.P.

The rapid reduction in the rate of sea-level rise as the maximum of the Post-glacial transgression was approached, subsequently followed by regression, indicates that by this time decaying ice sheet remnants were contributing much less water to the oceans and that the isostatic factor became dominant again. The latter is also reflected by the gradients of the younger Post-glacial shorelines.

Summary.

Early explanations for the elevation and slope of the carse clay included marine erosion, estuarine deposition related to tidal influence and land uplift associated with glacial unloading. The Geological Survey classified the marine deposits in the Forth valley into three horizontal beaches, the 100, 50 and 25 foot raised beaches. This scheme was later abandoned as a result of detailed height measurements and geomorphological evidence which revealed that the raised beaches were isostatically tilted; the rate of uplift being related to the age and distance of these features from the centre of isostatic recovery situated in the south-west Grampians.

After the earliest Late-glacial beaches were formed, at about 13,000 B.P., sea-level was low. Some time after this date, however, sea-level rise exceeded land uplift until about 10,300 B.P. From this date to c. 8,500 B.P., land uplift exceeded sea-level rise apart from minor reversals. Initially, land uplift was rapid following ice decay. After 8,500 B.P. world sea-level rose rapidly, as a result of the decay of the world's glaciers, overtaking the isostatically rising land and deposited carse clay over the earlier formed beaches. After the maximum of this transgression, at approximately 6,500 B.P., land uplift, although much diminished, became dominant again.

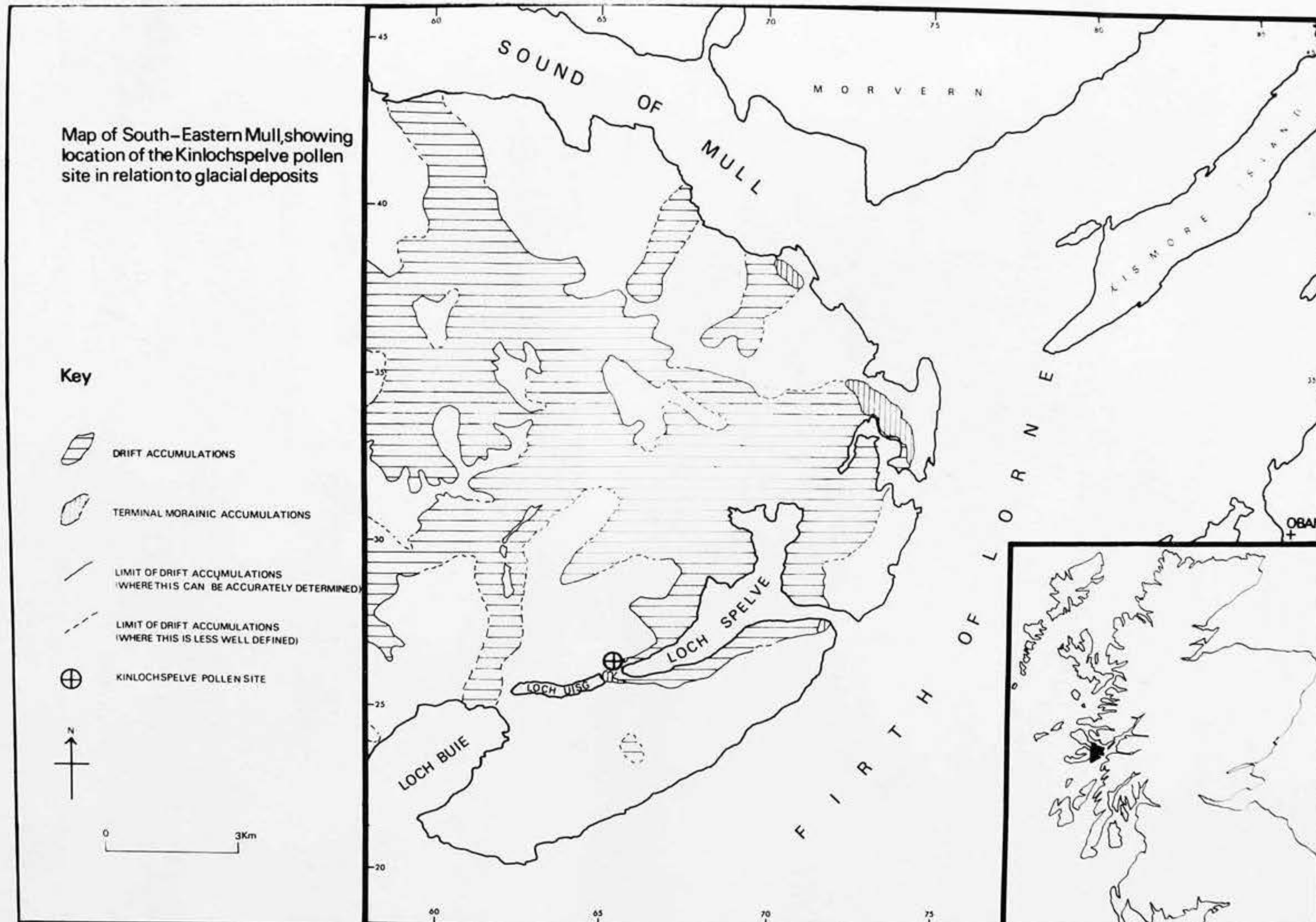

Map of South-Eastern Mull, showing location of the Kinlochspelve pollen site in relation to glacial deposits
Key
DRIFT ACCUMULATIONS
TERMINAL MORAINIC ACCUMULATIONS
LIMIT OF DRIFT ACCUMULATIONS (WHERE THIS CAN BE ACCURATELY DETERMINED)
LIMIT OF DRIFT ACCUMULATIONS (WHERE THIS IS LESS WELL DEFINED)
KINLOCHSPELVE POLLEN SITE
N
0
3Km
SOUND OF MULL
MORVERN
LOCH SPELVE
LOCH UISG
LOCH BUIE
FIRTH OF LORNE
OBAN

Fig 6

1.iv. Outline of the Late-Quaternary Geomorphology of South-East Mull in Relation to Pollen Investigations.

In the area investigated (Fig. 6) a period of local valley glaciation was correlated with the "valley" or "Moraine Glaciation" of the west Highlands (Bailey et al, 1924). Later this glacial stage was correlated with Simpson's (1933) Loch Lomond Readvance ice lobes at Menteith and Loch Lomond (Charlesworth, 1955; Sissons, 1967a, 1967b; Gray and Brooks, 1972) formed during pollen Zone III, between about 10,800 B.P. and 10,300 B.P. (Donner, 1957).

During Zone III in eastern Mull, glacier ice radiated from the mountains and coalesced to form a piedmont ice lobe which occupied Loch Spelve. Evidence of a readvance is provided by marine shells in the Kinlochspelve moraine, which marks the limit of this ice lobe at the head of Loch Spelve. The marine shells also indicate that prior to this readvance the sea occupied the loch. Further evidence of a forward movement of ice is demonstrated by varved clays overlain by crossbedded sand, both truncated by sand and gravel in a section in the moraine near Kinlochspelve Farm. This depositional succession indicates the ice advanced into an ice-dammed lake or sea-loch.

The Kinlochspelve moraine consists of a number of ridges chiefly composed of grey clay with stones. The clay is usually homogenous, but thin lenses of sand occur locally and these contain concentrations of small shell fragments. The latter, although normally weathered, are fairly abundant in certain layers while other parts of the clay are barren. Occasionally, however, better preserved shells are found in the clay. A collection of these shells consisted of species of Tridonta, Arctica islandica, Nuculana, Portlandia, Mya, Littorina, Acanthocardium, Trophonopsis, Buccinum, Tellinaceae, Arenomya, Lunatia and Trochidae, which constitute a marine assemblage of boreal to sub-arctic character, comparable to the molluscan fauna collected from the Loch Lomond and Menteith moraines (Gray and Brooks, 1972).

A radiocarbon date of 11,300 ± 170 B.P. was obtained from a sample of the shells from the Kinlochspelve moraine and which accords with dates of 11,800 ± 170 B.P. and 11,700 ± 170 B.P. from shells in the Menteith and Loch Lomond moraines respectively. The dates from the latter locations are referable to Zone II, (the Late-glacial Interstadial) which preceded the Loch Lomond Readvance (Sissons, 1967a). Thus on this basis the molluscan fauna at the Kinlochspelve moraine is also of Zone II age, which is supported by pollen evidence presented below. (4.viii.pp.122-130).

1.v. Previous Investigations into the Vegetational History of the Western Forth Valley.

Early accounts of vegetational history of the research area are mainly descriptions of plant remains, particularly trees, preserved in peat mosses in the Forth valley. These records, however, are useful to the present study as they shed some light upon the former arboreal vegetation of the Forth region.

Prior to the development of peat bogs, the Forth lowlands were apparently covered with forest vegetation, as indicated by remains of tree trunks projecting through carse clay into overlying peat at numerous locations (Sinclair, 1792). Most of these tree trunks were identified as oak, which signifies that this species was a common constituent of the forest vegetation in the region. Other probable components of this woodland were birch, alder, hazel and willow, as remains of these species were observed by Tait (1794) at the base of Kincardine and Flanders Mosses and at the bottom of Blair-Drummond Moss by Ramsey (1801).

It was generally believed that the forests in the Forth lowlands were mainly destroyed by human agency. Evidence of forest destruction was presented by Tait and later by Aiton (1811). They observed that numerous tree trunks buried beneath peat deposits bore axe marks. In addition, Ramsey reported the presence of wooden causeways and Roman artifacts at the base of Blair-Drummond and Flanders Mosses. Similar archaeological evidence from other peat mosses was recorded by Steele (1826). Thus it was generally accepted that widespread disforestation which, according to Hunter (1883) began about 81 AD, occurred during the Roman occupation of the Forth valley.

Further destruction of the forest resulted in the subsequent development of extensive peat mosses over the Forth lowlands (Sinclair, 1792; Aiton, 1811). Stratigraphic details of two of these peat bogs give an indication of the vegetation which apparently existed as these mosses developed. Ramsey noted that the lower peat of Blair-Drummond Moss was mainly composed of remains of wood and heather, which were overlain by a layer of moss. The upper peat contained abundant remains of wood, grasses and sedges. Thus woodland apparently existed at this site during the early stages of peat development. Later this arboreal vegetation was replaced by moss which in turn was subsequently colonized by trees. On the basis of archaeological evidence at this site Ramsey, and later Hunter, estimated that the peat of Blair-Drummond Moss accumulated over a period lasting nearly 2,000 years. Comparable stratigraphic evidence was obtained from a peat bog near Linlithgow by Steele. At this site woodland, indicated by remains of birch, alder and hazel in the lower peat, was replaced by moss. This type of vegetation was subsequently colonized by heather, as signified by abundant remains of Ericaceae in the upper peat.

These early descriptions of vegetational history, and those from other Scottish regions, were later used by McVean and Radcliffe (1962) and Anderson (1967) to construct maps of the former distribution of primeval forest types in Scotland. These maps show that there existed in the Forth lowlands an extensive mixed-oak forest. Anderson considered that the sheltered position, favourable climate and unleached base-rich soils of the Forth valley favoured the development of mixed-oak woodland.

Knowledge of vegetational history of the research area was advanced by detailed studies of stratigraphy, and in particular by pollen analysis and radiocarbon dating of peat deposits. Using these techniques, workers were able to demonstrate relationships between vegetational development, climate and recent geological changes in the research area, and further, to correlate these events with those in other countries.

Erdtman (1928) was the first to apply the technique of pollen analysis to the problem of the chronology of Post-glacial sea-level change and vegetational development in the Forth valley. In order to cast some light upon this problem, Erdtman selected a site at Ochtertyre Moss where peat rests upon carse clay. The frequencies of arboreal pollen from peat samples at this site indicate the probable existence of Alnus dominated woodland in the region. Betula and, to a lesser extent, Corylus were important constituents of this woodland. Low counts of Quercus pollen suggest that this species may also have been present. Pinus was probably unrepresented as only traces of this pollen type were recorded. Erdtman correlated this stage of forest development with the Sub-Boreal climatic stage recognised in Scandinavia by Blytt (1876) and Sernander (1908). Thus Erdtman considered that the peat of Ochtertyre Moss accumulated during the Sub-Boreal (later named sub-zone V11b by Godwin, 1940, and his followers). As the peat of Ochtertye Moss overlies carse clay, Erdtman concluded that the carse transgression culminated in the Forth valley prior to the Sub-Boreal.

Knowledge of Post-glacial vegetational history in the research area was advanced by Durno (1956). He was also the first to attempt to correlate stages of Post-glacial vegetational development in the Forth valley with Post-glacial vegetational zones recognised at many sites in England and Wales by Godwin (1940). Arboreal pollen frequencies in Durno's pollen diagram from a site at East Flanders Moss, west of Stirling, reflect the development of forest vegetation from Zones V to VIII (modern). In Zone V the arboreal vegetation was dominated by Betula, which was also the major woodland constituent in Zone VI. During Zone VI, however, the composition of the forest changed, as indicated by the rapid expansion of Corylus into the region at the beginning of the zone; the consistent presence of small amounts of Ulmus and, to a lesser extent, Quercus; and the immigration of Alnus into the area towards the end of Zone VI. The presence of thermophilous species, particularly Corylus, Ulmus and Quercus, together with Tilia, indicate the response of forest development to climatic amelioration. (The sub-zonal divisions of Zone VI recognised at English sites by Godwin are not distinguishable in Durno's diagram).

A further stage of forest development is recognised in Zone VII which is characterised by the dominance of *Alnus*. This stage of vegetational development is considered to indicate a cool wet Atlantic or oceanic type of climate, as opposed to the very dry Boreal climate of the preceding zones. Two sub-zones, Vlla and Vllb, are distinguished; the latter sub-zone being characterised by a marked decline of *Ulmus*, which is thought to have been initiated in part by Neolithic agricultural communities, and partly by climatic change unfavourable to this species.

Alnus dominated the arboreal vegetation in Zones VIII and VIII (modern). The latter zone is distinguished by increased representation of *Pinus* and the occurrence of small amounts of *Fagus* which are attributed to modern planting. During these zones herbaceous vegetation increased, indicating progressive forest clearances in response to increasing grazing and agricultural practices. Durno also thought that the representation of arboreal vegetation, particularly the expansion of *Betula* and corresponding decline of *Alnus* and *Corylus*, during these later zones may, in part, reflect progressive soil leaching and concomitant climatic deterioration.

The stages of Post-glacial vegetational development represented in Durno's diagram from East Flanders Moss are comparable to those displayed in Donner's (1957) diagrams from sites at Gartmore and Drymen in the westernmost part of the Forth valley. Donner's work, however, casts some light upon vegetational development during Zone IV (the earliest Post-glacial zone of Godwin's, 1940, schema) and the preceding Late-glacial period in the research area.

At Gartmore and Drymen Zone IV is stratigraphically represented by organic lake muds which overlie Late-glacial solifluction deposits. On the basis of pollen frequencies from the former deposits at both sites, Donner considered that tundra vegetation probably existed in the region during the early part of Zone IV, and that by the end of this zone the herbaceous flora was replaced by birch dominated woodland.

Information relating to Late-glacial vegetational history of the region is obtained from Donner's site at Drymen. At this location deposits referable to Late-glacial Zones I, II and III at other British sites are present. The earliest and latest Late-glacial deposits, of Zones I and III respectively, at Drymen are sparse in pollen and are thus defined by stratigraphy. Zone II deposits, however, are characterised by the predominance of non-arboreal pollen which are considered to reflect the presence of tundra vegetation in the region during this zone. According to Donner, this tundra vegetation probably consisted mainly of sub-arctic heaths composed of *Empetrum* and *Calluna* with many herbaceous species.

The work of Donner was followed by that of Turner (1965), who investigated man's influence upon vegetational development in the research area during the later stages of the Post-glacial period. This work was an advance on previous pollen investigations in the western Forth valley in that radiocarbon evidence was used to date critical stages of Post-glacial vegetational development.

At Turner's site at West Flanders Moss, peat deposits overlie carse clay. Radiocarbon assay of peat immediately overlying the carse clay indicates that organic material began to accumulate over the carse clay at this location at about 5,492 ± 130 B.P. (Godwin and Willis, 1962). According to Turner's pollen diagram, peat accumulated at this site during sub-zones VIIa, VIIb and Zone VIII. Radiocarbon dates of 5,192 ± 120 B.P. and 5,014 ± 120 B.P. were obtained for the VIIa/VIIb transition, while the VIIb/VIII junction was dated at 2,712 ± 120 B.P. Turner considered that the pollen and radiocarbon evidence from this site gives no indication of forest clearances in the western Forth valley before 2,750 B.P. Extensive clearances were made in the region during Zone VIII as indicated by high Gramineae pollen totals in the upper part of the diagram from this site. Additionally, relatively high values of Plantago and Pteridium with low Chenopodiaceae pollen totals are considered to be comparable to the representation of these pollen types in pollen samples from present day pastoral regions. Thus Turner concluded that forest clearances in the Forth valley were associated with pastoralism, practised by nomadic peoples. On the basis of the pollen and radiocarbon evidence from this site, Turner believed that nomadic pastoralism was practised on a small scale in the region during the Bronze and Iron Ages, and that extensive clearances associated with increased pastoral activities began during the Roman occupation of the Forth valley.

Post-glacial sea-level changes and vegetational development in the western Forth valley were investigated by Newey (1966) at two sites, one at West Flanders Moss, the other at Kippen. At the former site, deposits of the Main Buried Beach are overlain by peat which in turn is overlain by carse clay. At Kippen, deposits of the Low Buried Beach are similarly buried beneath peat and carse clay. According to Newey, relatively high Gramineae and low Chenopodiaceae pollen totals from the lower minerogenic layer at West Flanders Moss indicate the probable existence of saltmarsh vegetation as deposits of the Main Buried Beach accumulated at this site. During Zone IV, deposition of the Main Buried Beach ceased and Sphagnum moss began to develop over the beach surface, as indicated by abundant macro-remains of Sphagnum in the peat overlying the buried beach deposits. Oligotrophic vegetation ceased to develop towards the end of sub-zone VIa when carse clay began to be laid down at this location. Rising counts of Gramineae and Chenopodiaceae pollen in the carse clay signify the return of marine conditions as carse clay began to accumulate. Comparable pollen evidence from Kippen indicates the probable existence of saltmarsh conditions as deposits of the Low Buried Beach accumulated at this site in Zone V. During this zone, at about 8,700 B.P., beach deposition ceased. Biostratigraphic evidence from the overlying peat indicates that saltmarsh vegetation developed over the beach surface. Subsequently, marine influence diminished and saltmarsh vegetation was possibly replaced by brackish/freshwater swamp. This type of vegetation was replaced by woodland in sub-zone Vla. Towards the end of this sub-zone, at about 8,300 B.P., carse clay began to be laid down accompanied by the return of saltmarsh conditions. According to Newey, the expansion of marine influence as carse clay was deposited probably resulted in the recession and destruction of coastal woodland.

More recent pollen investigations in the research area relate to the re-investigation of Donner's (1957) Drymen site by Vasari and Vasari (1968). This work, although primarily an investigation of Late - and Post-glacial macrophytic vegetation, sheds more light upon Late-glacial vegetational development in the research area. The pollen frequencies in the lower part of the diagram from this site indicate that during Zone I herbaceous and dwarf shrub vegetation, mainly composed of Gramineae, <u>Rumex</u>, Ericaceae and <u>Empetrum</u>, predominated in the westernmost part of the Forth valley. In addition, small amounts of <u>Betula</u>, <u>Salix</u>, and <u>Juniperus</u> were possibly present. In Zone II <u>Betula</u> increased its representation at the expense of herbaceous vegetation. However, three sub-phases of vegetational development are distinguished in this zone and named after dominant pollen types. The earliest sub-phase is marked by the expansion of <u>Betula</u>, Ericaceae, and <u>Rumex</u>; the next by the spread of _Empetrum_; the third by the development of _Juniperus_. In Zone III open vegetational conditions increased at the expense of tree and shrubs. A transitional zone, III - IV, is distinguished by the increased representation of _Empetrum_ and _Juniperus_ which marks the passage from the Late-glacial to the Post-glacial period.

Summary.

According to early records there existed in the Forth lowlands a primeval forest which was subsequently destroyed by the Romans. Knowledge of vegetational history and chronology of the research area was later advanced by pollen analysis and radiocarbon techniques. The earliest pollen investigations in the research area, by Erdtman, indicate the existence of woodland as peat accumulated over carse clay at Ochtertyre Moss. This woodland stage was correlated with the Sub-Boreal climatic stage recognised in Scandinavia. Durno investigated Post-glacial vegetational history at a site at West Flanders Moss. At this location forest development from Zones V to VIII was distinguished and correlated with comparable stages of Post-glacial arboreal development at English sites. Donner's investigations at sites in the westernmost part of the Forth valley indicate that during the earliest part of the Post-glacial period (Zone IV) tundra vegetation was replaced by woodland. Pollen evidence from one site, at Drymen, indicates that during Late-glacial Zone II tundra vegetation was present in the region.

Anthropological influence upon forest development in the research area was investigated by Turner. On the basis

of pollen and radiocarbon evidence from a site at West Flanders Moss, she concluded that forest clearances, associated with pastoral activities, commenced about 2,800 B.P. and that extensive clearances began during the Roman occupation.

Newey investigated Post-glacial vegetational development and sea-level changes at sites at West Flanders Moss and Kippen. Pollen evidence indicates that phases of marine influence, during Zone IV and sub-zone VIa at West Flanders Moss and Zone V and VIa at Kippen, were associated with the development of saltmarsh vegetation at these sites.

Work by Vasari and Vasari at Drymen casts more light upon Late-glacial vegetational conditions in the research area. In Zone I open vegetational conditions predominated. In Zone II three sub-phases of vegetational development are distinguished; the earliest is marked by the expansion of Betula, Ericaceae and Rumex; the next by the spread of Empetrum; the third by the development of Juniperus. In Zone III herbaceous vegetation increased at the expense of trees and shrubs. The passage from the Late-glacial to the Post-glacial period is marked by the increased representation of Empetrum and Juniperus in Zone III-IV.

1.vi. Vegetational History of the Kinlochspelve Area in South-East Mull.

Maps of the distribution of primeval forest in Scotland, produced by McVean and Radcliffe (1962) and Anderson (1967), show that the original forest cover of the lowland corridor of south-east Mull consisted chiefly of oak with probably some ash. Apart from this information evidence of vegetational history of this area is apparently non-existent.

PART 2.

Research Aims and Selection of Sites.

2. Research Aims and Selection of Sites.

This thesis is an investigation into the characteristics and chronology of vegetational sequences that accompanied changes of climate, land and sea-level in the western Forth valley during the Late-Quaternary. A major part of this study relates to the chronology of vegetational development and raised beaches that accompanied high sea-levels in the research area during the Post-glacial period.

The most extensive and accessible raised beach deposit in the western Forth valley is the carse clay which was laid down during the main Post-glacial transgression. Thus a major aim was to investigate the characteristics of vegetational development in the research area during this period of high sea-level.

Evidence presented earlier (1.iii.pp.29-39) indicates that the initial rise of the main Post-glacial sea-level was relatively rapid. As the sea began to transgress up the Forth valley, however, the land was rising. Land uplift was increasingly pronounced westwards towards the centre of isostatic recovery in the south-west Grampians. In view of this evidence a further aim was to determine whether or not the early rise of the main Post-glacial transgression was progressively retarded westwards by increasing isostatic readjustment. To achieve this aim the commencement of carse clay deposition was dated at sites over a distance of about 23Km west of Stirling. These sites (displayed in Fig. 1) from east to west are, The Homesteads, Bield, Newburn, Easter Mye and Woodend Farm Site 2, and are located on or near the southern carse shoreline, at points where the carse clay is known to be relatively thin and where the underlying peat is well developed.

An attempt was made to determine the characteristics of vegetation and chronology of minerogenic deposits that accompanied the deposition of carse clay at Dollhouse Sites 1 and 2, located about 15Km east of Stirling.

Radiocarbon evidence presented by Godwin and Willis (1962) indicates that the main Post-glacial transgression culminated in the western Forth valley at about 5,500 B.P. This evidence was tested at Woodend Farm Site 1 situated at the south-west margin of West Flanders Moss. Borehole information (Fig. 7) shows that at this location the surface of the carse clay is buried beneath a relatively thin layer of peat. Thus it was possible to obtain organic material from the lower peat for radiocarbon assay in order to date the culmination of the main Post-glacial transgression and to test the pollen investigations at this site.

At The Homesteads and Bield sites raised beach deposits are buried beneath peat which underlies carse clay. Geomorphological evidence presented by Sissons (1972) indicates that the buried beach deposits at these locations are dislocated fragments of the Main Buried Raised Beach. The possibility exists, however, that the buried raised beach deposits at The Homesteads and Bield sites may be unrelated and of different ages. Thus a major objective of the investigations at these sites was to test the geomorphological evidence. A further objective was to investigate vegetational development that accompanied the deposition of the buried beach and overlying peat deposits at these locations. A layer of grey clay buried beneath peat and carse clay at a site at Easter Offerance, west of Stirling, was also assumed to be related to the Main Buried Beach. Thus the major aim of the investigations at this site was to test this assumption.

An important objective of the research presented in this thesis was to produce a pollen profile reflective of vegetational development in the western Forth valley during the Post-glacial period. To this end Woodend Farm Site 2, situated near the western end of the Forth valley, was selected; for at this site peat deposits over 7m thick are present and from which biostratigraphical evidence illustrative of Post-glacial vegetational history was obtained.

Stages of Post-glacial vegetational history recognised in earlier pollen diagrams from other sites in the research area were correlated with comparable Post-glacial vegetation sequences recognised at English sites by Godwin (1940, 1956). Some of Godwin's zonal divisions, however, have not been recognised at sites investigated by Durno (1956) and Donner (1957) in the research area, nor at sites in other parts of Scotland investigated by other workers, (e.g. Moar, 1969; Pennington and Lishman, 1971). Evidence presented by West (1970) shows that some of Godwin's zonal divisions are diachronous and that detailed correlation of vegetational history between distant areas based upon pollen zones is not always possible because of differences in vegetational development in different geographical regions. To overcome this problem, West proposed that a type pollen diagram showing the most complete pollen stratigraphical record available should be constructed for each region in Britain. The regional type diagram should be composed of pollen assemblage zones (as defined by the Report of the Stratigraphical Code Sub-Committee, 1967, and Recommendations on Stratigraphic Usage, 1969) with which comparable pollen assemblage zones in diagrams from other sites can be correlated. Thus spurious correlations with pollen assemblages at sites outwith the region are avoided.

In the light of West's proposals a main aim of the investigations at Woodend Farm Site 2 was to produce a regional type pollen diagram illustrative of Post-glacial vegetational history in the western Forth valley. In addition, an attempt is made to correlate the pollen assemblage zones tentatively recognised in the type diagram with comparable pollen assemblages displayed in diagrams from other sites investigated in the research area.

Late-glacial deposits were investigated at two sites, one of which is situated by the Lake of Menteith in the western Forth valley, the other located at Kinlochspelve (Fig. 6) in south-east Mull. At these locations Zone III end moraine complexes contain ice-transported marine deposits which, according to radiocarbon evidence presented by Gray and Brooks (1972), are referable to Zone II. The main objectives at these sites were to test the radiocarbon evidence and to obtain information of, and correlate, Late-glacial vegetational conditions at these locations.

PART 3.

Research Techniques.

3.i. Field Equipment and Techniques.

The field equipment used in this research consisted of a Hiller peat sampler with a chamber length of 50cm; light alloy extension rods, each 1.5m in length and marked at 10cm intervals; level and staff; plus the usual sterilised bottles, spatulas, labels etc.

At most sites investigated buried beach and overlying peat deposits are concealed beneath carse clay; thus a Hiller sampler was used to obtain stratigraphic information and samples for pollen analysis. A soil auger was first used to remove unwanted surface material, where present, in order to facilitate entry of the sampler. Successive cores were then extracted from alternate closely spaced boreholes; samples being taken at 5cm intervals from the centre of each core. Additional samples were taken for examination of macrofossils. Where deposits were exposed, as at Dollhouse Sites 1 and 2, Newburn and Easter Offerance, samples for analysis were obtained from a cleaned face.

A sample of wood from minerogenic deposits at Dollhouse Site 1 and samples of peat from Newburn and Easter Mye were obtained for radiocarbon assay. At these locations the samples for radiocarbon dating were collected from cleared faces. At Woodend Farm Site 1, however, organic material for radiocarbon assay was extracted from the lowest 10cm of peat by sinking about 30 closely spaced bores and taking from the bore chamber in each case only a narrow central band of peat (about 1cm). Despite these precautions, contamination from higher levels in the peat was possible, therefore additional samples of peat from 30 - 40cm higher in the bores were obtained for dating. These samples consisted of wood from a branch or trunk of birch, about 10cm thick, and contamination of this material during boring was unlikely. About 450gm of peat and a similar amount of wood fragments were collected for radiocarbon assay at this site. All samples for radiocarbon dating were oven dried in the laboratory prior to despatch to a radiocarbon laboratory for processing.

Each site investigated was accurately levelled from Ordnance Survey Bench Marks and critical stratigraphical levels were related to Ordnance Datum.

3.ii. Laboratory Techniques.

Samples for pollen analysis were chemically treated in the laboratory with the objects of separating pollen from their matrix and then concentrating the former in a suitable mounting medium prior to examination. The chemical treatment used depended upon the nature of the deposit. For pure peats a method outlined by Godwin (1956) was used. First, 2gm of each sample were disintegrated by digestion at 100^{o}C in 10% potassium hydroxide, followed by sieving and alternate washing and centrifuging; second, delignification of the centrifugate was obtained by adding to this material a mixture of glacial acetic acid (8 c.c.), sodium chlorate (4.5 c.c.) and concentrated sulphuric acid (1 c.c.) followed by centrifuging and washing; third, acid hydrolysis of the celluloses was achieved by adding a mixture of glacial acetic acid (10 c.c.) and concentrated sulphuric acid (1 c.c.) to the centrifugate which was then heated at 100^{o}C for about 30 minutes, after which the sample was washed and centrifuged. Mineral matter, when present, was removed prior to acetolysis by boiling the sample in 40% hydrofluoric acid, as described by Faegri and Iversen (1964). This procedure was also used to treat pure clay and silt samples.

Microscopic slides were prepared by mounting the centrifugate in approximately twice its bulk of safranin-stained glycerine jelly. Pollen and spores were then identified and counted with the aid of a Baker Patholette microscope fitted with binocular tubes and a micrometer stage. The usual magnification was X320, being increased to X1,000, with oil immersion, when required. To assist identification of the pollen and spores reference slides, together with illustrations, keys and descriptions in text books by Erdtman (1943); Erdtman et al (1961, 1963); Hyde and Adams (1958); Knox (1938); Kuprianova (1965) and Wodehouse (1935) were used.

To examine macroscopic contents of the deposits, samples were first broken down by soaking in 5% sodium hydroxide. Seeds and plant fragments were then washed and inspected.

3.iii. The Pollen Diagrams.

In order to obtain pollen frequencies illustrative of Post-glacial vegetational development in the research area, a total of 150 arboreal pollen grains, excluding *Corylus* and *Salix*, was counted from each prepared sample; non-arboreal pollen and spore frequencies being expressed as percentages of the tree pollen sum. In The Homesteads diagrams (Figs. 19 and 20) the pollen and spore counts at 420cm are expressed as percentages of 100 arboreal grains, as the sample at this level was poor in pollen.

Small numbers of *Polypodium* spores are grouped with those of Filicales; while similar counts of *Lycopodium annotinum*, *L.clavatum*, *L.inundatum* and *L.selago* are combined under Lycopodiaceae. Where applicable, these species are mentioned in the text, as are derived spore types which are grouped under the heading Derived Carboniferous Spores. It is possible, however, that some of these Pre-Quaternary spores may have originated from rocks other than those of Carboniferous age.

A total of 300 pollen and spores, excluding derived Pre-Quaternary spores, was counted from each sample obtained from Late-glacial ice-transported marine deposits in the Menteith and Kinlochspelve end moraines, as arboreal pollen were sparse in the samples from these sites.

PART 4.

Pollen and Stratigraphy of the Deposits at the Selected Sites.

4.i. Woodend Farm Site 2. (NS 561954).

Woodend Farm Site 2 is located in the westernmost part of the Forth lowland and is situated at a point on the south-western edge of West Flanders Moss. Until recently the surface vegetation of the moss at this location consisted mainly of *Sphagnum* spp with grasses, sedges and Ericoids. This vegetation has been cleared, the moss surface drained and planted with young conifers by the Forestry Commission.

This site has been chosen to provide data relevant to Post-glacial vegetation development of the area because, as the stratigraphic diagram (Fig. 7) shows, the bore traverses (1) the upper raised moss peat of Flanders Moss, (2) the carse clay, (3) the lower peat, and reaches minerogenic deposits of the Main Buried Beach. Hence the principal physical phenomena of the Post-glacial of the upper Forth valley are represented by the samples from each of the distinctive horizons intersected by this bore.

Stratigraphy and Macrofossil Content.

The lowest minerogenic layer at this site consists of grey micaceous silty clay of the Main Buried Beach which contains macro-remains of reed and sedge. The surface of this buried beach, at 680cm, is overlain by over 2m of *Phragmites/Carex* peat. This organic material includes bands of birchwood fragments from 636-600cm, 510-480cm and 457-451cm. The peat is replaced by a thin wedge of carse clay from 450-420cm and contains abundant macro-remains of reed and sedge. Overlying the carse clay are

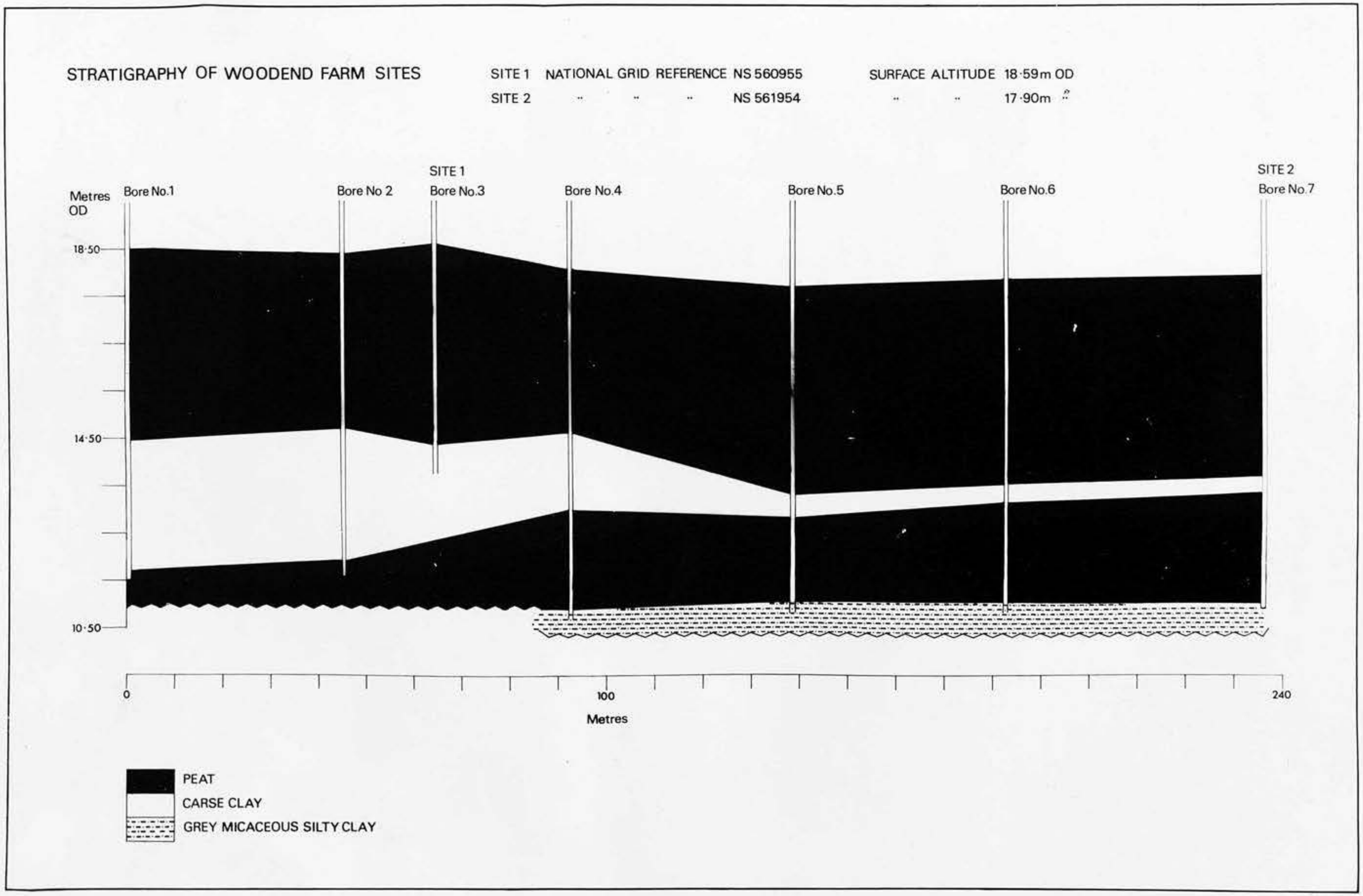

STRATIGRAPHY OF WOODEND FARM SITES
SITE 1 NATIONAL GRID REFERENCE NS 560955 SURFACE ALTITUDE 18·59m OD
SITE 2 " " " NS 561954 " " 17·90m "
Metres OD
18·50
14·50
10·50
Bore No.1
Bore No 2
SITE 1
Bore No.3
Bore No.4
Bore No.5
Bore No.6
SITE 2
Bore No.7
0
100
240
Metres
PEAT
CARSE CLAY
GREY MICACEOUS SILTY CLAY

Fig 7

raised bog peat deposits over 4m thick. The lowest 19cm of this peat layer, from 419-400cm, consists predominantly of reed and sedge remains. This peat type is overlain by 1.8m of mainly Eriophorum spp peat which merges into that of Sphagnum which extends from about 170cm to the surface of the moss. Details of stratigraphy and macro-fossils at this site are tabulated below in Table 1.

Table 1.

Cm from surface	Deposit and Macrofossil Content
0-170	Sphagnum peat, poorly humified.
171-220	Poorly humified Sphagnum/Eriophorum spp peat, macro-remains of the latter type increase in abundance with depth.
221-400	Eriophorum spp peat, of low humification.
401-419	Phragmites/Carex peat, poorly humified; Sphagnum leaves common.
420-450	Carse clay containing abundant leaves and stems of reed and sedge; 1 Carex sp. fruit; 1 Scirpus sp. seed; 3 Lynchis - flos - cuculi seeds; 1 Rumex acetosa fruit; 1 Betula sp. fruit.
	From 451-679cm are peat deposits composed predominantly of Phragmites and Carex remains. The humification of this peat layer is low.
451-457	Numerous fragments of Betula wood; 1 Betula sp. seed; 1 Menyanthes trifoliata seed.
458-480	Phragmites/Carex remains.
481-510	Betula wood; 1 Betula sp. seed; 1 Eriophorum sp. fruit.
511-590	Phragmites/Carex remains.

Continued/

Table 1, continued.

Cm from surface	Deposit and Macrofossil Content
591-599	Abundant *Sphagnum* leaves.
600-612	Numerous *Sphagnum* leaves and *Betula* twigs.
613-636	Abundant pieces of *Betula* wood.
637-670	Abundance of *Sphagnum* leaves.
671-679	*Phragmites/Carex* macrofossils.
680 +	Grey micaceous silty clay (base not reached) containing leaves and stems of *Phragmites* and *Carex*; 1 *Carex* sp. fruit.

The arboreal pollen diagram (Fig. 8) from Woodend Farm Site 2, the longest of all the pollen diagrams presented in this thesis, is of key importance as its features provide a standard of reference with which vegetational and geomorphological data at other locations in the research area can be compared and correlated.

Pollen zones proposed by Godwin (1940) have been widely accepted and used for the sub-division of Post-glacial pollen diagrams throughout the British Isles. When first proposed, they were correlated with the Blytt-Sernander sequence of Post-glacial climatic periods in Scandinavia and archaeological and geological events in Britain and Scandinavia, and given connotations of time synchroneity and climatic equivalence. Little difficulty has been found in applying this zonal scheme to pollen diagrams in England and Wales. The application of

Godwin's zonal criteria at many Scottish sites (including those investigated by Durno, 1956, 1957, 1958c, 1959; Donner, 1957, 1962; Vasari and Vasari, 1968; Moar, 1969), however, is not always possible, as the pollen frequencies in the diagrams from these locations differ from those exhibited in diagrams from more southerly sites.

In view of differences in Post-glacial vegetational history reflected in many pollen diagrams from sites in different geographical areas of Britain, detailed correlation of pollen zones between distant locations is not always possible; although broad correlations of regional vegetational history may be made (West, 1970). The problem of correlating vegetational history within the British Isles has been discussed by West, who proposed a method of correlation based upon biostratigraphy in accordance with accepted rules of geological nomenclature.

According to West, a type site should be selected for each region where the most complete pollen and stratigraphic record for a given period is available. From the biostratigraphical data at this site, a regional type pollen diagram may be constructed. The pollen assemblages in this diagram should be divided into pollen assemblage zones, and these biostratigraphical units into broad chronozonal divisions as defined in the Report of the Stratigraphical Code Sub-Committee (1967).

In the light of West's proposals, the diagrams from Woodend Farm Site 2 are divided into pollen assemblage zones; a pollen assemblage zone being defined as a body of strata characterised by certain assemblages of fossils without regard to their ranges, as stated in the Report of the Stratigraphical Code Sub-Committee. Thus eight pollen assemblage zones, Forth Valley (F.V.) Zones I-III, are tentatively recognised in Fig. 8, each Zone being distinguished by and named after dominant arboreal pollen frequencies.

These biostratigraphical units are divisible into three broadly defined Post-glacial chronozones, PG1 - PG3; a chronozone being defined as a segment of a rock sequence adopted as a standard unit of chronostratigraphy distinguished by marker points in type sections (as stated in the above Report, 1967). Thus Chronozone PG1 covers the period of immigration of woodland species into the research area from Zones F.V.1 - F.V.5. PG2 corresponds to forest development in response to probable optimal climatic conditions in the Forth valley during Zone F.V.6. PG3 corresponds to probable anthropogenic influence upon forest vegetation in the upper Forth valley during Zones F.V.7 and F.V.8. These broad divisions of the Post-glacial, based upon similar chronozonal divisions of the Flandrian (Post-glacial) proposed by West for sites in England and Wales, are regarded as provisional as the limits of these chronozones are not dated by radiocarbon.

According to West, his chronozone sequence for Flandrian deposits can be applied to Godwin's (1940) pollen assemblage zones at Post-glacial sites in England and Wales. Thus West's earliest chronozone, F.1, relates to Zones IV-VI of

Godwin's schema, and embrace the Pre-Boreal and Boreal periods; F.2 corresponds to sub-zone Vlla, the Atlantic period, and F.3 to sub-zone Vllb and Zone VIII, the Sub-Boreal and Sub-Atlantic. The applicability of West's schema to that proposed by Godwin has been demonstrated by Hibbert et al (1971); radiocarbon dates of pollen assemblage and chronozone boundaries of Flandrian deposits at their site at Red Moss, Lancashire, agreeing with dates from comparable boundaries at Godwin's (1957) site at Scaleby Moss, Cumberland.

The main diagram, the arboreal pollen diagram, from Woodend Farm Site 2 illustrates trends in Post-glacial forest history comparable to many others of the British Isles, and the zones characteristic of British forest history, as proposed by Godwin, appear clearly recognisable in it. There are, of course, some differences, explainable by differences in the regional physical environment. There is also a divergence in the chronology of the zonal boundaries as shown (later) by C^{14} dates.

In view of broad similarities between the pollen assemblage zones displayed in Fig. 8 from Woodend Farm and those of Godwin's schema, the zonal and sub-zonal divisions proposed by Godwin are displayed with equivalent Forth Valley pollen assemblage zones in the diagrams at Woodend Farm Site 2 and in those from the other sites investigated. As stated, Godwin's Post-glacial pollen assemblage zones are correlated with the climatic periods of Blytt and Sernander; thus in the light of the preceding discussion these climatic periods are also applicable to the pollen assemblage zones at Woodend Farm.

The Forth valley chronozones, pollen assemblages and zones, and their relationship to Godwin's zonal divisions and the Blytt-Sernander climatic periods are summarised in Table 2 below.

Table 2.

Post-glacial (PG) Chrono-zone.	Pollen Assemblages, Woodend Farm, Site 2.	Forth Valley zones.	Godwin's (1940) zones and sub-zones.	Climatic Periods of Blytt and Sernander.
PG3	*Betula* - *Alnus* - *Quercus*.	8	VIII	Sub-Atlantic
	Alnus - *Betula* - *Quercus*.	7	VIIb	Sub-Boreal
PG2	*Alnus* - *Betula* - *Quercus* - *Ulmus*.	6	VIIa	Atlantic
PG1	*Alnus* - *Betula*.	5	VIc	Boreal
	Quercus - *Alnus* - *Betula* - *Ulmus*.	4	VIb	
	Betula - *Pinus* - *Ulmus* - *Corylus*.	3	VIa	
	Betula - *Ulmus* - *Corylus*.	2	V	
	Betula - *Salix*	1	IV	Pre-Boreal

The Pollen Diagrams (Figs. 8 and 9).

The outstanding regional features illustrated by the AP (arboreal pollen) diagram, (Fig. 8) are as follows:-

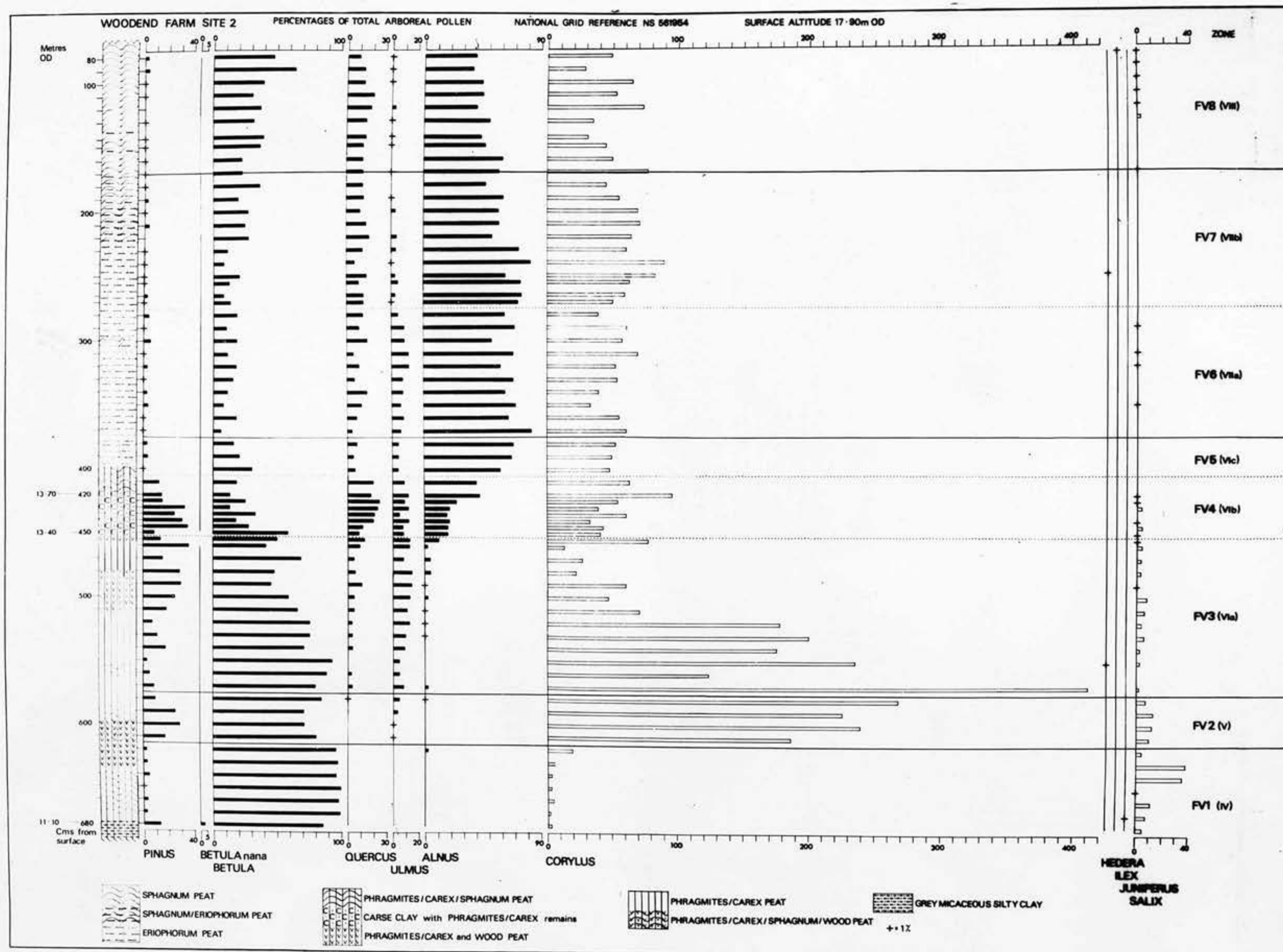

WOODEND FARM SITE 2
PERCENTAGES OF TOTAL ARBOREAL POLLEN
NATIONAL GRID REFERENCE NS 561954
SURFACE ALTITUDE 17·90m OD
Metres OD
Cms from surface
PINUS
BETULA nana
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
HEDERA
ILEX
JUNIPERUS
SALIX
ZONE
FV8 (VIII)
FV7 (VIIb)
FV6 (VIIa)
FV5 (VIc)
FV4 (VIb)
FV3 (VIa)
FV2 (V)
FV1 (IV)
SPHAGNUM PEAT
SPHAGNUM/ERIOPHORUM PEAT
ERIOPHORUM PEAT
PHRAGMITES/CAREX/SPHAGNUM PEAT
CARSE CLAY with PHRAGMITES/CAREX remains
PHRAGMITES/CAREX and WOOD PEAT
PHRAGMITES/CAREX PEAT
PHRAGMITES/CAREX/SPHAGNUM/WOOD PEAT
GREY MICACEOUS SILTY CLAY
+ = 1%

Fig 8

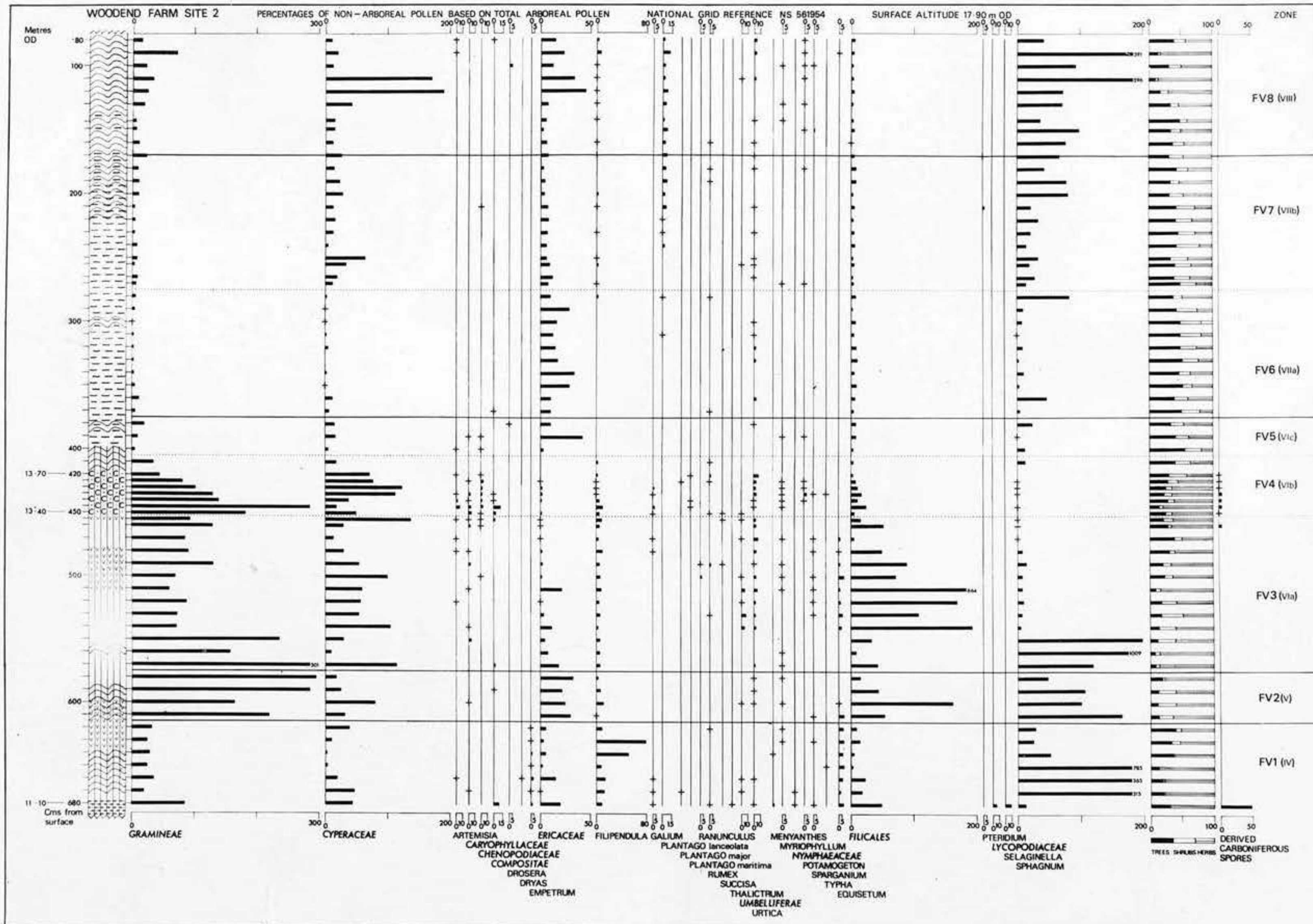

WOODEND FARM SITE 2
PERCENTAGES OF NON-ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
NATIONAL GRID REFERENCE NS 561954
SURFACE ALTITUDE 17·90 m OD
ZONE
Metres OD
13·70
13·40
11·10
Cms from surface
GRAMINEAE
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
DROSERA
DRYAS
EMPETRUM
ERICACEAE
FILIPENDULA
GALIUM
PLANTAGO lanceolata
PLANTAGO major
PLANTAGO maritima
RANUNCULUS
RUMEX
SUCCISA
THALICTRUM
UMBELLIFERAE
URTICA
MENYANTHES
MYRIOPHYLLUM
NYMPHAEACEAE
POTAMOGETON
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
PTERIDIUM
LYCOPODIACEAE
SELAGINELLA
SPHAGNUM
TREES SHRUBS HERBS
DERIVED CARBONIFEROUS SPORES
FV8 (VIII)
FV7 (VIIb)
FV6 (VIIa)
FV5 (VIc)
FV4 (VIb)
FV3 (VIa)
FV2 (V)
FV1 (IV)

Fig 9

Throughout Post-glacial time Betula has been either dominant or a subdominant component of the woodland vegetation, even if the known over-representation of its presence by pollen is allowed for. Its pollen is extremely abundant in the early Post-glacial (Zones F.V. 1, 2, 3) but it becomes less frequent in the middle Post-glacial when the larger deciduous species such as Ulmus and Quercus advanced into the forests in response to increasing climatic warmth and to the development of more eutrophic soil conditions in the area. In the later Post-glacial (Zones F.V.7 and 8) Betula pollen again became important, since climatic and soil deterioration together with forest destruction by man, all favoured its re-establishment.

On the other hand, Pinus has clearly never exercised the dominance indicated by the pollen diagrams of northern Highland sites (Durno, 1958b, 1959; Donner, 1957, 1962; Vasari and Vasari, 1968) or those of eastern England in the earlier Post-glacial (Godwin, 1956). Although the pollen representation of the tree is fairly constant until Zone F.V.6, this is very likely the result of long distance transport of the pollen and many studies have shown that such transport is important (Erdtman, 1943; Faegri and Iversen, 1964). Maps of the former forest cover of Scotland, published by Steven and Carlisle (1959) and by McVean and Radcliffe (1962), indicate that the Forth Valley was south of the area where Pinus was dominant, i.e. the Central and Northern Grampian Highlands.

The type diagram shows clearly, however, that there has been in Central Scotland a considerable middle Post-glacial immigration of the large broad-leaved species, namely Quercus and Ulmus, as shown in Zones F.V.3, 4 and 5. This is contrary to the general supposition expressed by workers more familiar with conditions in southern England. When allowance is made for the known under-representation of Ulmus and Quercus pollen, it becomes clear that these species were dominant over large areas and there is also macro-evidence to support this (e.g. oak stumps in peat bogs, as described in Section 1.v.P.42).

Nevertheless, there are differences in the manner in which these species have developed in the middle Post-glacial forests, contrasting with the evidence from English sites. Thus the rise of both species has been very gradual; Ulmus pollen slowly increases in Zone F.V.3, indicating a gradual change in the composition of the birchwoods of that period, but it was evidently more numerous than oak, which increases its representation even more slowly. Hence the sub-division of the Boreal is different from that at English sites; the English sub-zone Vla is represented by a longer period of time here. Eventually the Ulmus dominance gave way to that of Quercus, allowing the demarcation of sub-zone Vlb, as in England.

A further contrast with English sites is the earlier and more gradual advance of Alnus. This may be due to the widespread existence in Scotland of sites favourable to Alnus, such as low-lying hollows floored by heavy and wet clays, or kettleholes, the result of more recent glaciation.

(We are reminded of the opinion of Tacitus, the Roman historian who, at a later time, described Scotland as "a land of bogs and marshlands"). This early appearance of considerable Alnus pollen frequencies is seen in Zones F.V.4 and 5, before the main rise in Zone F.V.6. In fact, so gradual is this rise, it becomes very difficult to place the zonal boundary with absolute precision. Alnus, however, as in southern England, became very abundant above that level, and thus the Atlantic sub-zone shows many of the features recognised elsewhere in the British Isles.

Corylus again is very similar in status to that which it occupies at English sites. Its values rise very sharply in the early Boreal and it must have formed either a dense pioneer scrub or possibly also a dense understory shrub layer in the deciduous broad-leaved woodlands. It forms a very high proportion of the pollen rain throughout the Boreal period (Zones F.V.2 and 3) although values diminish sharply with the development of closed broad-leaved deciduous woodland, indicated by the Ulmus and Quercus values in Zones F.V.4 and 5.

The decline in Ulmus, used as the zonal criterion marking the passage from F.V.6 to F.V.7, is clearly indicated in the diagram. This event has been the subject of much discussion; in general it has been considered to be the result of selective destruction of this species by primitive farming communities who used the foliage of the tree for feeding their stock; at the same level, pollen of Plantago *lanceolata*, a common weed of land cleared for pasture, becomes frequent with other plants characteristic of open cleared land. The NAP (non-arboreal pollen) diagram (Fig.9) from Woodend Farm Site 2, however, contains no such evidence of the presence of *Plantago lanceolata* at this level, although the activities of primitive farming communities are indicated by the occurrence of *Plantago* pollen at higher levels in the diagram, from 240 - 170cm and from 178 - 80cm. The fluctuations in the frequencies of *Plantago* pollen at these levels are accompanied by reciprocal fluctuations of tree species indicating forest disturbance and its replacement by non-arboreal species.

The Woodend Farm Site 2 diagram thus provides an indication of the broad development of forest vegetation in the western Forth Valley. Other diagrams from sites in the same area have provided a closely comparable picture. Thus Durno (1956) has described forest vegetation on the evidence of a diagram from East Flanders Moss, fairly close to Woodend Farm. His curves for the *Betula*, *Quercus*, *Ulmus*, and *Corylus* species are strikingly similar to the pollen profiles of these taxa in the diagram from Woodend Farm Site 2. In addition the AP curves in Donner's (1957) Drymen diagram reflect a comparable stage of Post-glacial forest history to that reflected in Fig.8 from Woodend Farm.

Shorter cores, again from the same area, have been analysed for pollen also by Newey (1966). The tree pollen curves, particularly those of *Betula*, *Quercus*, *Ulmus* and *Corylus*, from his diagrams at sites at West Flanders Moss and Kippen, also closely resemble the pollen profiles of these taxa which characterise the expansion of woodland at Woodend Farm from the early to the middle Post-glacial. This stage of Post-glacial time is also characterised by comparable woodland development reflected by similar AP curves in a diagram presented by Vasari and Vasari (1968) from Drymen, a short distance west of Woodend Farm. In addition, Turner (1965) has described a sequence of forest development in the upper Forth valley during the late Post-glacial (from the Atlantic to the Sub-Atlantic) from a site at West Flanders Moss. The trends of the AP curves in her diagram are also comparable to those reflecting late Post-glacial woodland history in the diagram from Woodend Farm Site 2.

The NAP diagram (Fig.9), together with biostratigraphy, provides some evidence of local vegetational changes in the area, as distinct from the general pattern of change of the tree cover.

The near horizontal surfaces provided by the buried beach and the carse clay surface, being composed of deposits of low permeability and poor drainage, were suitable sites for the development of peat. In the lower part of the diagram, represented by Zones F.V.1, 2 and 3, this organic deposit is marked by an abundance of <u>Phragmites</u> and <u>Carex</u> fragments and high pollen values of these plants together with <u>Sphagnum</u> spores.

A significant event was the flooding of this peat by the rise in sea-level produced by the main Post-glacial marine transgression and the deposition upon it of the carse clay. Some evidence of the presence of plants of brackish or saline conditions, such as those of Chenopodiaceae and Compositae, is shown in the NAP diagram, although this event is indicated by pollen evidence much more clearly at other sites to be described later.

The upper peat deposit, which appears above the carse clay, belonged to the phase of terrestrial oligotrophic peat formation, which resulted in the development of the large raised bogs of the area of which Flanders Moss is part. Hence *Sphagnum*, the principal peat-building plant, is represented in the diagram by its spore counts together with Cyperaceae and Ericoid pollen. The extremely rapid growth of these bogs, produced in the area by the climatic deterioration which began in Zone F.V.8, is indicated by the increased values of these pollens and particularly of the spores of *Sphagnum*.

Summary.

Woodend Farm Site 2, located in the westernmost part of the Forth Valley, was chosen to provide data of Post-glacial vegetational history in this area. This site is of key importance as deposits reflecting the principal physical events of the Post-glacial in the upper Forth Valley are represented at this location.

The main diagram, the AP diagram, is thus of major importance, as its features provide a standard of reference with which vegetational and physical history at other sites investigated can be compared and correlated.

Following the rules of geological nomenclature, as laid down by the Report of the Stratigraphical Code Sub-Committee (1967), the arboreal pollen frequencies in the Woodend Farm Site 2 diagram are divided into pollen assemblage zones. Each of these zones, of which there are eight, is distinguished by and named after characteristic pollens. They provide an indication of the stages of Post-glacial forest history in the upper Forth Valley and are comparable to the sequences of Post-glacial woodland development recorded at more southerly sites.

The pollen assemblage zones in the Woodend Farm Site 2 diagram are divided into three Post-glacial chronozones (PG 1-3). Chronozone PG1 covers the period of immigration of woodland species in the area, the development of the lower peat, the carse clay and the peat represented in Zone F.V.5. Chronozone PG2 corresponds to Zone F.V.6 when broad-leaved deciduous trees reached their maximum development in the region and raised moss developed at Woodend Farm Site 2 in response to probable optimal climatic conditions in the research area. Chronozone PG3 represents the period of probable anthropogenic influence upon forest development in the upper Forth Valley and the continued development of raised bog at Woodend Farm Site 2. These chronozonal divisions and the boundaries of the pollen assemblage zones at this site are provisional, however, as they have not been dated by radiocarbon.

4.ii. Woodend Farm Site 1. (NS 560955)

This site is situated 175m north of Woodend Farm Site 2 in the south-westernmost part of West Flanders Moss. At the time of the site investigations the moss surface at Woodend Farm Site 1 had recently been prepared for afforestation by the Forestry Commission. As a result the surface of the moss had been cleared of vegetation, drained and planted with young conifers. Beneath these trees and uncleared spaces, the moss surface was being colonised by grasses, sedges and Ericoids.

Borehole evidence (displayed in Fig. 7) shows that there is a great thickness of peat in this locality. Within this organic layer is a wedge of carse clay which decreases in altitude and thickness southwards. Woodend Farm Site 1 is situated at a point where the surface of the carse clay attains a maximum altitude of 14.5m OD, as a major objective was to date the termination of carse clay deposition and associated marine conditions of the main Post-glacial transgression in this part of the western Forth valley.

Stratigraphy and Macrofossil Content.

As the main aim of the investigations relates to ascertaining the termination of the main Post-glacial transgression, only the top 19cm of carse clay, from 450-431cm, and the lowest 10cm of the overlying peat, from 430-410cm, at this site were investigated in detail. The former deposit contained remains of Phragmites and Carex, which became less abundant as depth increased.

Similar organic remains are predominant in the lowest 5cm of peat (from 430-425cm) overlying the carse clay surface. This peat type was replaced by that of Sphagnum from 424-410cm. A summary of the stratigraphy and macrofossils investigated at this location is given in Table 3 below.

Two radiocarbon dates were obtained from separate horizons in the peat. Organic material from the lowest 10cm of peat (from 430-420cm) gave a date of 6,490 ± (I-5309) 125 B.P., and a date of 6,135 ± 105 B.P. was obtained from birchwood from 390-380cm. (I-5839)

Table 3.

Cm from surface	Deposit and Macrofossil Content
410-424	Sphagnum peat, of low humification.
425-430	Phragmites/Carex peat, of low humification.
431-450	Carse clay, containing leaves and stems of Phragmites and Carex which decrease in abundance with depth; 2 Carex sp. seeds.

The Pollen Diagrams (Figs. 10, 11)

The non-arboreal pollen evidence indicates that Woodend Farm Site 1 was influenced by marine conditions as carse clay accumulated at this location. Evidence of marine influence is furnished by high frequencies of Gramineae and small sums of Chenopodiaceae pollen, which indicate the probable local presence of saltmarsh vegetation in response to a high sea-level. This type of vegetation diminished as carse clay deposition drew to a close as signified,

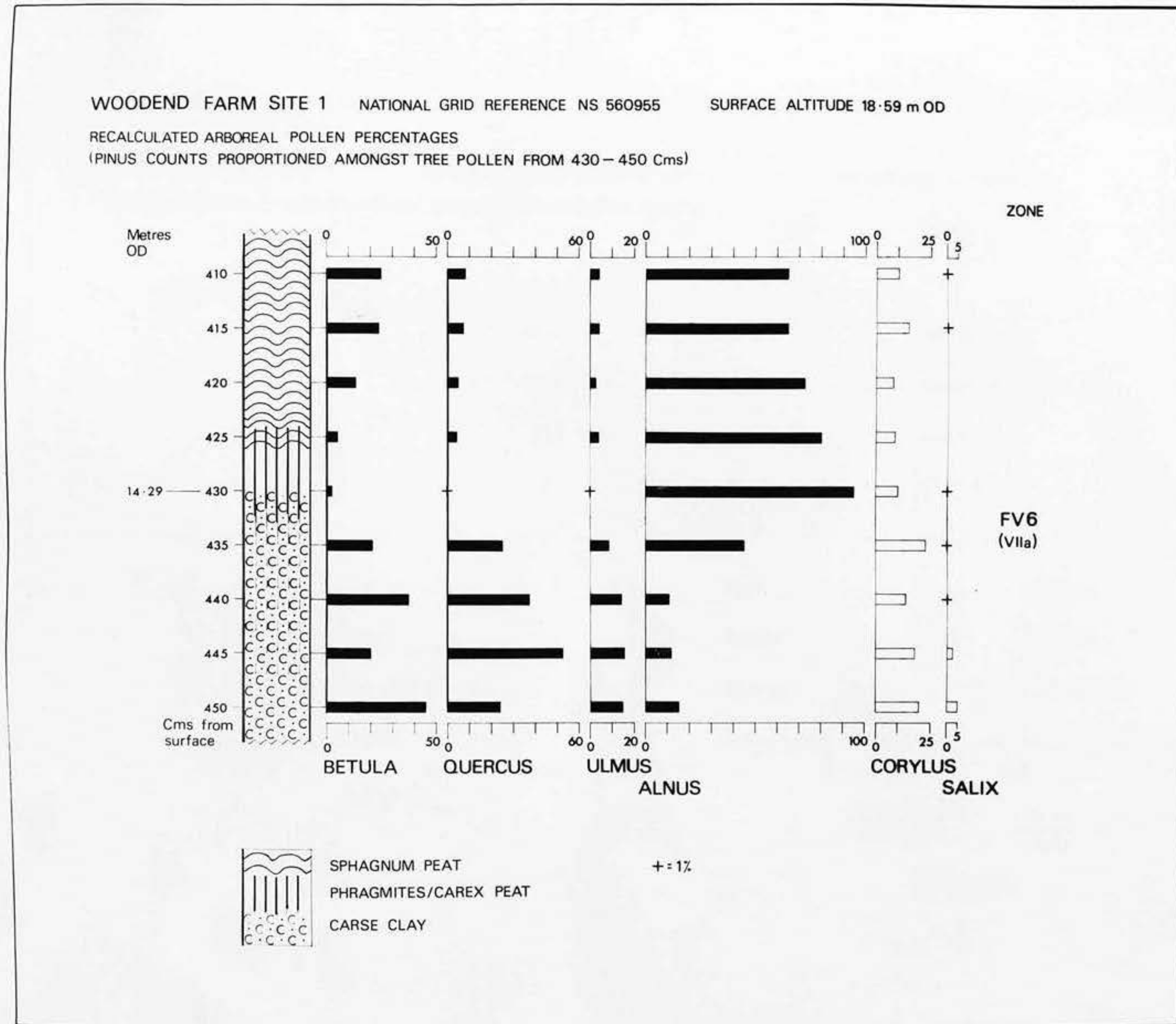

WOODEND FARM SITE 1
NATIONAL GRID REFERENCE NS 560955
SURFACE ALTITUDE 18·59 m OD
RECALCULATED ARBOREAL POLLEN PERCENTAGES
(PINUS COUNTS PROPORTIONED AMONGST TREE POLLEN FROM 430 – 450 Cms)
ZONE
Metres OD
14·29
Cms from surface
410
415
420
425
430
435
440
445
450
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
SALIX
FV6
(VIIa)
SPHAGNUM PEAT
PHRAGMITES/CAREX PEAT
CARSE CLAY
+ = 1%

Fig 10

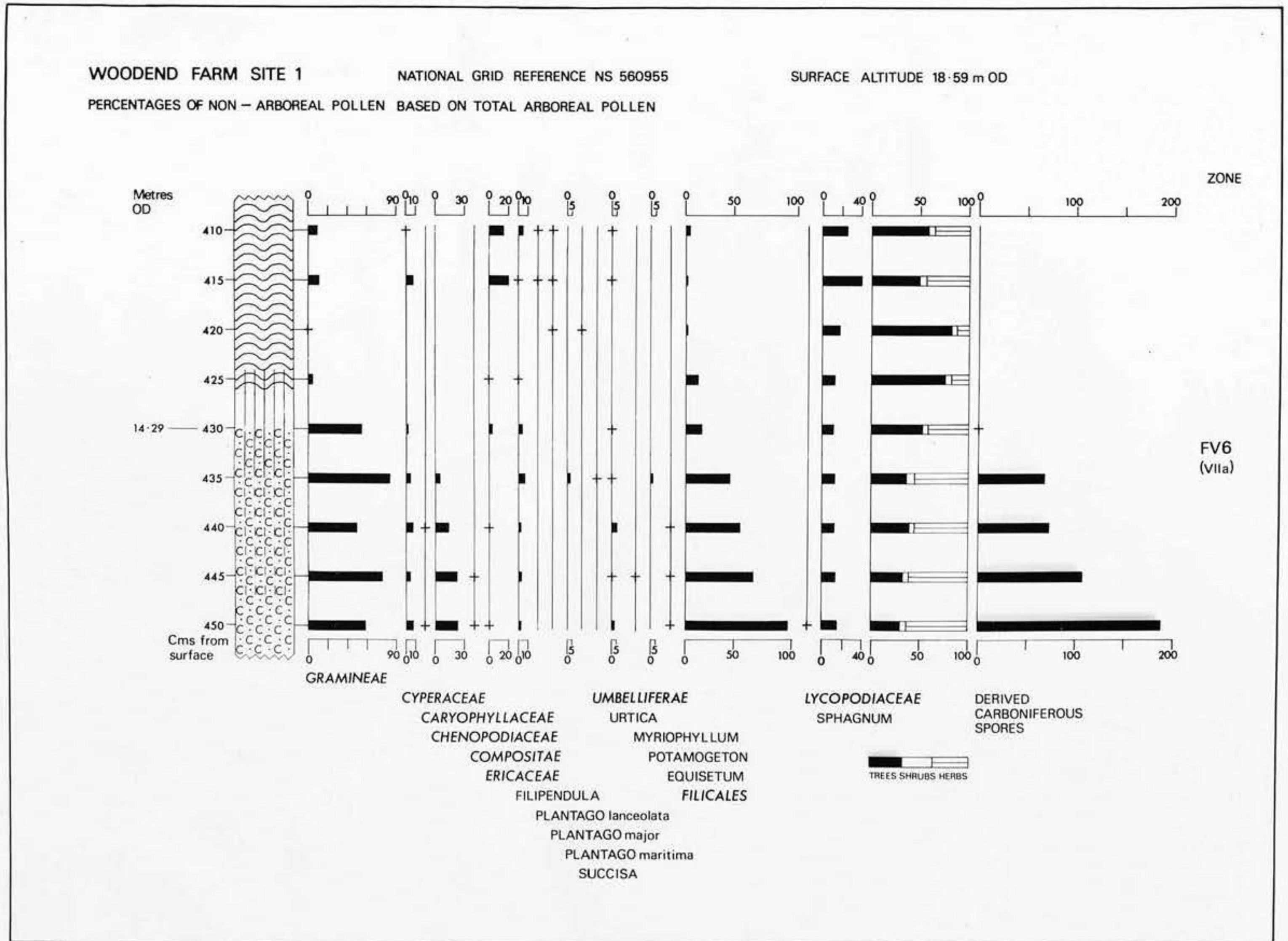

WOODEND FARM SITE 1
NATIONAL GRID REFERENCE NS 560955
SURFACE ALTITUDE 18·59 m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
ZONE
Metres OD
14·29
Cms from surface
FV6 (VIIa)
GRAMINEAE
CYPERACEAE
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
ERICACEAE
FILIPENDULA
PLANTAGO lanceolata
PLANTAGO major
PLANTAGO maritima
SUCCISA
UMBELLIFERAE
URTICA
MYRIOPHYLLUM
POTAMOGETON
EQUISETUM
FILICALES
LYCOPODIACEAE
SPHAGNUM
TREES SHRUBS HERBS
DERIVED CARBONIFEROUS SPORES

Fig 11

notably, by the progressive fall in Chenopodiaceae pollen values towards the carse clay surface.

The withdrawal of the sea from this site is represented firstly, by the replacement of carse clay by peat; secondly, by the abrupt diminution of pollens indicative of marine influence. As the sea withdrew, saltmarsh conditions were evidently replaced by freshwater swamp which developed over the almost level carse clay surface, as indicated by abundant macrofossils of Phragmites and Carex in the lowest 5cm of peat, from 430-425cm.

Freshwater swamp was later replaced by raised moss, as signified by the replacement of Phragmites/Carex peat by that of Sphagnum. The development of oligotrophic communities is confirmed by rising values of Sphagnum spores and Ericaceae pollen in the upper part of Fig. 11. The development of ombrogenous bog at this site may well have been favoured by a change in site conditions such as the replacement of base-rich drainage water by acid water; the latter being associated with poor drainage of the carse clay surface. In addition the development of raised bog at this location was probably associated with increased precipitation, for evidence presented below shows that the moss peat deposits investigated at this location are of Atlantic age; a period characterised by a wet climate and widespread development of raised bogs in Britain.

The arboreal pollen frequencies from 450-435cm in Fig. 10 are dominated by Pinus, which suggests that this species was a major component of the regional woodland during the time when carse clay was deposited at this site. Most, if not all, of the Pinus pollen in this minerogenic deposit, however, may be derived, having been incorporated into the carse clay during tidal movements, because firstly, this pollen type is well adapted to transport by sea (Erdtman, 1943); secondly, large numbers of Pinus pollen are characteristic of marine deposits and associated high sea-level at coastal sites in England (Godwin, 1943) and Germany (Brinkmann, 1934). On this basis the Pinus pollen frequencies from 450-435cm are probably unrepresentative of the regional forest vegetation during the time carse clay was laid down at Woodend Farm Site 1. The remainder of the arboreal pollen totals probably indicate that as carse clay was deposited at this site the regional forest vegetation consisted of oak, elm and birch together with shrubby species such as hazel. In addition low pollen values of Alnus pollen may signify that this plant was also present in the region.

As peat developed over the carse clay surface at this site, alder became an important woodland constituent as indicated by high pollen values of this genus from 430-410cm in Fig. 10. It is possible that alder was present in favourable damp hollows in the carse clay in the vicinity of Woodend Farm Site 1. The possibility also exists that the pollen values of Alnus from the peat are over-represented, as this genus is a prolific producer of pollen, (as described in Section 4.i. above) thus the remainder of the arboreal pollen totals may be depressed.

The representation of Alnus pollen from the peat is comparable to the pollen totals of this plant represented in Zone F.V.6, the Atlantic period, in the type diagram from Woodend Farm Site 2. An Atlantic age for the peat at Woodend Farm Site 1 is also indicated by the radiocarbon dates of 6,490 ± 125 B.P. and 6,135 ± 105 B.P. obtained from this organic layer, as these dates fall within the Atlantic period dated at Scaleby Moss by Godwin, Walker and Willis (1957) as between 7,425 ± 350 B.P. and 4,925 ± 134 B.P.

It might be suggested that the low Alnus pollen values from the carse clay may be referable to an earlier pollen assemblage zone, such as Zone F.V.6 at the type site at Woodend Farm Site 2, as the pollen totals of Alnus in this zone are comparable to those from the carse clay at Woodend Farm Site 2. This suggestion implies that there is either a hiatus between the carse clay and the peat, or that the Alnus pollen values are depressed by those of Pinus. The first possibility is not likely in view of the presence of macro fragments of Phragmites and Carex in the peat immediately above the carse clay indicating a phase of freshwater swamp following the transgression. The second possibility seems also inadmissible as the arboreal pollen values from the carse clay were recalculated, firstly, by excluding those of Pinus, secondly, by proportioning Pinus pollen totals amongst the remainder of the AP frequencies, and no significant changes are apparent as illustrated in Figs. 12a, 12b.

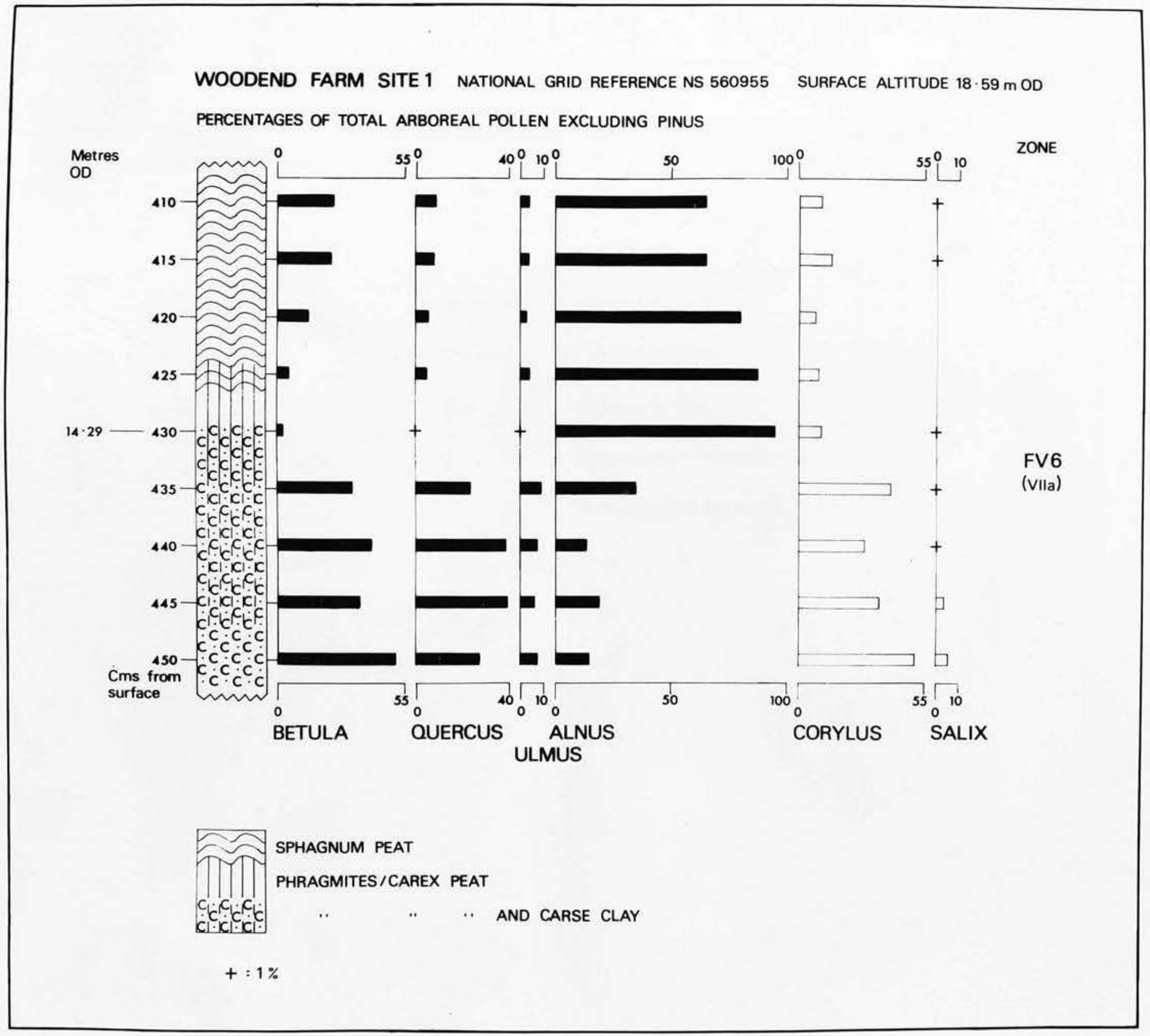
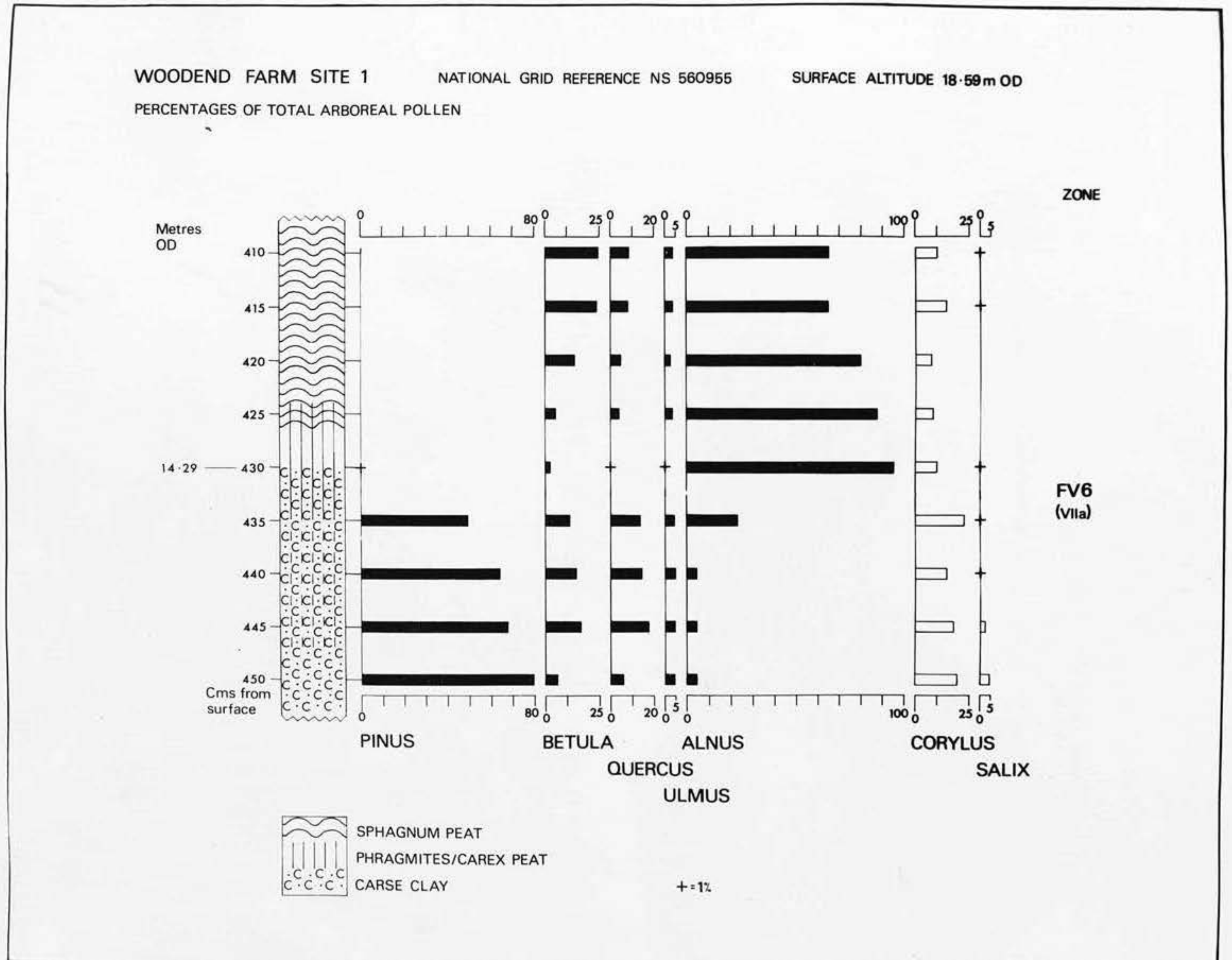

WOODEND FARM SITE 1 NATIONAL GRID REFERENCE NS 560955 SURFACE ALTITUDE 18·59 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN EXCLUDING PINUS
Metres OD
14·29
Cms from surface
410
415
420
425
430
435
440
445
450
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
SALIX
ZONE
FV6 (VIIa)
SPHAGNUM PEAT
PHRAGMITES/CAREX PEAT
" " " AND CARSE CLAY
+ : 1%

Fig 12a



WOODEND FARM SITE 1
NATIONAL GRID REFERENCE NS 560955
SURFACE ALTITUDE 18·59m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
ZONE
Metres OD
14·29
410
415
420
425
430
435
440
445
450
Cms from surface
PINUS
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
SALIX
FV6 (VIIa)
SPHAGNUM PEAT
PHRAGMITES/CAREX PEAT
CARSE CLAY
+=1%

Fig 12b

As sea-level was high during the time when the carse clay was laid down at Woodend Farm Site 2, it is possible that the expansion of <u>Alnus</u> in this locality was delayed until the sea retreated and peat began to develop over the carse clay, as alder is highly intolerant of saltwater (Buxton, 1942; Richardson, 1955). On this basis the carse clay appears to be referable to the Atlantic period (Zone F.V.6). Thus in the light of the above pollen and radiocarbon evidence, the main Post-glacial marine transgression terminated at Woodend Farm Site 1 about 6,500 B.P. during the Atlantic period.

<u>Summary</u>.

Pollen and radiocarbon evidence indicate that the main Post-glacial marine transgression terminated at Woodend Farm Site 1, situated in the south-westernmost part of the Forth valley, during the Atlantic period, at about 6,500 B.P.

4.iii. Easter Offerance Site. (NS 582962)

This site is located in a channel occupied by a small stream which flows northwards to join the river Forth. For most of its length the channel is a narrow, shallow depression in the carse but becomes progressively deeper with steep-sided banks towards the Forth. In many places these steep banks have slumped, covering parts of the channel floor with variable thicknesses of carse clay.

Site investigations were carried out at a point on the channel bottom about 15m south of the Forth. At this location the stream bed consists of a thin layer of peat. Buried beneath this organic deposit is a layer of tenacious grey clay. These organic and minerogenic deposits were traced laterally a short distance beneath a relatively thin layer of slumped carse clay from the stream to the west bank of the channel. Southwards the peat and underlying grey clay extend as essentially horizontal features for about 10m and are then replaced by carse clay. The peat and grey clay could not be traced northwards owing to considerable thicknesses of slumped carse clay.

The main aim of the investigations was to obtain biostratigraphic evidence which would indicate whether or not the grey clay beneath the peat is related to the Main Buried Beach in this part of the western Forth valley. To this end only three samples from the upper grey clay close to the west bank of the channel were analysed.

Stratigraphy and Macrofossil Contents.

The top deposit at this site is carse clay, over 3.5m thick, in which no organic material was seen. Beneath this minerogenic layer is a band of peat, about 10cm thick, which consists predominantly of leaves and stems of Phragmites and Carex. The peat rests upon the surface of a layer of grey clay which contains abundant leaves and stems of Phragmites, the stems of which pass vertically into the overlying peat. Owing to the tenacity of the grey clay the base of this minerogenic deposit was not reached. A summary of the stratigraphy and macrofossils at this site is presented in Table 4 below.

Table 4.

Cm from surface	Deposit and Macrofossil Content
0-363	Carse clay.
364-374	Peat, highly humified, consisting predominantly of leaf and stem fragments of Phragmites and Carex.
375-385 +	Grey clay, containing abundant leaves and stems of Phragmites and Carex.

The Pollen Diagram. (Fig. 13)

An indication of probable vegetational conditions at Easter Offerance, as the grey clay accumulated at this site, is furnished by macrostratigraphy and non-arboreal pollen. Abundant leaf and stem fragments of Phragmites, together with high Gramineae and Cyperaceae pollen totals, signify the presence of reedswamp. Low values of Chenopodiaceae and Plantago maritima pollen indicate that representatives of these saltmarsh plants were also probably present in the

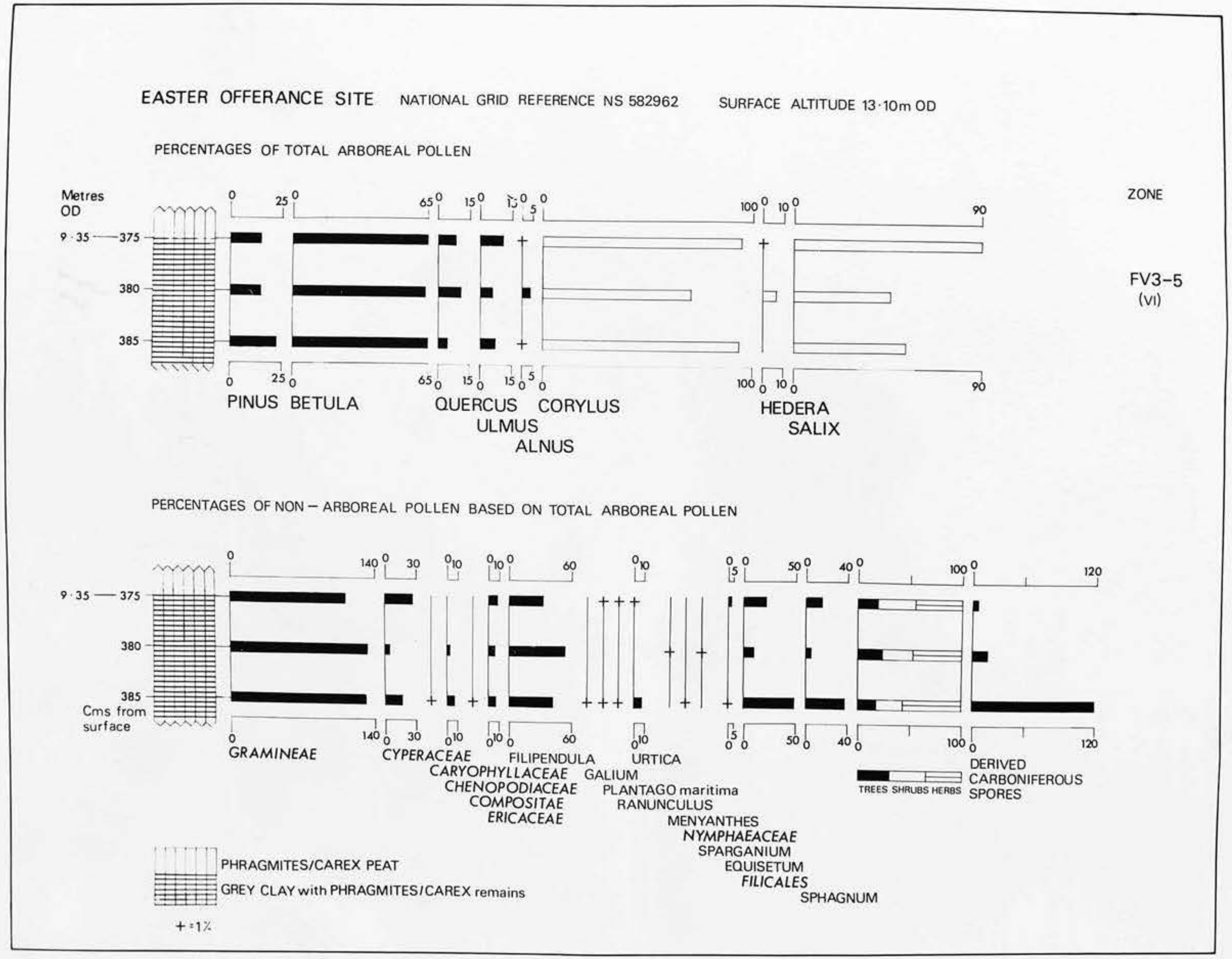

EASTER OFFERANCE SITE
NATIONAL GRID REFERENCE NS 582962
SURFACE ALTITUDE 13·10m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
Metres OD
9·35
375
380
385
PINUS
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
HEDERA
SALIX
ZONE
FV3-5 (VI)
PERCENTAGES OF NON-ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Cms from surface
GRAMINEAE
CYPERACEAE
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
ERICACEAE
FILIPENDULA
GALIUM
PLANTAGO maritima
RANUNCULUS
URTICA
MENYANTHES
NYMPHAEACEAE
SPARGANIUM
EQUISETUM
FILICALES
SPHAGNUM
TREES SHRUBS HERBS
DERIVED CARBONIFEROUS SPORES
PHRAGMITES/CAREX PEAT
GREY CLAY with PHRAGMITES/CAREX remains
+ = 1%

Fig 13

site vicinity, and further indicate that the Easter Offerance site was influenced by marine conditions. On this basis it appears that the grey clay was deposited at this site during a period of high sea-level.

During the time when the grey clay was being laid down at Easter Offerance, woodland apparently existed in the region. The AP frequencies signify that this arboreal vegetation consisted of oak, elm and birch together with shrubby species, notably hazel and willow. Pinus may also have been present in the region, but it seems more likely that the pollen grains of this genus in Fig. 13 are unrepresentative of the vegetation, having been probably incorporated into the grey clay during the period of the prevailing high sea-level.

The pollen totals of warmth demanding species such as Quercus, Ulmus and Corylus broadly agree with the pollen frequencies of these taxa represented in Zones F.V.3-5, the Late-Boreal period, in the regional type diagram from Woodend Farm Site 2. A Late-Boreal age is also suggested by low values of Hedera pollen, as comparable pollen totals of this thermophilous genus are recorded in Late-Boreal deposits by Donner (1957) at sites in central Scotland. On this basis it appears that the grey clay at Easter Offerance was laid down during the Late-Boreal. This interpretation is, however, very tentative owing to the small number of samples analysed for pollen.

The Late-Boreal age of the grey clay indicates that this deposit is not related to the Main Buried Beach as this feature, according to the researches of Newey (1966) and Brooks (1972), ceased to accumulate earlier, during the Pre-Boreal. In addition the grey clay lacks mica, a constituent that is highly characteristic of the Main Buried Beach throughout the research area. The grey clay cannot be related to the High Buried Beach as this feature is found east of the Menteith Moraine and was formed while Zone III ice was at, or in the vicinity, of the moraine. Correlation of the grey clay with the Low Buried Beach can also be excluded because firstly, Newey (1966) has shown that this beach ceased to be formed during Zone V; secondly, the surface altitude of the Low Buried Shoreline west of the Menteith Moraine is about 1.6m lower than that of the grey clay at Easter Offerance.

As the grey clay cannot be correlated with any of the buried beaches it might be suggested that the grey clay and overlying peat are not <u>in situ</u>. This suggestion, however, can be dismissed for the following reasons; firstly, the peat and grey clay are essentially horizontal features; secondly, vertical stems of <u>Phragmites</u> pass through the grey clay into the overlying peat; thirdly, local slumping of peat from the sides of the channel can be excluded because no organic layer is present in the channel walls.

According to pollen and radiocarbon evidence from other sites in the research area (described in Section 4), carse clay was deposited in the western Forth valley during a major marine transgression in the Late-Boreal (Zones F.V. 3-5). As the grey clay also accumulated at Easter

Offerance during this period it appears that this deposit is related to the carse clay.

The evidence above may shed some light upon the sequence of events which took place at this site. 1. Deposition of carse clay by a transgressing sea. 2. A temporary withdrawal of marine influence from this site (discussed later) and development of peat over the carse clay surface. 3. Subsequently, the sea rose and began to deposit carse clays over the peat.

<u>Summary</u>.

A layer of grey clay buried beneath peat and carse clay at Easter Offerance was thought to be related to the Main Buried Beach. Pollen evidence from the grey clay indicates that this minerogenic deposit is unrelated to the Main Buried Beach but appears to be related to the carse clay. This interpretation is, however, very tentative, being based on the analysis of only three samples and a very thin band of pollen bearing deposit.

4.iv. Easter Mye Site. (NS 582952)

The Easter Mye site is located on cultivated carse-land west of the Menteith moraine, and is situated at a point on the southern shoreline of the carse clay. A major objective was to obtain biostratigraphical data by which the rise of the main Post-glacial marine transgression at this site could be dated.

Stratigraphy and Macrofossil Content.

Investigations were carried out at a point where carse clay and peat were exposed in the bank of a small stream. At this location the carse clay is about 76cm thick and contains remains of *Phragmites*, *Carex* and *Juncus*. These organic remains increase in abundance towards the base of the carse clay. Underlying this minerogenic layer is a band of peat composed mainly of *Phragmites* and *Carex* remains. The bottom of this organic layer was not reached, but it is almost certain that it overlies sand and gravel, as a stratigraphic sequence of carse clay, peat, sand and gravel was recorded from a trench dug within 2m of this site (Sissons, unpublished). A radiocarbon date of 7,480
(I-2797) ± 125 B.P. was obtained from the upper 3cm of peat, from 80 - 83cm, exposed in this trench. Summaries of stratigraphy and macrofossils from the deposits exposed in the stream bank and the trench close to this site are presented in Tables 5 and 6 respectively.

Table 5.

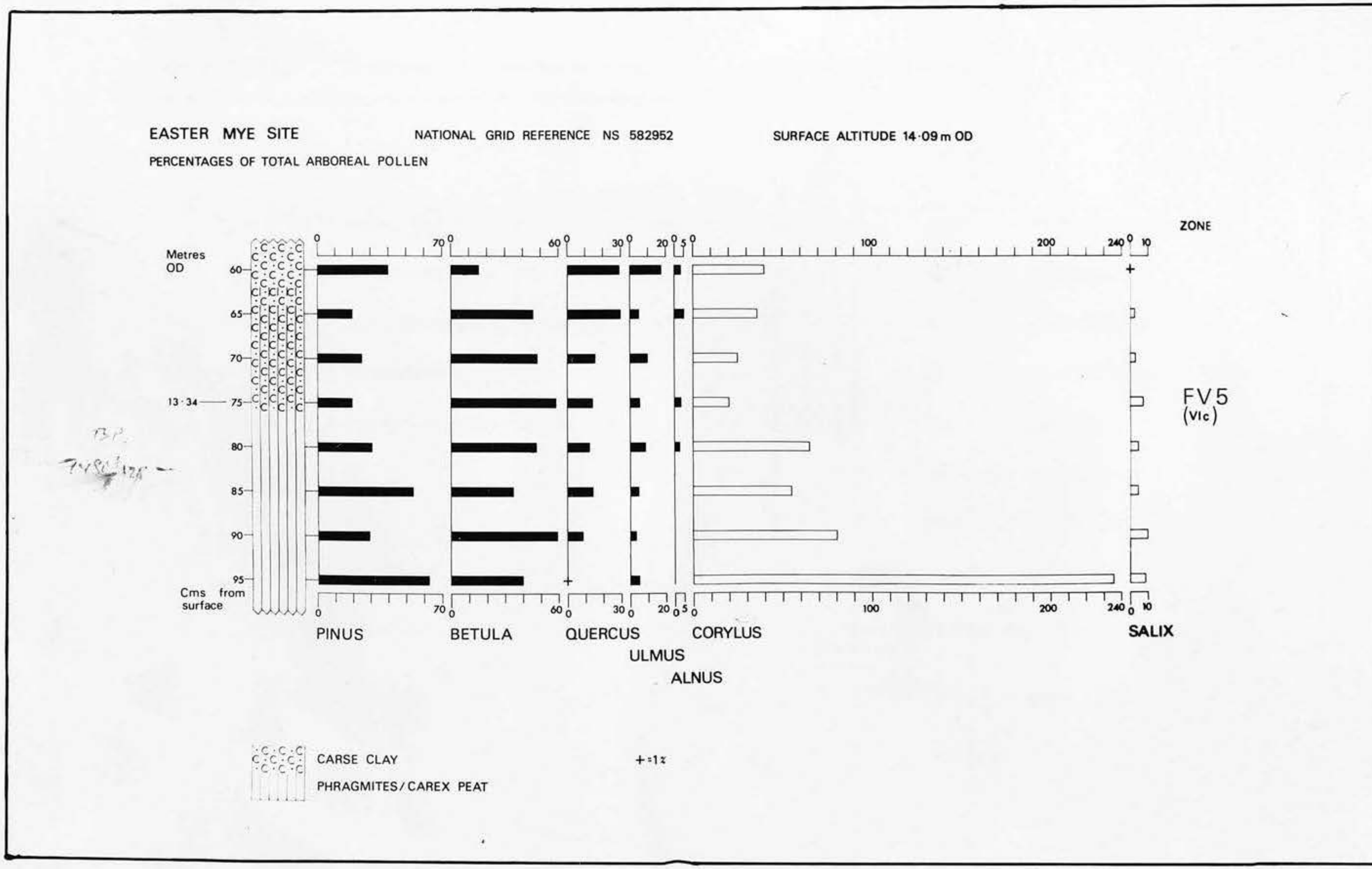
Cm from surface	Deposit and Macrofossil Content
0-76	Carse clay, containing leaves and stems of *Phragmites* and *Carex* which increase in abundance with depth; 2 *Juncus* seeds.
77-95 +	*Phragmites*/*Carex* peat, highly humified; 1 *Rubus saxatilis* seed.

Table 6.

Cm from surface	Deposit and Macrofossil Content (recorded by Sissons)
0-80	Carse clay, containing a flat lying tree-trunk from 70-80cm.
81-100	Peat, containing abundant remains of reed; abundant hazel nuts, some whole at the top of the peat; some wood fragments are also present in the peat.
101 +	Sand and gravel of the Menteith moraine.

The Pollen Diagrams. (Figs. 14, 15)

The AP diagram permits an interpretation of the general vegetational conditions of this area. Pollen of broad-leaved trees, notably *Quercus* and in somewhat lesser amount *Ulmus*, are conspicuous, together with those of *Corylus* and *Betula*. *Pinus* may have been present also, though probably over-represented. Allowing for the known under-representation of pollen of the dominants, a picture of mixed oak wood is conveyed by the diagram, with perhaps a dense understory of



EASTER MYE SITE
NATIONAL GRID REFERENCE NS 582952
SURFACE ALTITUDE 14·09 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
ZONE
Metres OD
13·34
Cms from surface
60
65
70
75
80
85
90
95
PINUS
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
SALIX
FV5 (VIc)
CARSE CLAY
PHRAGMITES/CAREX PEAT
+ = 1 %

Fig 14

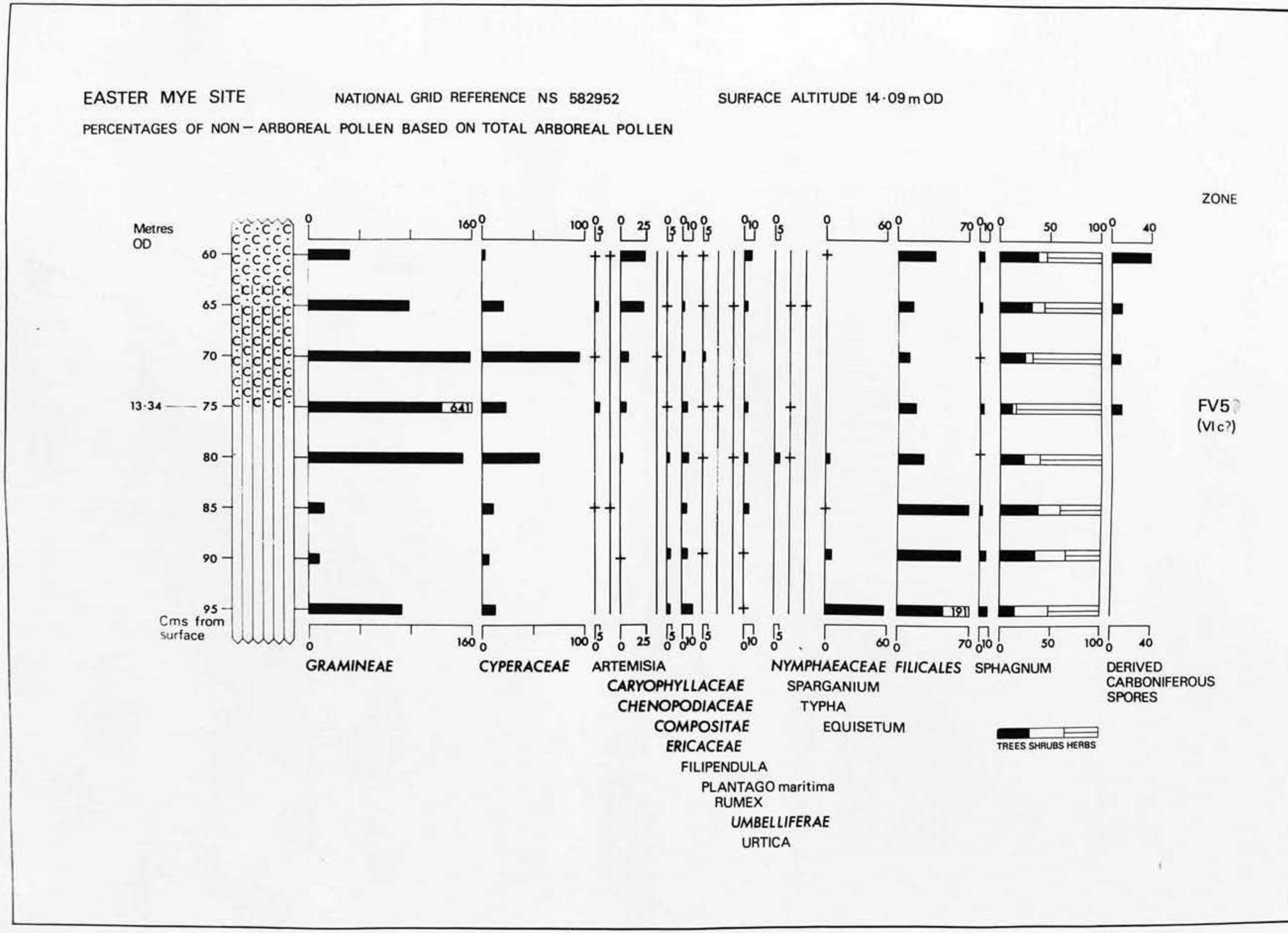

EASTER MYE SITE
NATIONAL GRID REFERENCE NS 582952
SURFACE ALTITUDE 14·09 m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
ZONE
Metres OD
13·34
Cms from surface
60
65
70
75
80
85
90
95
641
191
FV5
(VIc?)
GRAMINEAE
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
ERICACEAE
FILIPENDULA
PLANTAGO maritima
RUMEX
UMBELLIFERAE
URTICA
NYMPHAEACEAE
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
SPHAGNUM
DERIVED CARBONIFEROUS SPORES
TREES SHRUBS HERBS

Fig 15

Corylus; the latter indicated both by pollen and by nuts of Corylus avellana among the macro-remains. Counts of Alnus show a fluctuating rise towards the top of the diagram.

All these features are characteristic of the closing stages of the Boreal and correspond fairly closely to the English sub-zone VIc and to some extent with pollen Zone F.V.5 of the type site at Woodend Farm Site 2. Discrepancies in the actual pollen frequencies are tentatively explainable by differences in site conditions between Easter Mye and Woodend Farm Site 2. As these sites are about 3Km apart, exact correlation cannot be expected; but Easter Mye, being on the edge of the carse clay and nearer to higher and probably more freely drained land than at Woodend Farm, evidently carried a greater frequency of oak and elm and a lesser frequency of alder.

However, the radiocarbon date of 7,480 ± 125 B.P. confirms the Late-Boreal age of the upper part of the peat at Easter Mye. The Late-Boreal period, according to Godwin, Walker and Willis (1957) lasted from 9,000 B.P. to 7,500 B.P. According to this dating the peat at Easter Mye accumulated during the closing stage of the Boreal.

Considering the NAP diagram (Fig. 15) together with the stratigraphy, the main event is the replacement of a freshwater swamp peat, with abundant Phragmites and Carex remnants, by a deposit consisting of increasing amounts of mineral matter representing the carse clay. This feature reflects the initial rise of the main Post-glacial marine transgression at this site. The rise in sea-level produced a saltmarsh type of habitat at first, indicated by pollen of plants tolerant of brackish water or saline conditions such as Phragmites, the Cyperaceae and Chenopodiaceae. However, as the transgression progressed, increasing salinity and a less stable substratum suppressed the growth of reed and sedge so that only the plants of the pioneer stages of the saltmarsh succession, such as representatives of the Chenopodiaceae, remained. A reversal of the usual saltmarsh succession is thus suggested by the pollen frequencies and by the nature of the stratigraphy, brought about by the transgression.

Summary.

Pollen and radiocarbon evidence from Easter Mye indicate that carse clay began to accumulate during the rise of the main Post-glacial marine transgression at this location at about 7,500 B.P. almost at the end of the Boreal period.

4.v. Newburn Site. (NS 613961)

The Newburn site is located in a small valley cut in the carse clay immediately east of the Menteith moraine. The valley floor consists of carse clay, over which a small stream, the Arngibbon Burn, flows northwards to meet the Forth. Site investigations were carried out at a point on the west bank of the Arngibbon Burn, where the following stratigraphic sequence, in descending order, carse clay, peat and grey clay is exposed. The main objective was to date the rise of the main Post-glacial marine transgression at this location.

Stratigraphy and Macrofossil Content.

The carse clay exposed at this site is over 2.5m thick, containing, between 263-268cm, wood fragments of *Populus* and remains of reed and sedges. Underlying this minerogenic layer is a thin band of *Phragmites/Carex* peat which overlies grey clay. This latter deposit also contains remains of *Phragmites* and *Carex* which pass vertically from the grey clay into the overlying peat.

The base of the grey clay was not exposed at the time site investigations were carried out, but according to stratigraphic data recorded by Sissons (unpublished), the grey clay at this site rests upon sand and gravels associated with the Menteith moraine.

From samples of organic material from the top 3cm of peat, from 269-272cm, a radiocarbon date of 8,010 ± 130 B.P. was obtained. (I-2798)

Summaries of stratigraphy and macrofossil content recorded at this location by the writer and by Sissons are presented in Tables 7 and 8 respectively.

Table 7.

Cm from surface	Deposit and Macrofossil Content
0-268	Carse clay, containing wood fragments of Populus and leaf and stem fragments of Phragmites and Carex from 263-268cm.
269-277	Peat, highly humified, containing abundant leaves and stems of Phragmites and Carex.
278 +	Grey clay, containing remains of reed and sedge which decrease in abundance with depth; 3 Carex sp. nutlets.

Table 8.

Cm from surface	Deposit and Macrofossil Content (recorded by Sissons)
0-268	Carse clay.
269-310	Peat.
311-321	Grey clay, containing many plant remains and scattered stones, the latter up to 2cm long.
322-359	Sand and gravel, containing stones up to 5cm long from 322-330cm; from 331-358cm deposits are iron-cemented.

The Pollen Diagrams. (Figs. 16 and 17)

The tree pollen curves in Fig. 16 signify the existence of a regional woodland as the grey clay, peat and carse clay accumulated at the Newburn site. This regional forest

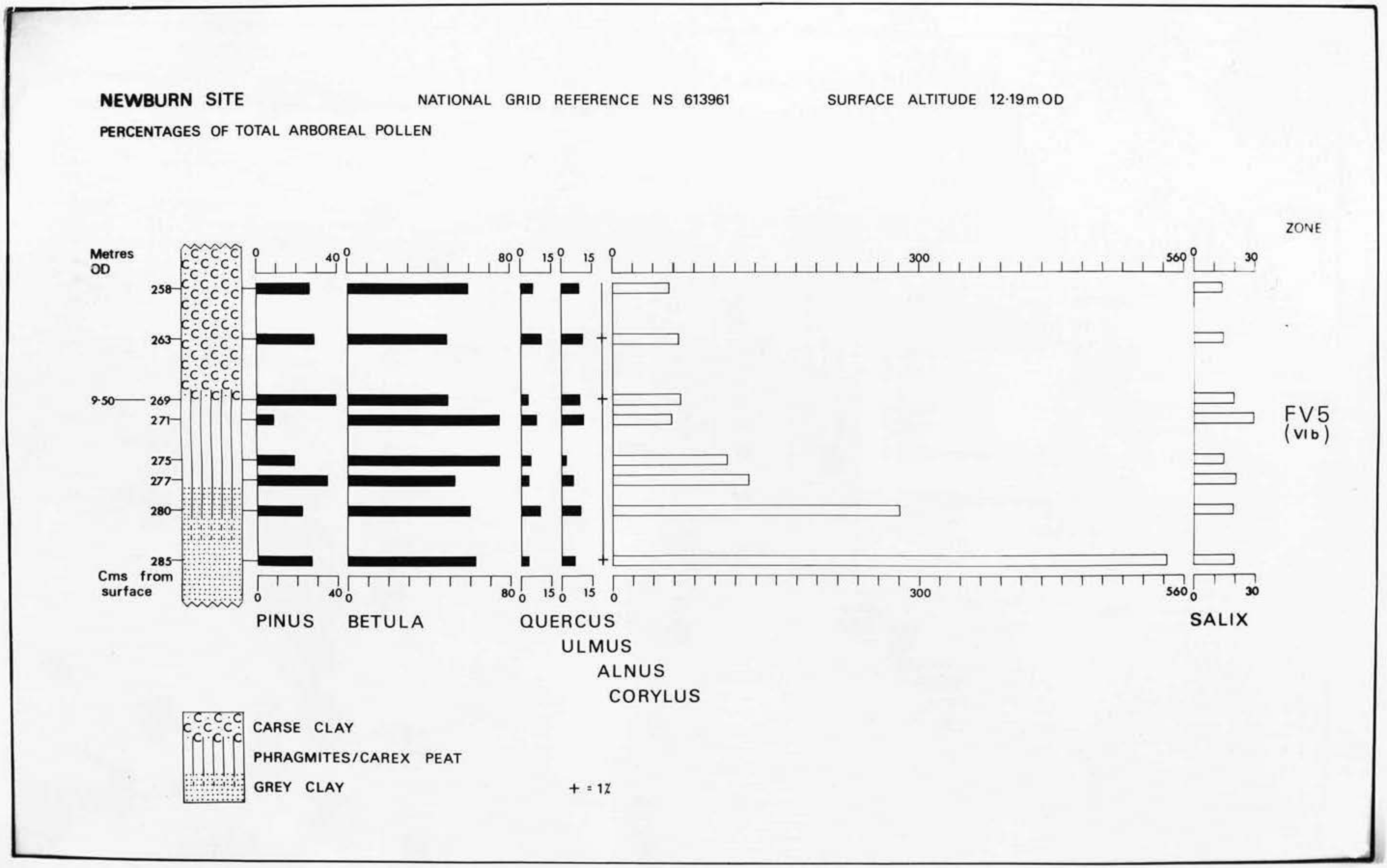
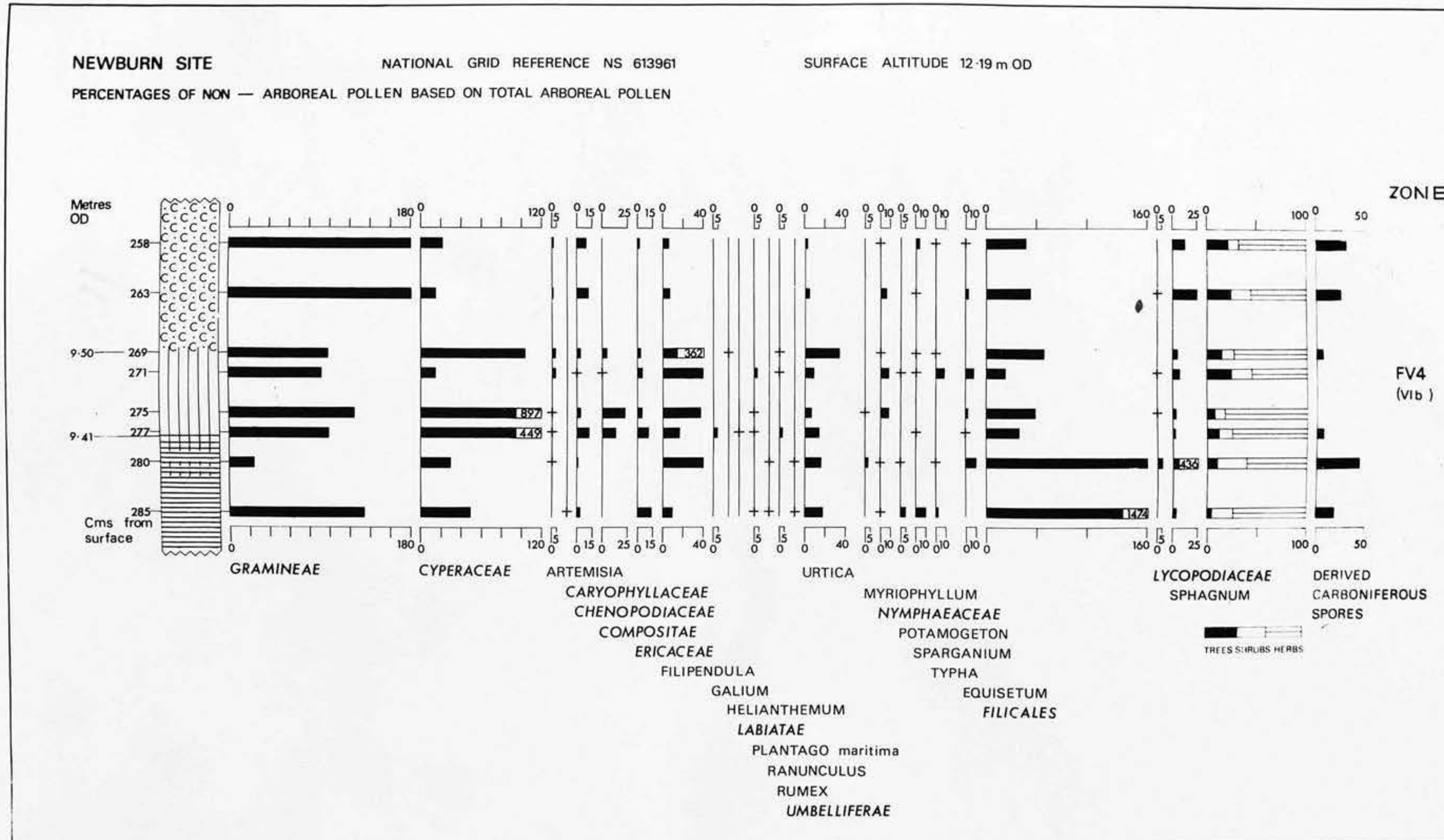

NEWBURN SITE
NATIONAL GRID REFERENCE NS 613961
SURFACE ALTITUDE 12·19 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
ZONE
Metres OD
9·50
258
263
269
271
275
277
280
285
Cms from surface
PINUS
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
SALIX
FV5 (VIb)
CARSE CLAY
PHRAGMITES/CAREX PEAT
GREY CLAY
+ = 1%

Fig 16



NEWBURN SITE
NATIONAL GRID REFERENCE NS 613961
SURFACE ALTITUDE 12·19 m OD
PERCENTAGES OF NON — ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Metres OD
Cms from surface
ZONE
FV4 (VIb)
GRAMINEAE
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
ERICACEAE
FILIPENDULA
GALIUM
HELIANTHEMUM
LABIATAE
PLANTAGO maritima
RANUNCULUS
RUMEX
UMBELLIFERAE
URTICA
MYRIOPHYLLUM
NYMPHAEACEAE
POTAMOGETON
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
LYCOPODIACEAE
SPHAGNUM
DERIVED CARBONIFEROUS SPORES
TREES SHRUBS HERBS

Fig 17

appears to have consisted of oak, elm and birch, together with hazel and willow. Pine may also have been present in the region. The possibility exists, however, that the Pinus pollen from the grey clay and carse clay are unrepresentative; for according to stratigraphic and pollen evidence below, these minerogenic deposits were laid down during periods of high sea-level; thus some or all of the Pinus pollen from these horizons may have been subject to marine transport and deposition.

Some changes in the composition of the regional woodland during the time when grey clay, peat and carse clay accumulated at Newburn are discernible in the arboreal pollen profiles. The most striking change in the woodland vegetation is the decline of hazel. This species appears to have been a major woodland element as grey clay accumulated at Newburn, but was of relatively minor importance as carse clay began to be deposited at this site, as signified by the progressive fall in Corylus pollen values from 560% at 285cm to 28% at 258cm in Fig. 16. It is possible that Corylus declined as Quercus and Ulmus expanded in the region, as rising pollen totals of oak and elm are accompanied by relatively low hazel pollen frequencies from the carse clay.

The occurrence of wood fragments of Populus sp. in the carse clay, from 263-268cm, suggests that this genus was also present in the region as carse clay began to be deposited at Newburn. Populus sp. is a widely distributed tree, having a northerly range, and according to Tansley (1939), is often found in present day oakwoods. Thus it seems possible that poplar was present during the time oakwood expanded in the Newburn region. No pollen or macro-remains of Populus sp. have been recorded at other sites in the western Forth valley. In fact Populus has been recorded at a very small number of other Scottish sites. Of these, small frequencies of poplar pollen have been recorded from Boreal deposits at a site in southern Scotland by Godwin (1956) and from deposits of a similar age from a site in south-west Scotland by Moar (1969). In addition macro-remains of Populus have been recorded from material of equivalent age at a site in Aberdeenshire by Vasari and Vasari (1968). In contrast, macrofossils of poplar have often been found in Late-glacial Zone II deposits at more southerly sites.

With regard to zoning, the similar frequencies of Quercus and Ulmus pollen in Fig. 16 are unhelpful. However, the decline of Corylus, the very low values of Alnus and substantial counts of Betula pollen in this diagram broadly agree with the pollen profiles of these taxa displayed in Zones F.V.3 and/or F.V.4 in the type diagram from Woodend Farm Site 2. In addition the counts of Corylus, Alnus and Betula in Fig. 16 are comparable to the pollen frequencies of these species recorded in sub-zone Vlb at Newey's (1966) site at Kippen, about 1Km east of Newburn. At the former site the Vla/Vlb transition has been dated by radiocarbon at 8,270 ± 130 B.P. Thus the younger date of 8,010 ± 130 B.P. obtained from the peat/carse clay junction at Newburn indicates that carse clay began to cover the peat at this site during VIb. As this sub-zone corresponds to Zone F.V. 4 at Woodend Farm Site 2, it appears that the deposits at Newburn are referable to Zone F.V. 4.

Information of local site conditions as grey clay, peat and carse clay accumulated at Newburn is furnished by stratigraphy and non-arboreal pollen. The frequencies of Gramineae, Cyperaceae and Filipendula pollen from 285-280cm in Fig. 17 indicate the probable presence of freshwater marsh in the vicinity of Newburn as grey clay was deposited. In addition, small sums of Chenopodiaceae suggest that saltmarsh vegetation was also present, and further suggest that the Newburn site was influenced by a high sea-level as the grey clay was laid down at this location.

A change in stratigraphy from grey clay to peat at 278cm indicates a withdrawal of marine conditions from this site. This event, discussed later, was followed by the development of freshwater marsh, signified by pollen frequencies of Gramineae, Cyperaceae and Filipendula over the grey clay surface. The sea, however, did not retreat far from Newburn, as saltmarsh vegetation continued to develop as peat accumulated at this site, as indicated by the totals of Chenopodiaceae, Compositae and Artemisia maritima pollen from this organic material.

A return of marine conditions and the expansion of saltmarsh vegetation is signified by rising values of Chenopodiaceae and, to a lesser extent, Artemisia maritima pollen from 269-258cm. During this time sea-level rose and carse clay began to be laid down over the peat at Newburn.

In the light of the above evidence, the following sequence of events possibly took place at Newburn.

1. Grey clay was deposited at this site during a period of high sea-level. As this minerogenic deposit is of Zone F.V.4 age it cannot be related to the buried beaches in the western Forth valley as these features were formed at earlier times (as shown in Section 4.iii above). It is possible, however, that the grey clay is related to the carse clay, as this latter material began to accumulate, during a period of high sea-level, at Kippen during Vlb about 8,300 B.P., a short time before carse clay began to be laid down at Newburn. 2. Marine influence temporarily withdrew from Newburn and freshwater marsh and peat developed over the surface of the carse clay. As this minerogenic layer is probably related to the carse clay and as the land was still rising as this latter deposit was being laid down in the western Forth valley, it seems possible that at Newburn the land rose faster than the sea and favoured the development of peat over the exposed carse clay surface at this site. 3. Sea-level subsequently rose, overtaking the rising land and began to deposit carse clay over the peat.

Summary.

Pollen evidence indicates that grey clay, peat and carse clay accumulated at Newburn probably during Zone F.V.4. The following sequence of events possibly took place at this site. 1. Grey clay, possibly related to the carse clay, was deposited at this site. 2. This was

followed by a temporary withdrawal of marine conditions and the development of freshwater peat over the surface of the grey clay. 3. Subsequently sea-level rose and began to deposit carse clays over the peat at about 8,000 B.P.

4.vi. The Homesteads and Bield Sites. (NS 778932.NS 696947)

These sites are located at points close to the southern carse shoreline east of the Menteith moraine. At both locations carse clay overlies peat which in turn rests upon deposits of the Main Buried Beach. The Main Buried Shoreline in this area slopes gently eastwards at an average gradient of 0.12m/Km and then descends sharply through 1.5m over a horizontal distance of less than 1Km; it then becomes horizontal for a distance of about 10Km (Sissons, 1972). This evidence indicates that there is a pronounced dislocation of the Main Buried Beach. It is possible, however, that two buried beach surfaces of different ages are represented in this part of the western Forth lowlands. Thus a major aim of the investigations was to test this possibility.

Both sites are situated within 10m of the southern Main Buried Shoreline, one on each side of the dislocation of the buried beach (as shown in Fig. 18) and where overlying peat was known to be well developed. At Bield the buried beach surface is at 9.04m OD while farther east at The Homesteads site it is at 7.44m OD.

At each site samples for pollen analysis were collected from the upper part of the buried beach, from the overlying peat and the lower part of the carse clay. Samples at 10cm intervals were analysed initially, intervening samples at 5cm intervals being analysed later where more information was required.

Radiocarbon dating of the peat at these locations was not attempted since, with the equipment available,

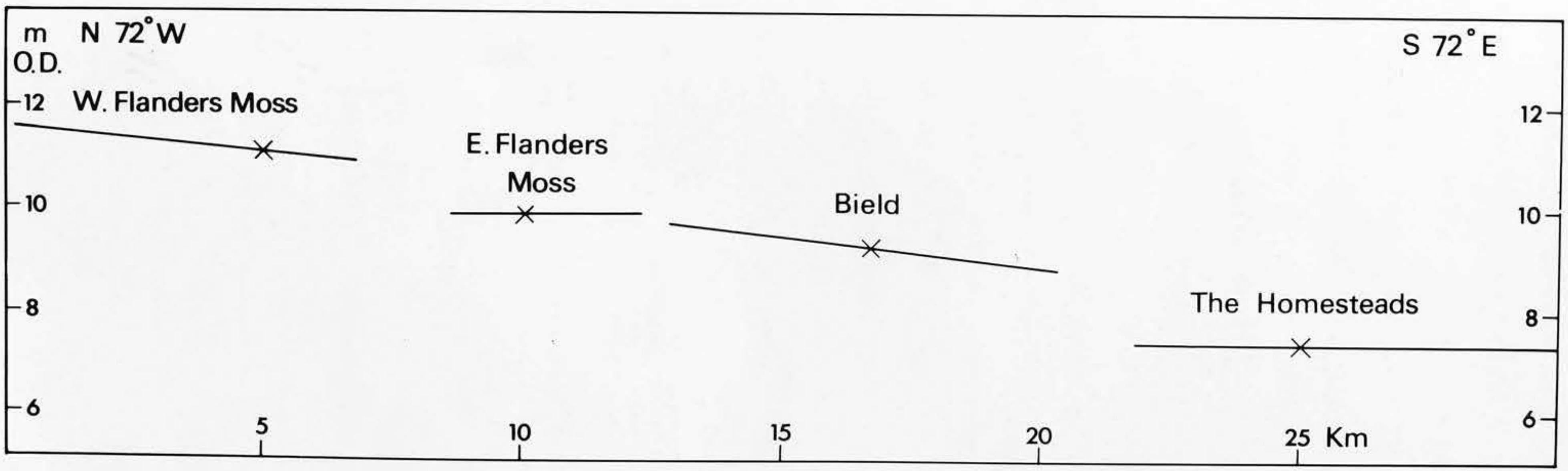


Fig 18 Location of pollen sites in relation to the Main Buried Shoreline

sufficiently large samples could have been obtained only by putting down numerous closely spaced bores and the risk of contamination was therefore high. It should be added that the buried peat which rests upon the Main Buried Beach is nowhere exposed in the area investigated.

Stratigraphy and Macrofossil Content.

At The Homesteads site the buried beach deposits are composed of grey micaceous clay. This minerogenic layer contains leaf and stem fragments of Phragmites and Carex from 420-409cm and abundant Sphagnum leaves from 410-405cm. Overlying the buried beach deposits is a band of highly humified peat about 74cm thick. The basal 4cm of this organic layer, from 404-400cm, consists of Sphagnum peat which is replaced by that of Phragmites/Carex from 399-391cm. From 390-368cm is Sphagnum peat which is replaced by Phragmites/Carex peat from 367-355cm. From 375-355cm the peat is impregnated with micaceous silt. From 354-355cm is Sphagnum peat which is replaced by that of Phragmites/ Carex from 339-330cm. Overlying this organic deposit is carse clay which contains abundant remains of reed and sedge. Details of stratigraphy and macrofossils at this site are summarized in Table 9 below.

Table 9.

Cm from surface	Deposit and Macrofossil Content
0-329	Carse clay, containing abundant leaf and stem fragments of Phragmites and Carex from 320-329cm. Also in this horizon 1 Gramineae caryopsis.

/Continued

Table 9, continued.

Cm from surface	Deposit and Macrofossil Content
	The peat layer underlying the carse clay, from 330-404cm, is highly humified.
330-339	Phragmites/Carex peat.
340-354	Sphagnum peat, containing 1 Empetrum fruitstone.
355-367	Phragmites/Carex peat, impregnated with micaceous silt.
368-390	Sphagnum peat; 2 Carex nutlets. From 368-375cm this peat type contains micaceous silt.
391-399	Phragmites/Carex peat; 1 Betula sp. fruit; 1 Carex sp. nutlet utricle with fungal fruiting bodies; 2 Menyanthes trifoliata seeds.
400-404	Sphagnum peat; 1 Carex sp. nutlet; 1 Menyanthes trifoliata seed.
405-420 +	Grey micaceous clay, containing abundant Sphagnum leaves from 405-410cm and leaf and stem fragments of Phragmites and Carex from 411-420cm.

The buried beach deposits at Bield consist of grey micaceous clay, similar to that of the buried beach at The Homesteads. At the former site this minerogenic layer contains macro-remains of Phragmites and Carex together with fruits of Eleocharis sp., Scirpus sp., Triglochin maritima and Carex sp. Stems of reed and sedge pass vertically from the grey clay into a band of highly humified Phragmites/ Carex peat, about 45cm thick. This peat is overlain by nearly 4m of carse clay. The basal 4cm of this deposit, from 394-390cm, contains abundant macro-remains of reed and sedge together with fruits of Betula sp. The stratigraphy and macrofossil contents at this site are tabulated below in Table 10.

Table 10.

Cm from surface	Deposit and Macrofossil Content
0-394	Carse clay, containing, from 380-394cm, abundant leaves and stem fragments of Phragmites and Carex; 3 Betula sp. fruits; 3 Gramineae caryopses.
395-435	Phragmites/Carex peat, highly humified.
436-480 +	Grey micaceous clay, containing abundant macro-remains of reed and sedge; 2 Carex sp. embryo fruits; 8 Eleocharis palustris fruits; 1 E.uniglumis fruit; 16 Scirpus tabernaemontanus fruits; 1 S.tabernaemontanus/lacustris fruit; 5 Triglochin maritima fruits.

The Pollen Diagrams. (Figs. 19, 20, 21, 22)

High non-arboreal pollen ratios recorded from 420-390cm at The Homesteads site (Fig. 20) and from 480-450cm at Bield, (Fig. 22) include small numbers of Dryas, Empetrum (which reaches, however, a maximum of 60% of the NAP total at Bield), Helianthemum and Thalictrum alpinum pollen and spores of Lycopodiaceae and Selaginella. These pollen and spores are characteristic of Scottish Late-glacial and early Post-glacial vegetation (Donner, 1957; Kirk and Godwin, 1963; Vasari and Vasari, 1968; Moar, 1969; Newey, 1965, 1966, 1970).

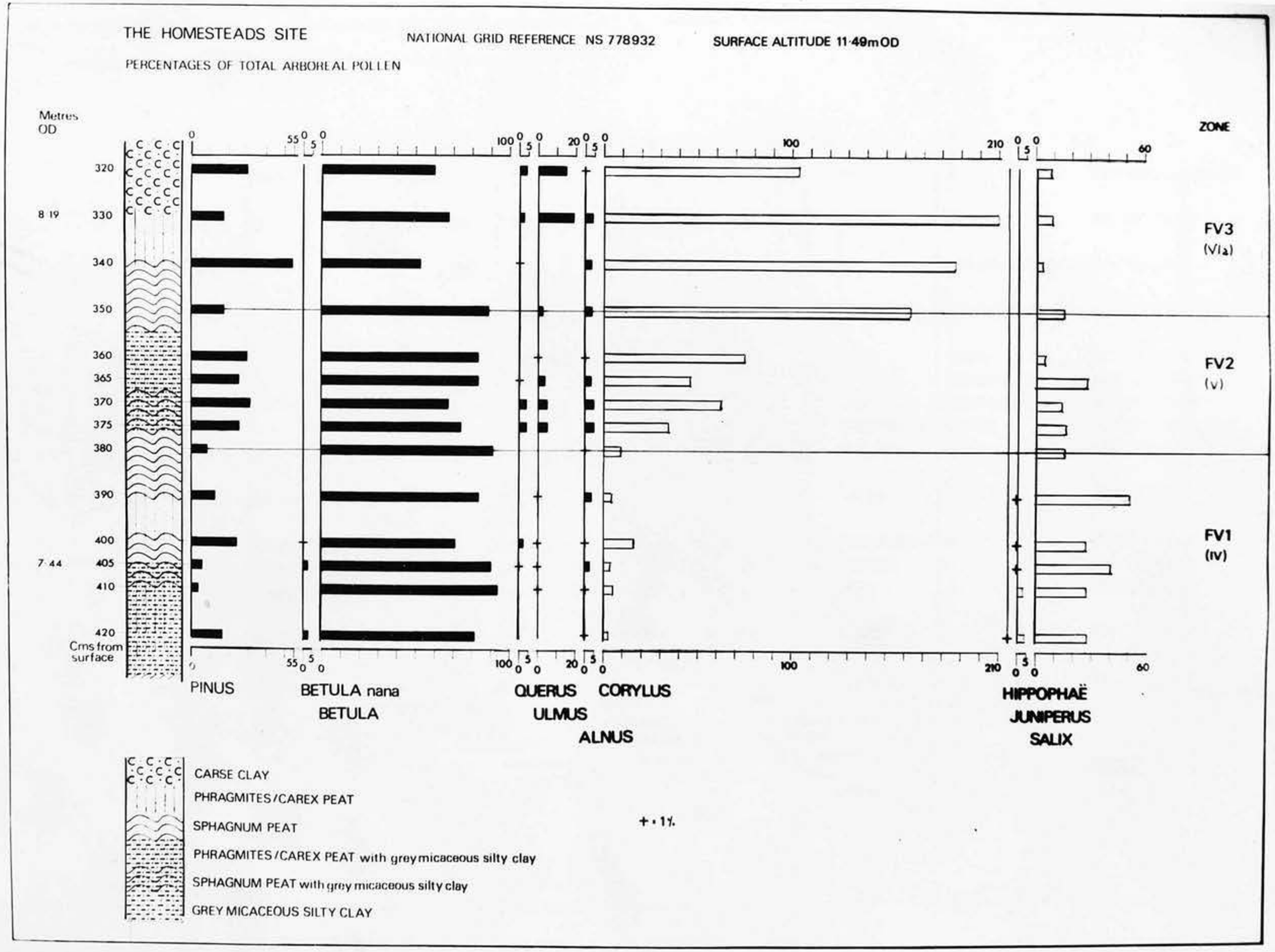

THE HOMESTEADS SITE
NATIONAL GRID REFERENCE NS 778932
SURFACE ALTITUDE 11·49m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
Metres OD
8·19
7·44
Cms from surface
ZONE
FV3 (VIa)
FV2 (V)
FV1 (IV)
PINUS
BETULA nana
BETULA
QUERUS
ULMUS
ALNUS
CORYLUS
HIPPOPHAË
JUNIPERUS
SALIX
CARSE CLAY
PHRAGMITES/CAREX PEAT
SPHAGNUM PEAT
PHRAGMITES/CAREX PEAT with grey micaceous silty clay
SPHAGNUM PEAT with grey micaceous silty clay
GREY MICACEOUS SILTY CLAY
+ • 1%

Fig 19

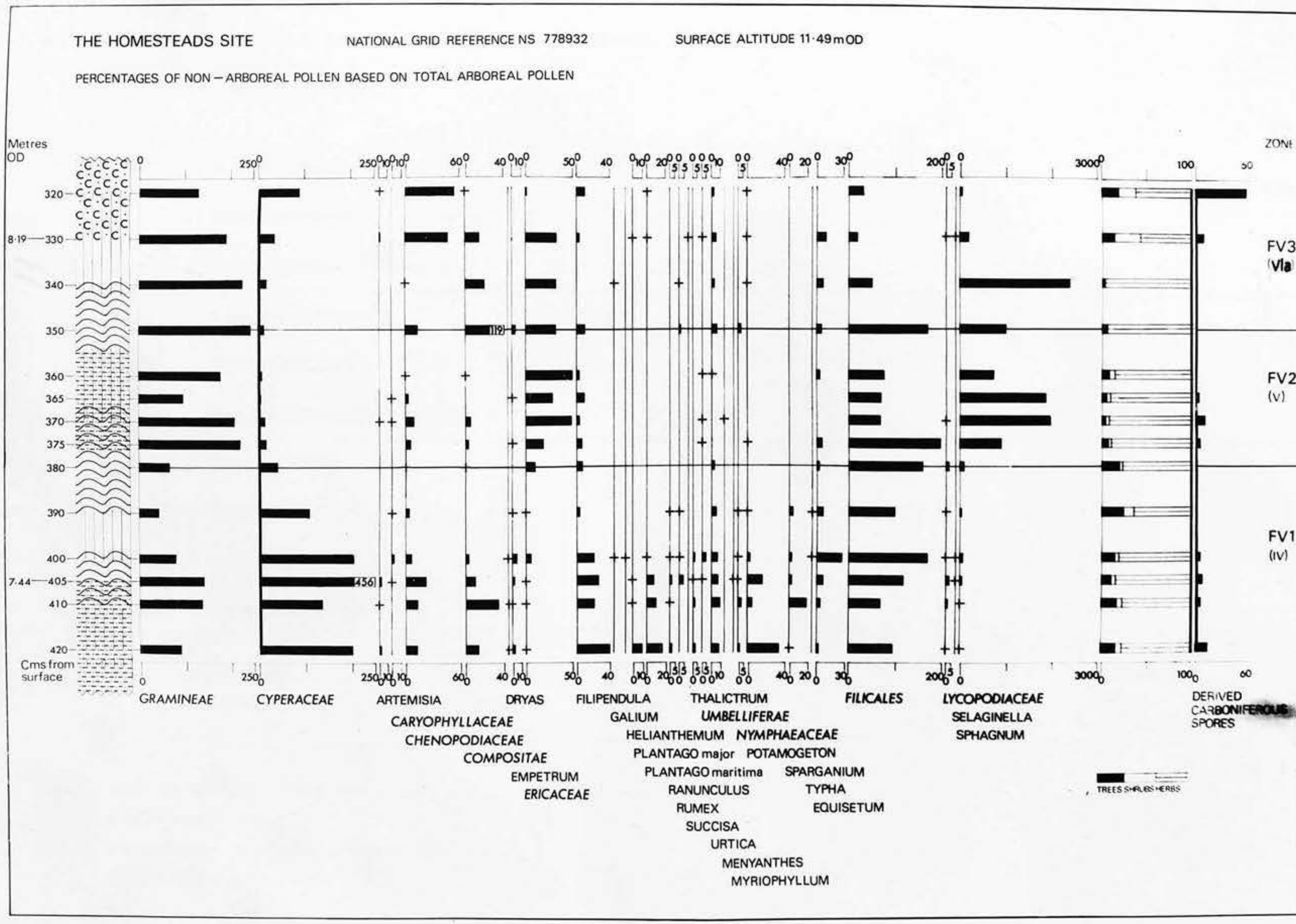
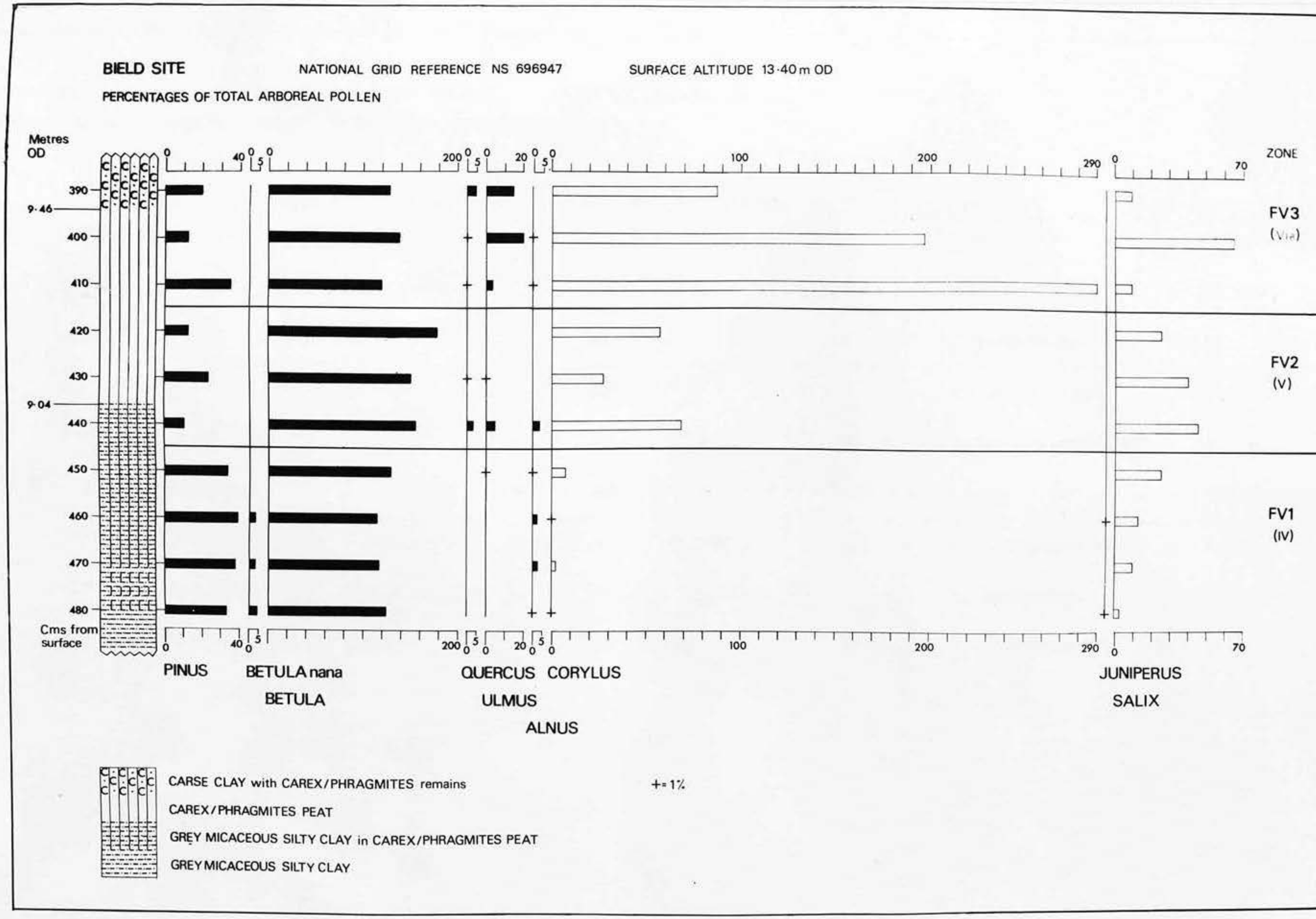

THE HOMESTEADS SITE
NATIONAL GRID REFERENCE NS 778932
SURFACE ALTITUDE 11·49 m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Metres OD
Cms from surface
8·19
7·44
ZONE
FV3 (VIa)
FV2 (V)
FV1 (IV)
GRAMINEAE
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
EMPETRUM
ERICACEAE
DRYAS
FILIPENDULA
GALIUM
HELIANTHEMUM
PLANTAGO major
PLANTAGO maritima
RANUNCULUS
RUMEX
SUCCISA
URTICA
MENYANTHES
MYRIOPHYLLUM
THALICTRUM
UMBELLIFERAE
NYMPHAEACEAE
POTAMOGETON
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
LYCOPODIACEAE
SELAGINELLA
SPHAGNUM
DERIVED CARBONIFEROUS SPORES
TREES SHRUBS HERBS

Fig 20



BIELD SITE
NATIONAL GRID REFERENCE NS 696947
SURFACE ALTITUDE 13·40 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
Metres OD
9·46
9·04
Cms from surface
390
400
410
420
430
440
450
460
470
480
ZONE
FV3 (VIa)
FV2 (V)
FV1 (IV)
PINUS
BETULA nana
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
JUNIPERUS
SALIX
CARSE CLAY with CAREX/PHRAGMITES remains
CAREX/PHRAGMITES PEAT
GREY MICACEOUS SILTY CLAY in CAREX/PHRAGMITES PEAT
GREY MICACEOUS SILTY CLAY
+ = 1%

Fig 21

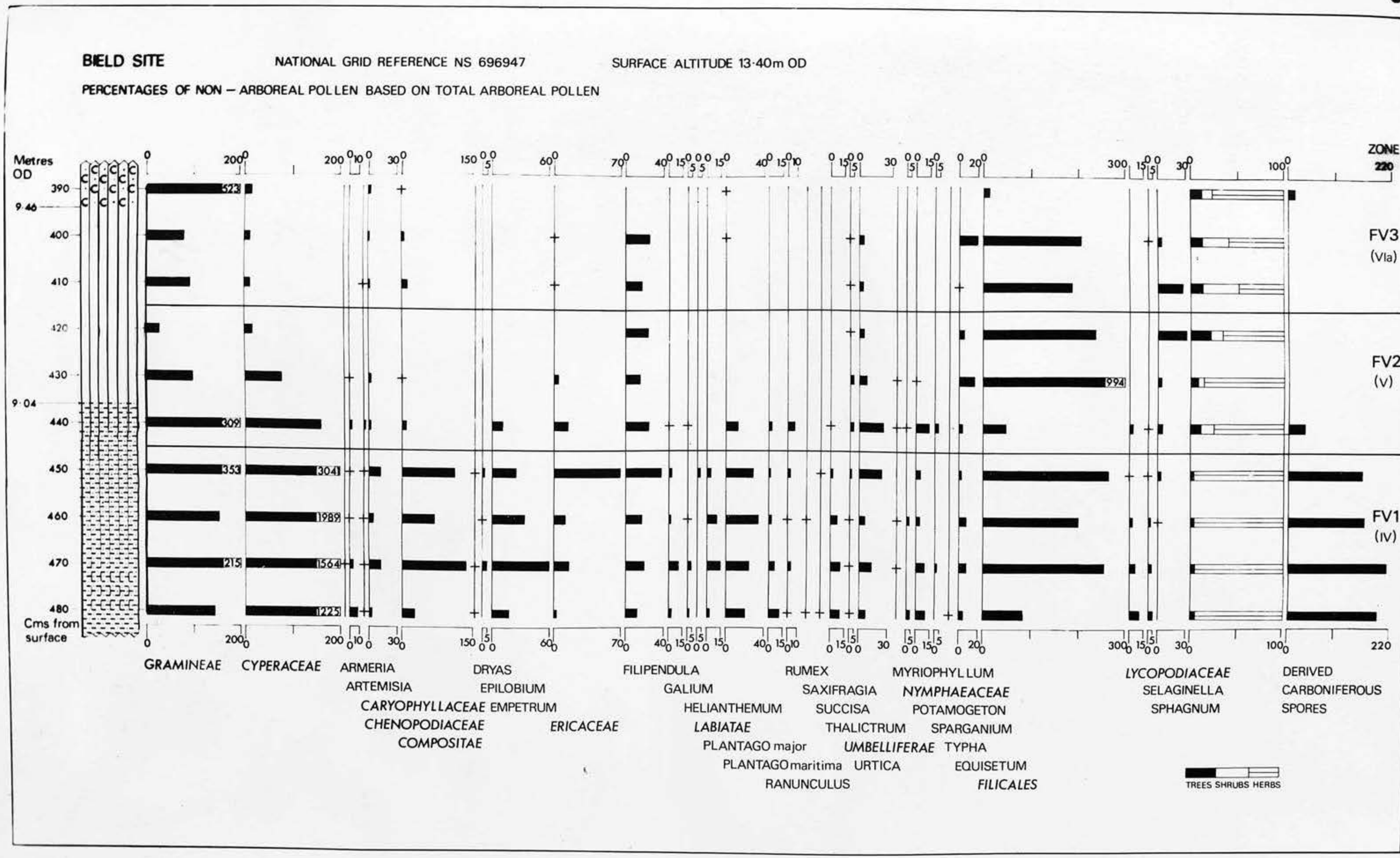

BIELD SITE
NATIONAL GRID REFERENCE NS 696947
SURFACE ALTITUDE 13·40m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Metres OD
9·46
9·04
Cms from surface
ZONE
FV3 (VIa)
FV2 (V)
FV1 (IV)
GRAMINEAE
CYPERACEAE
ARMERIA
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
DRYAS
EPILOBIUM
EMPETRUM
ERICACEAE
FILIPENDULA
GALIUM
HELIANTHEMUM
LABIATAE
PLANTAGO major
PLANTAGO maritima
RANUNCULUS
RUMEX
SAXIFRAGIA
SUCCISA
THALICTRUM
UMBELLIFERAE
URTICA
MYRIOPHYLLUM
NYMPHAEACEAE
POTAMOGETON
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
LYCOPODIACEAE
SELAGINELLA
SPHAGNUM
DERIVED CARBONIFEROUS SPORES
TREES SHRUBS HERBS

Fig 22

They reflect the presence of open communities and the absence of a continuous tree cover. Similar conditions probably existed at both The Homesteads and Bield sites. This interpretation is supported by low values of _Betula nana_ (tentatively identified by pore characteristics) and _Juniperus_, as these species are also characteristic of open habitat.

The arboreal pollen profiles, from 420-380cm at The Homesteads and from 480-450cm at Bield (in Figs. 19 and 21 respectively), indicate an early stage of regional woodland development and a landscape dominated by _Betula_, representing the first colonisation by trees before the advance of thermophilous species such as _Corylus_, _Ulmus_ and _Quercus_. In addition to birch, _Salix_ was present, possibly in favourable marsh situations at or near these locations. The presence of pine in the region seems doubtful for the following reasons; firstly, the _Pinus_ pollen from the minerogenic deposits at both sites may not be representative, being deposited at these locations during periods of high sea-level, which according to pollen evidence below, was contemporaneous with the deposition of the clay layers at The Homesteads and Bield sites; secondly, this pollen type is subject to long distance transport by wind.

Frequencies of _Betula_, _Salix_ and non-arboreal pollen comparable to those from The Homesteads and Bield sites characterise the Pre-Boreal (Zone F.V.I) at the type site at Woodend Farm. On this basis the vegetational conditions which existed at The Homesteads and Bield are referable to

Zone F.V.I, the earliest stage of the Post-glacial period.

The arboreal pollen profiles from 380-350cm in Fig. 19, and from 440-420cm in Fig. 21 reflect an advance of woodland in The Homesteads and Bield area. This stage of forest history is characterised at both sites by the immigration into the region of thermophilous species, notably Corylus and, on a much smaller scale, elm followed by oak. Betula, however, remained the dominant tree in the region. Salix expanded at Bield, probably in response to favourable local marsh conditions, whereas local conditions at The Homesteads appear to have been less favourable for the development of this plant, as suggested by falling Salix pollen totals. Similar arboreal pollen profiles are displayed in Zone F.V.2 at Woodend Farm Site 2; thus the immigration of hazel, followed by elm and oak into The Homesteads and Bield region, took place during the early part of the Boreal (Zone F.V.2).

A further stage of forest development in The Homesteads and Bield areas is signified by the arboreal pollen spectra from 350-320cm in Fig. 19 and from 410-390cm in Fig. 21. The tree pollen from these horizons records the marked expansion of hazel which accompanied the spread of elm, which in turn expanded more quickly than oak. Birch, however, declined, probably as a result of the expansion and competition from these deciduous species.

The pollen curves of Corylus, Betula, Ulmus and Quercus, which reflect this stage of forest history at these sites, relate to the beginning of Zone F.V.3, as similar arboreal pollen profiles characterise the early part of this pollen assemblage zone at the Woodend Farm Site 2 type site.

Evidence of local site conditions which existed at The Homesteads and Bield sites during Zones F.V.I - F.V.3 is furnished by non-arboreal pollen and macro-stratigraphy. In Figs. 20 and 22, the frequencies of Chenopodiaceae, *Plantago maritima*, *Artemisia maritima* and Compositae, together with those of Gramineae and Cyperaceae from the buried beach deposits at both sites, indicate the probable presence of saltmarsh vegetation at these locations. This evidence also indicates that the formation of the buried beaches at The Homesteads and Bield was associated with a high sea-level. The most significant indication of marine conditions during this period, however, is furnished by macrofossils from the buried beach deposits at Bield, which include fruits of *Eleocharis palustris*, *E.uniglumis*, *Scirpus tabernaemontanus* and *Triglochin maritima*. These plants are frequently found in present day saltmarsh and brackish water locations, for example at Aberlady Bay, East Lothian, and were evidently represented at Bield and perhaps at The Homesteads sites during Zone F.V.I.

A change in site conditions at The Homesteads occurred during Zone F.V.I. The replacement of grey micaceous clay by peat at 405cm and falling pollen totals of saltmarsh plants indicate a withdrawal of the sea from this site. As the sea retreated, oligotrophic communities began to develop over the beach surface, as signified by macro-remains and rising spore totals of *Sphagnum* and Ericaceae pollen in the peat from 405-400cm. Towards the end of Zone F.V.I the development of these plants appears to have been temporarily arrested and replaced by reedswamp, as suggested by a thin band of Phragmites/Carex peat from 399-391cm. This type of vegetation was later replaced by Sphagnum which, according to macrofossils and spores of this plant, continued to develop at this location from upper Zone F.V.I to the early part of Zone F.V.2.

The development of moss at this site during Zone F.V.2 was, however, temporarily interrupted perhaps by an incursion of the sea. This interpretation is based upon the replacement of Sphagnum macro-remains by those of reed and sedge in the peat from 375-355cm; the presence of micaceous silt in the peat at this horizon, and increased values of pollen of saltmarsh plants, notably Chenopodiaceae. Towards the end of Zone F.V.2 these marine conditions had diminished and saltmarsh vegetation was replaced by Sphagnum, as indicated by the replacement of reed and sedge peat by that of Sphagnum at 354cm, falling pollen totals of Chenopodiaceae and rising values of Sphagnum spores.

Oligotrophic conditions continued to exist at The Homesteads until the early part of Zone F.V.2 when they were replaced by freshwater swamp as indicated by the replacement of Sphagnum peat by that of Phragmites/Carex at 330cm. This change in vegetational conditions was accompanied by the expansion of saltmarsh vegetation, reflected in the increased totals of Chenopodiaceae, Compositae, Cyperaceae and Gramineae pollen, in response to increasing marine influence. As carse clay began to be laid down at this site, sea-level rose and saltmarsh vegetation increased as indicated, in particular, by the pronounced rise of Chenopodiaceae pollen values from 330-320cm.

The marine conditions associated with the formation of the buried beach at Bield in Zone F.V.I ended very early in Zone F.V.2. That the sea retreated from this location at about this time is marked firstly, by the replacement of grey micaceous clay by peat at 436cm; secondly, by falling values of Chenopodiaceae, Artemisia maritima and Compositae together with those of grass and sedge pollen. As the sea withdrew, peat developed over the beach surface. The predominance of Phragmites and Carex remains in this organic layer, together with relatively high counts of Filipendula pollen, indicates that freshwater marsh developed over the surface of the buried beach. This type of vegetation continued to develop at Bield during the remainder of Zone F.V.2 until the early part of Zone F.V.3, when sea-level began to rise and carse clay began to be laid down at this site. Small increases in Chenopodiaceace together with rising values of Gramineae and Cyperaceae from 410-390cm, signify the spread of saltmarsh vegetation in the locality of this site as sea-level rose.

That buried beach deposits ceased to accumulate at The Homesteads during late Zone F.V.I. and at Bield at approximately the beginning of Zone F.V.2, indicates that these features are related. In addition the dating of these beaches accords with that for the Main Buried Beach at a site at West Flanders Moss. At this latter location the

Main Buried Beach, according to Newey (1966), was completed at the end of Zone IV (Zone F.V.I). In addition Durno (1956) has shown that peat overlying the surface of the Main Buried Beach at a site at East Flanders Moss is of Zone V (F.V.2) age. Although the buried beach deposits at this location were not analysed for pollen, it seems probable that the top of this minerogenic material represents Zone IV, for at this site Zone V, which is a relatively short zone, is represented by fully 1m of peat. On the basis of the above evidence, the buried beach deposits at The Homesteads and Bield sites are related to the Main Buried Beach and are thus synchronous (or approximately synchronous) features.

<u>Summary</u>.

The Homesteads and Bield sites are situated on both sides of a major dislocation of a buried beach presumed, on geomorphic evidence, to be the Main Buried Beach. A major objective of the investigations was to test this assumption. Pollen evidence indicates that accumulation of buried beach material at The Homesteads ceased late in Zone F.V.I. and at Bield at approximately the beginning of Zone F.V.2. Pollen data from other sites in the research area indicates that the Main Buried Beach was completed at about the IV/V (F.V.I/F.V.2) transition. Hence the buried beach deposits at The Homesteads and Bield sites are related to the Main Buried Beach and are thus essentially synchronous features.

The following sequence of events probably took place at The Homesteads and Bield sites. 1. Deposition of the Main Buried Beach during a period of high sea-level.

2. The sea then retreated and peat developed over the surface of the Main Buried Beach at both sites. A temporary marine incursion may have influenced The Homesteads as peat accumulated at this site during Zone F.V.2.

3. Sea-level later rose and carse clay began to be deposited over the peat at these sites during the early part of Zone F.V.3.

4.vii. The Dollhouse Sites. (NS 92927952, NS 92987954)

These sites are located in a former coastal embayment; the landward margin of this feature being defined by numerous small headlands and re-entrant valleys. This embayment has been largely infilled with carse clay which stretches northwards from the southern edge of the bay to the Forth. Investigations were carried out at two sites located in a trench near Dollhouse Farm, and named Dollhouse Site 1 and Dollhouse Site 2. North of these sites the River Carron, and in the south a small stream (the Grangeburn) and the River Avon, flow northwards across the carse clay lowland to meet the Forth.

At Dollhouse Site 1 the carse clay overlies a thick band of gravel which rests upon a layer of grey clay. The gravel layer slopes northwards for about 60m to Dollhouse Site 2. Towards this latter site a thin bed of peat begins to appear intermittently above the gravel. At Site 2 silt and sand deposits lie in a hollow in the gravel surface. These silts and sands merge upwards into a thin layer of peat which is overlain by carse clay. The stratigraphic sequences at these two sites are diagrammatically displayed in Fig. 23.

A major aim of the investigations was to interpret and obtain a dating of the sequence of events which took place at these sites as indicated by pollen, stratigraphic and radiocarbon evidence. To this end, samples for pollen analysis were extracted from the grey clay beneath the gravel and the lower part of the carse clay overlying the gravel surface at Dollhouse Site 1, and from the silts,

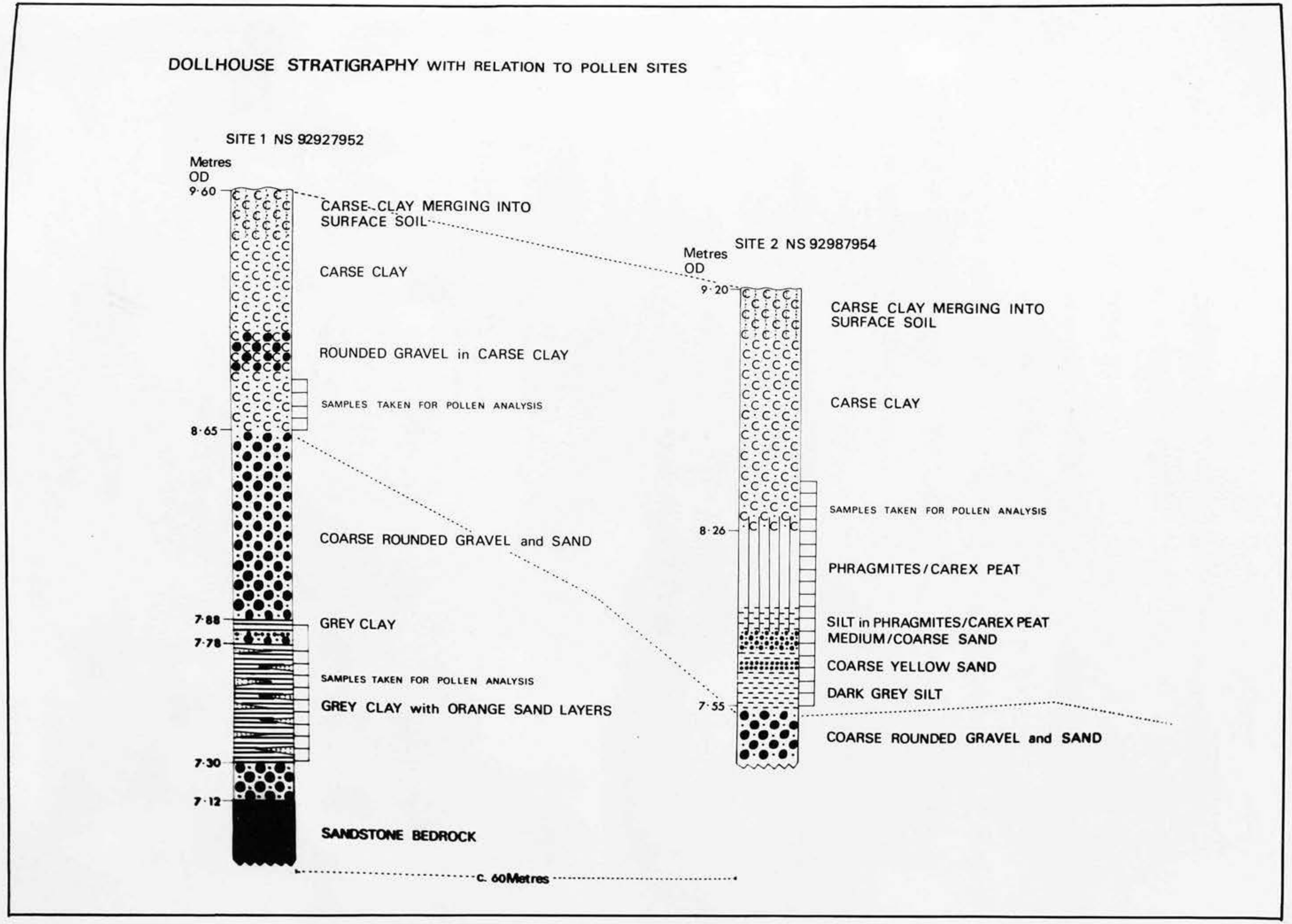

DOLLHOUSE STRATIGRAPHY WITH RELATION TO POLLEN SITES
SITE 1 NS 92927952
Metres
OD
9·60
CARSE CLAY MERGING INTO SURFACE SOIL
CARSE CLAY
ROUNDED GRAVEL in CARSE CLAY
SAMPLES TAKEN FOR POLLEN ANALYSIS
8·65
COARSE ROUNDED GRAVEL and SAND
7·88
GREY CLAY
7·78
SAMPLES TAKEN FOR POLLEN ANALYSIS
GREY CLAY with ORANGE SAND LAYERS
7·30
7·12
SANDSTONE BEDROCK
c. 60Metres
SITE 2 NS 92987954
Metres
OD
9·20
CARSE CLAY MERGING INTO SURFACE SOIL
CARSE CLAY
SAMPLES TAKEN FOR POLLEN ANALYSIS
8·26
PHRAGMITES/CAREX PEAT
SILT in PHRAGMITES/CAREX PEAT
MEDIUM/COARSE SAND
COARSE YELLOW SAND
DARK GREY SILT
7·55
COARSE ROUNDED GRAVEL and SAND

Fig 23

sands, peat and lower carse clay above the gravel at Dollhouse Site 2.

Stratigraphy and Macrofossil Content.

At Dollhouse Site 1 nearly 1m of carse clay, containing a thin band of gravel, overlies the surface of a bed of coarse gravel and sand. This latter deposit, about 1.3m in thickness, rests upon a thin layer of grey clay, which in turn overlies a shallow band of coarse sand and gravel. Beneath these deposits is a bed of grey clay, nearly 50cm thick, containing orange coloured sand layers of variable thicknesses. This grey clay layer rests upon coarse gravel and sand, about 18cm thick, which overlies sandstone bedrock. Stratigraphic and macrofossil details recorded at this site are tabulated below in Table 11.

Table 11.

Cm from surface	Deposit and Macrofossil Content
0-95	Carse clay, containing a thin band of rounded gravel from 60-70cm. The diameter of the gravel was about 1cm.
96-172	Coarse rounded gravel and sand, crudely bedded, containing many stones with diameters up to 7cm and some with diameters over 15cm.
173-175	Grey clay.
176-177	Medium/Coarse sand.
178-182	Coarse rounded gravel and sand.
183-230	Grey clay, of buttery texture, interbedded with orange coloured medium sand layers which vary rapidly in thickness.

/Continued

Table 11, continued.

Cm from surface	Deposit and Macrofossil Content
231-249	Coarse rounded sand and gravel.
250 +	Sandstone bedrock.

60cm away from the point where samples were extracted, a large fragment of Quercus sp. wood, about 30cm in diameter, rests on the surface of the lowest gravel bed at 230cm. Radiocarbon assay of a sample of this wood gave a date of 7,860 ± 125 B.P. (I-2133)

The surface of the gravel at Dollhouse Site 2 is overlain by 35cm of silt and sand deposits which merge upwards into a layer of Phragmites/Carex peat, about 30cm thick. Overlying this organic material is nearly 1m of carse clay. Stratigraphic and macrofossil details at this site are presented in Table 12 below.

Table 12.

Cm from surface	Deposit and Macrofossil Content
0-93	Carse clay.
94-127	Phragmites/Carex peat, highly humified; 1 Carex sp. fruit.
128-133	Silt, containing abundant leaves and stems of reed and sedge. Sand, medium/coarse.
134-142	Medium/Coarse sand.
143-145	Silt, 1 Menyanthes trifoliata seed.

/Continued

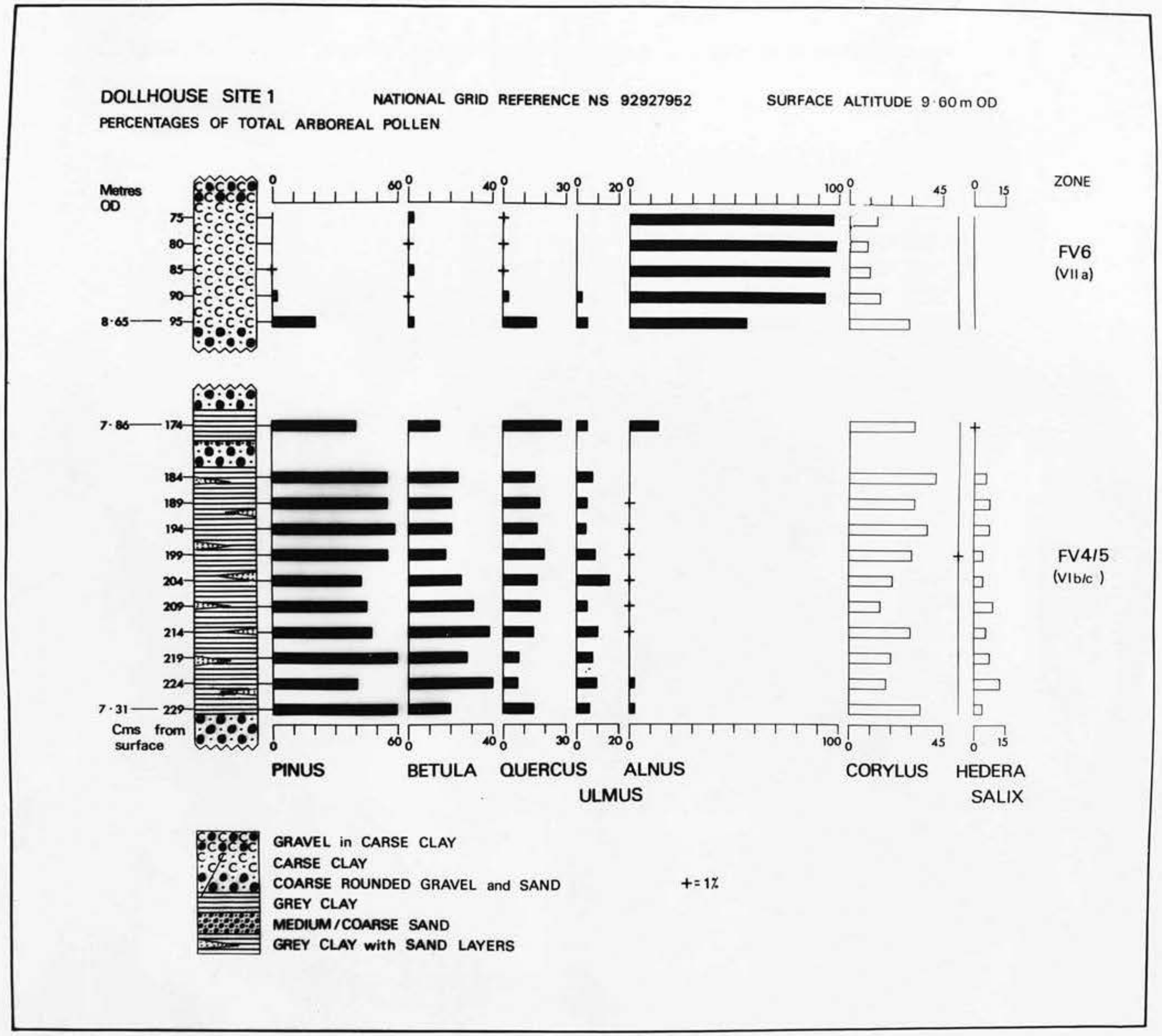
Table 12, continued.

Cm from surface	Deposit and Macrofossil Content
146-150	Coarse yellow sand.
151-163	Grey silt, containing 4 *Carex* sp. seeds.
165 +	Coarse rounded gravel and sand.

The stratigraphic columns in the pollen diagrams represent material from which samples were extracted for pollen analysis. The positions of these sampled horizons in the stratigraphy at these locations are, however, indicated in Fig. 23.

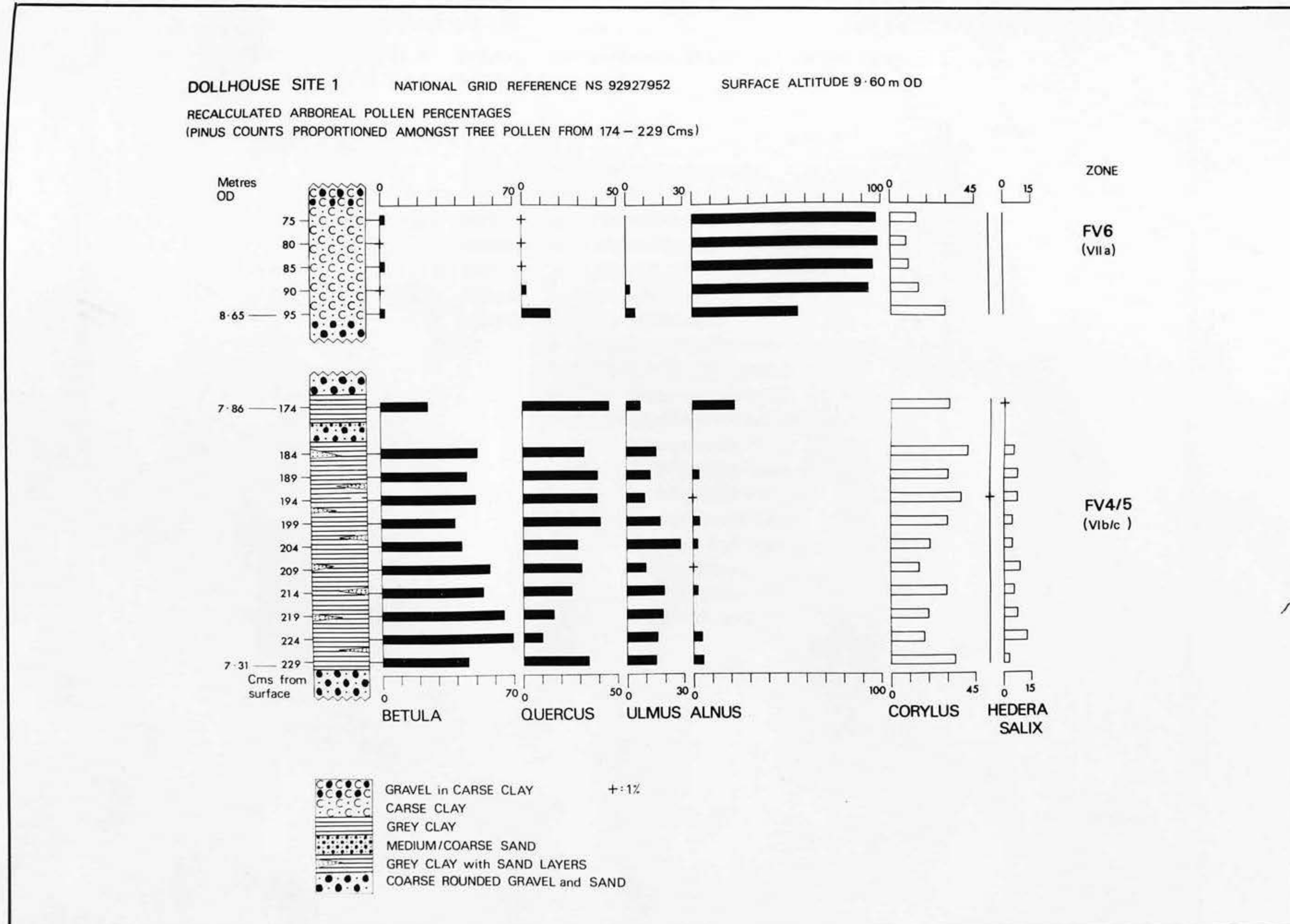
The Pollen Diagrams. (Figs. 24, 25, 26, 27, 28)

The arboreal pollen frequencies recorded at Dollhouse Site 1 (Fig. 24) reflect the development of woodland in the region as minerogenic material accumulated at this site. Tree pollen spectra from 229-184cm indicate that oak and elm were probably major elements of this woodland. That the former tree was present is attested by a large fragment of *Quercus* sp., at 230cm, resting upon the gravel surface 60cm from this site. In addition to these broad-leaved taxa birch was also present in the region, together with shrubby species such as hazel and willow. Pine may also have been a component of this regional woodland, although it seems likely that the high *Pinus* pollen totals may be over-represented, as evidence presented below indicates that the minerogenic deposits from which this pollen type was



DOLLHOUSE SITE 1
NATIONAL GRID REFERENCE NS 92927952
SURFACE ALTITUDE 9·60 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
Metres OD
8·65
7·86
7·31
75
80
85
90
95
174
184
189
194
199
204
209
214
219
224
229
Cms from surface
ZONE
FV6
(VIIa)
FV4/5
(VIb/c)
PINUS
BETULA
QUERCUS
ALNUS
ULMUS
CORYLUS
HEDERA
SALIX
GRAVEL in CARSE CLAY
CARSE CLAY
COARSE ROUNDED GRAVEL and SAND
GREY CLAY
MEDIUM/COARSE SAND
GREY CLAY with SAND LAYERS
+ = 1%

Fig 24



DOLLHOUSE SITE 1
NATIONAL GRID REFERENCE NS 92927952
SURFACE ALTITUDE 9·60 m OD
RECALCULATED ARBOREAL POLLEN PERCENTAGES
(PINUS COUNTS PROPORTIONED AMONGST TREE POLLEN FROM 174 – 229 Cms)
Metres OD
ZONE
FV6
(VIIa)
FV4/5
(VIb/c)
8·65
7·86
7·31
Cms from surface
BETULA
QUERCUS
ULMUS
ALNUS
CORYLUS
HEDERA
SALIX
GRAVEL in CARSE CLAY
+ : 1%
CARSE CLAY
GREY CLAY
MEDIUM/COARSE SAND
GREY CLAY with SAND LAYERS
COARSE ROUNDED GRAVEL and SAND

Fig 25

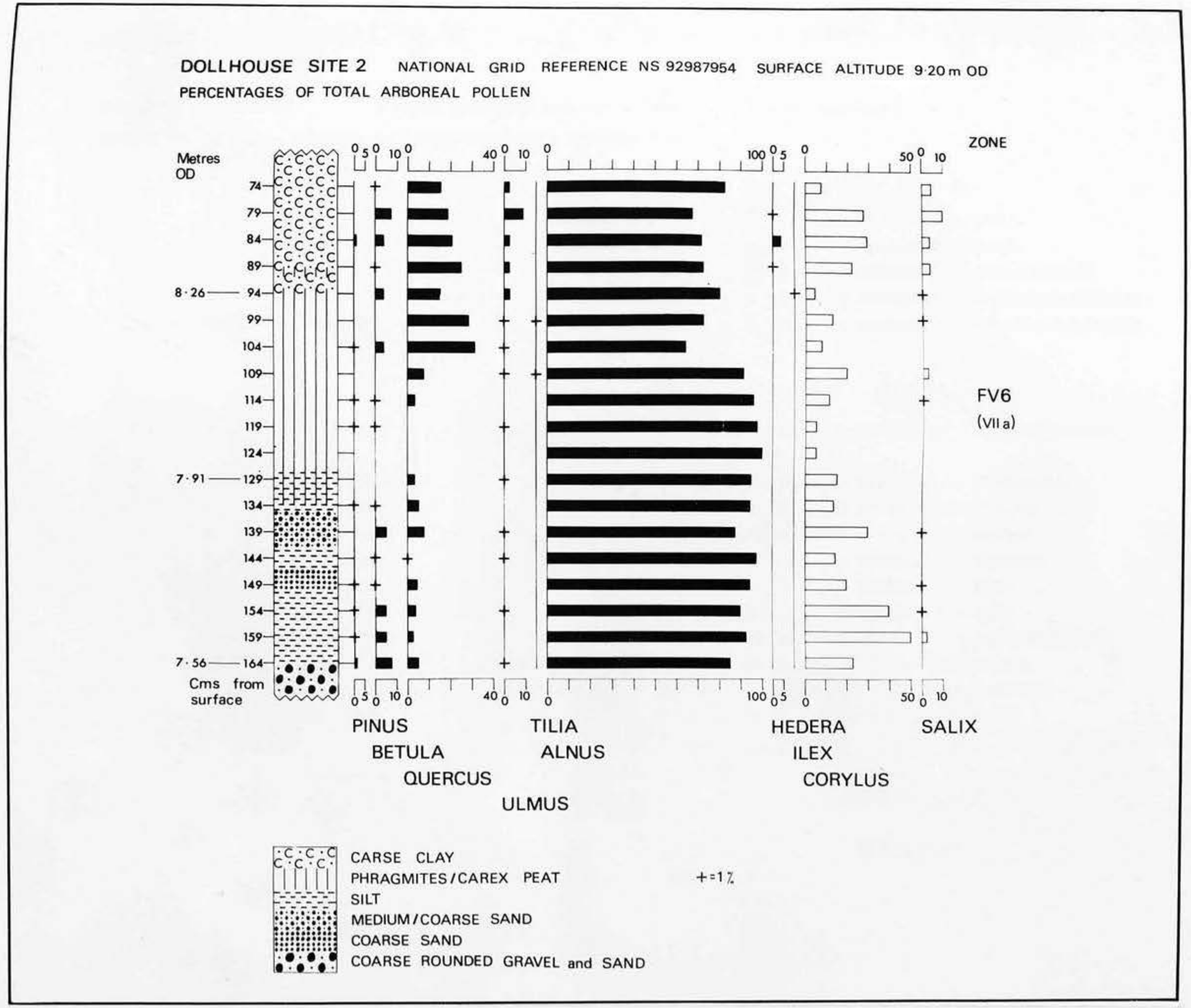

DOLLHOUSE SITE 2 NATIONAL GRID REFERENCE NS 92987954 SURFACE ALTITUDE 9·20 m OD
PERCENTAGES OF TOTAL ARBOREAL POLLEN
Metres OD
8·26
7·91
7·56
Cms from surface
74
79
84
89
94
99
104
109
114
119
124
129
134
139
144
149
154
159
164
ZONE
FV6
(VII a)
PINUS
BETULA
QUERCUS
ULMUS
TILIA
ALNUS
HEDERA
ILEX
CORYLUS
SALIX
CARSE CLAY
PHRAGMITES/CAREX PEAT
SILT
MEDIUM/COARSE SAND
COARSE SAND
COARSE ROUNDED GRAVEL and SAND
+=1%

Fig 26

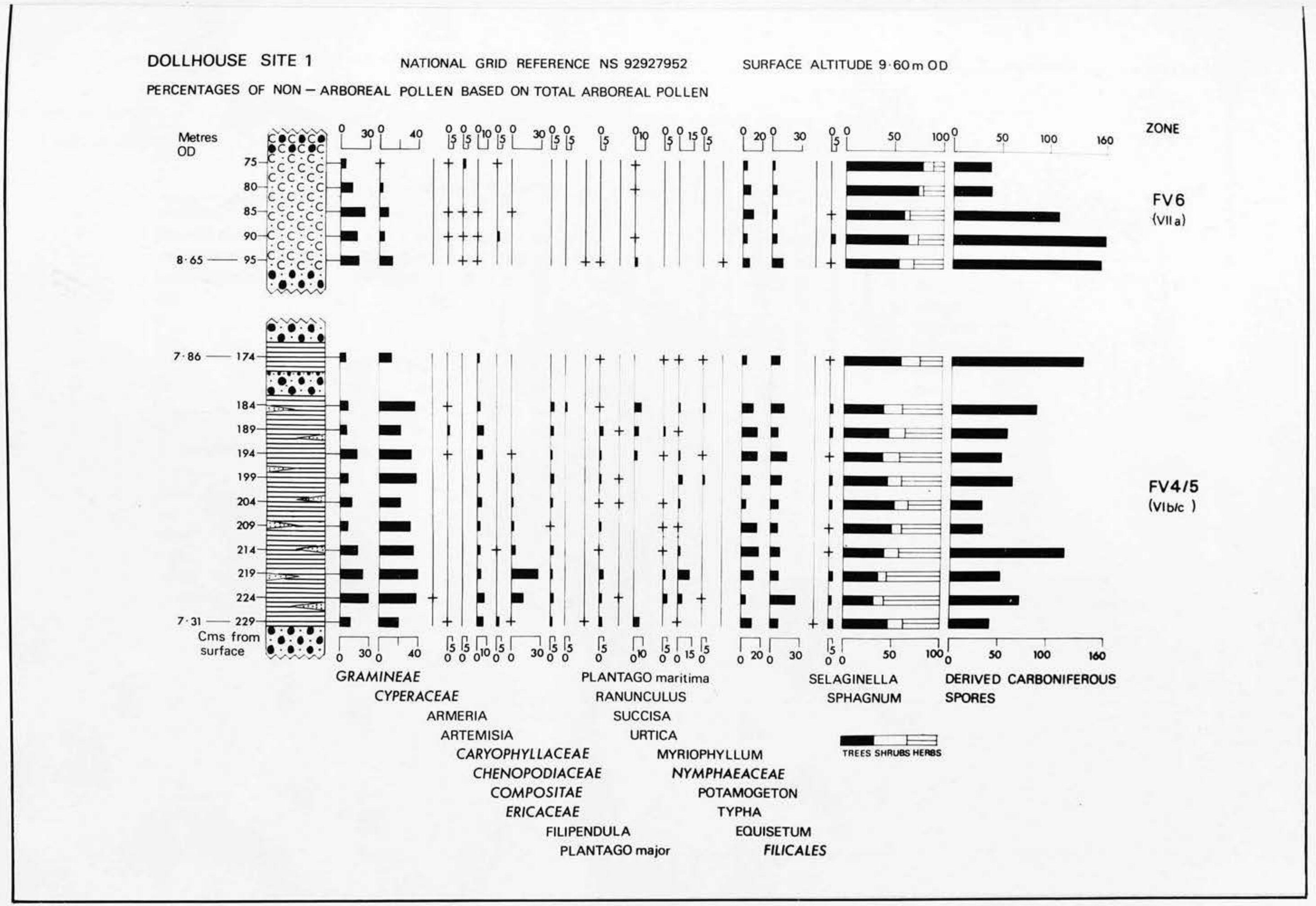

DOLLHOUSE SITE 1
NATIONAL GRID REFERENCE NS 92927952
SURFACE ALTITUDE 9·60 m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Metres OD
Cms from surface
8·65
7·86
7·31
ZONE
FV6 (VIIa)
FV4/5 (VIb/c)
GRAMINEAE
CYPERACEAE
ARMERIA
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITAE
ERICACEAE
FILIPENDULA
PLANTAGO major
PLANTAGO maritima
RANUNCULUS
SUCCISA
URTICA
MYRIOPHYLLUM
NYMPHAEACEAE
POTAMOGETON
TYPHA
EQUISETUM
FILICALES
SELAGINELLA
SPHAGNUM
TREES SHRUBS HERBS
DERIVED CARBONIFEROUS SPORES

Fig 27

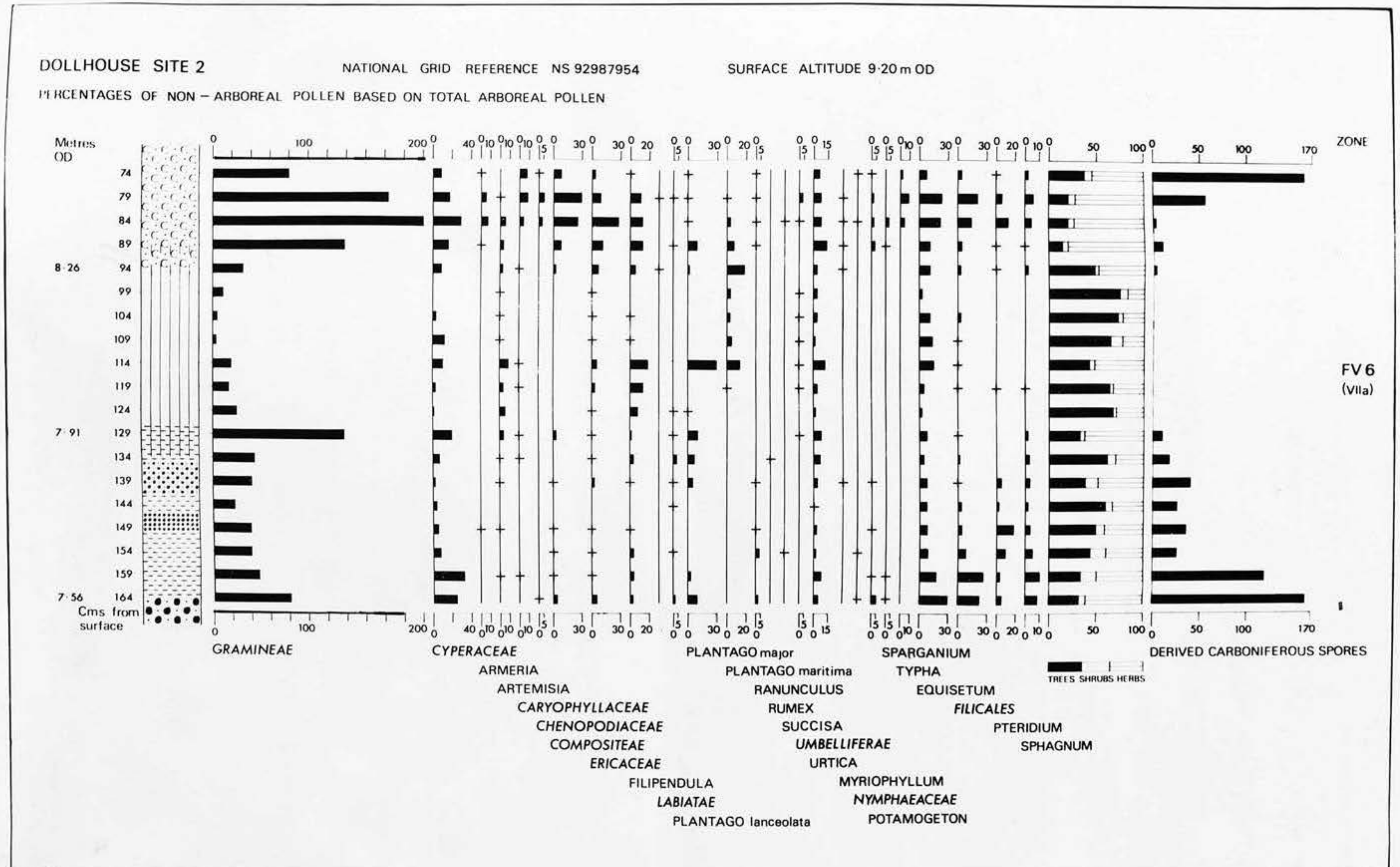

DOLLHOUSE SITE 2
NATIONAL GRID REFERENCE NS 92987954
SURFACE ALTITUDE 9·20 m OD
PERCENTAGES OF NON – ARBOREAL POLLEN BASED ON TOTAL ARBOREAL POLLEN
Metres OD
8·26
7·91
7·56
Cms from surface
ZONE
FV 6 (VIIa)
GRAMINEAE
CYPERACEAE
ARMERIA
ARTEMISIA
CARYOPHYLLACEAE
CHENOPODIACEAE
COMPOSITEAE
ERICACEAE
FILIPENDULA
LABIATAE
PLANTAGO lanceolata
PLANTAGO major
PLANTAGO maritima
RANUNCULUS
RUMEX
SUCCISA
UMBELLIFERAE
URTICA
MYRIOPHYLLUM
NYMPHAEACEAE
POTAMOGETON
SPARGANIUM
TYPHA
EQUISETUM
FILICALES
PTERIDIUM
SPHAGNUM
TREES SHRUBS HERBS
DERIVED CARBONIFEROUS SPORES

Fig 28

extracted, are associated with high sea-level. Thus high numbers of Pinus pollen may have been transported and deposited at this site by the sea, and possibly by air currents. In view of these possibilities, the arboreal pollen curves from 229-174cm may be depressed by substantial totals of Pinus pollen. To test this possibility the tree pollen totals from this horizon were recalculated, excluding those of Pinus. The recalculated profiles of Betula, Quercus, Ulmus, Alnus, Corylus and Salix pollen (displayed in Fig. 25), however, show no significant change from the pollen curves of these taxa in Fig. 24. On this basis the arboreal pollen curves are not depressed by that of Pinus and are thus reflective of the regional arboreal vegetation during the time when grey clay, from 229-174cm, accumulated at Dollhouse Site 1.

A short time before the main gravel layer, from 172-96cm, began to be laid down over the grey clay at this site, Alnus began to expand in the region, as signified by a rise in Alnus pollen numbers from the grey clay at 174cm. Although the gravel above this level was not analysed for pollen, it seems possible that alder continued to spread in the region during the time the gravel was laid down at Dollhouse Site 1. This interpretation is strengthened by rising totals of Alnus pollen from the carse clay immediately overlying the surface of this gravel layer from 95-75cm. The very high alder pollen totals from this level and reduced values of birch, oak and elm pollen probably reflect the importance of Alnus in the region as carse clay began to accumulate over the main gravel layer at this site.

From the arboreal pollen profiles in Fig. 24 the deposits at Dollhouse Site 1 can be dated. Falling Betula values, Quercus totals higher than those of Ulmus, together with rising Alnus pollen frequencies from the grey clay beneath the main gravel layer, broadly agree with the pollen profiles of these taxa displayed in Late-Boreal Zones F.V.4 and F.V.5 in the type diagram from Woodend Farm Site 2. Exact zonal correlation, however, does not seem possible as the tree pollen frequencies from 229-174cm at Dollhouse Site 1, particularly those of Alnus, differ from those in Zones F.V.4 and F.V.5 at Woodend Farm, probably because of differences in site conditions. The presence of higher, better drained land at the edge of the carse clay at Dollhouse Site 1 would be more favourable for oak and elm than alder; whereas the type site, about 37Km west from Dollhouse, is situated on flatter, less well drained land more conducive to the formation of bog and the development of moisture-loving species such as alder. Despite these differences, the above arboreal pollen evidence indicates a Late-Boreal age for the grey clay at Dollhouse Site 1. This interpretation is supported by the radiocarbon date of 7,860 ± 125 B.P. obtained from wood at the base of the grey clay, as this date falls within the Late-Boreal period, dated by Godwin, Walker and Willis (1957) at Scaleby Moss in northern England, from about 9,000 B.P. to 7,500 B.P.

The predominance of Alnus pollen in the carse clay, from 95-75cm, at Dollhouse Site 1 appears to be referable to Zone F.V.6, the Atlantic period, as comparable pollen totals of this genus characterise this pollen assemblage zone in the type diagram from Woodend Farm Site 2.

The arboreal pollen spectra from Dollhouse Site 2 are dominated by consistently high frequencies of Alnus pollen, as shown in Fig. 26. This evidence indicates that alder was an important woodland element in the region as deposits accumulated over the surface of the gravel at this site. As Alnus is a prolific producer of pollen and as the highest values of this pollen type occur in the samples from 109-164cm, in Fig. 26, it is possible that other arboreal pollen frequencies from these samples are depressed. This possibility is strengthened by the increased pollen values of Betula, Quercus and Ulmus and reduced Alnus pollen totals from 104-74cm in Fig. 26. Despite this possibility, the arboreal pollen evidence in this diagram suggests that oak, together with small amounts of elm, birch, hazel and willow were also present in the region, but pine was absent. Hedera, Ilex and Tilia may also have been present in the Dollhouse area, but as pollen of these taxa are rarely found at Scottish sites, it seems more likely that the very low pollen totals of these species in Fig. 26 have been wind transported from distant sources.

The predominance of Alnus pollen in Fig. 26 accords with similar high frequencies of this pollen type in Zone F.V.6, the Atlantic period, at Woodend Farm Site 2. Thus the deposits above the gravel at Dollhouse Site 2 are of Zone F.V.6 age.

Evidence of non-arboreal vegetational and site conditions as grey clay and carse clay were laid down at Dollhouse Site 1 is furnished by non-tree pollen frequencies in Fig. 27. The profiles of Gramineae and Cyperaceae, together with small sums of Chenopodiacea, Artemisia maritima and Compositae from these minerogenic deposits, indicate the probable existence of saltmarsh vegetation in response to high sea-level which accompanied the deposition of the grey clay and carse clay at this site.

The non-arboreal pollen spectra (in Fig. 28) from the silt and sand deposits at Dollhouse Site 2 include substantial counts of Gramineae. The frequencies of this pollen type, together with those of Cyperaceae, suggest the existence of reedswamp in the vicinity of this site. Intermittent and very low totals of Artemisia maritima and Compositae may suggest that saltmarsh vegetation was also present in the site region as the silts and sands were laid down at this site. Subsequently freshwater reedswamp developed over these minerogenic deposits, as indicated by the replacement of silt by Phragmites/Carex peat. The development of this organic material appears to have been accompanied by that of saltmarsh plants, suggested by rising values of Artemisia maritima and very low totals of Caryophyllaceae (possibly Silene maritima) pollen. From 94-74cm the values of these latter pollen types together with those of Chenopodiaceae, Compositae, Armeria, and grass and sedge increase, reflecting the expansion of saltmarsh and a high sea-level as carse clay began to cover the peat at this site.

The above pollen and stratigraphic evidence sheds some light upon the sequence of events which took place at the Dollhouse sites, beginning with the deposits below the main gravel layer at Dollhouse Site 1 which are of Zone F.V.4/F.V.5 age. 1. Coarse sand and gravel were deposited over sandstone bedrock. Probably the former material was laid down during a period of high sea-level as it is overlain by grey clay associated with marine conditions. 2. The sea rose, saltmarsh began to develop and grey clay began to cover the lower gravel shortly after 7,800 B.P. This event took place during the Late-Boreal. Deposition of the grey clay was temporarily halted as a thin band of gravel and sand was laid down at this site. The grey clay is probably related to the carse clay, for according to pollen and radiocarbon evidence presented by Newey (1966), this latter deposit began to accumulate in the western Forth valley during a major marine transgression in VIa, which began at about 8,300 B.P.; approximately 500 years before the grey clay began to be laid down at Dollhouse Site 1. Thus the latter minerogenic deposit is related to the carse clay.

The third event which took place was the deposition of the main gravel layer at both Dollhouse sites. Numerous large rounded stones, coarse texture and crude bedding of this gravel suggest that this material was laid down during a river flood. This interpretation is supported by records of coarse, crudely bedded gravel and sand laid down by present day river floods in south-east Scotland (Learmonth, 1950) and in Morayshire (Green, 1958). In the light of this evidence and stratigraphy at Dollhouse Site 1, it is probable that carse clay deposition at this location was temporarily replaced by that of gravel and sand associated with periods of river flooding; a major flood occurring at about the Late-Boreal/Atlantic transition, when gravel and sand were discharged into the sea by floodwater and accumulated over the sea floor from Dollhouse Site 1 to Site 2.

Pollen evidence from Dollhouse Site 1 indicates that the main gravel layer ceased to accumulate early in Zone F.V.6. As the minerogenic deposits immediately overlying the gravel at Site 2 appear unrelated to marine influence, and as these deposits are, on stratigraphic and pollen evidence, slightly older than the carse clay at Site 1, it seems probable that the surface of the main gravel layer was above sea-level. Thus the next event (No. 4) which took place was the deposition of silt and sand over the surface of the main gravel layer at Site 2. The former deposits may have been laid down by river action, the probable presence of freshwater being suggested by the development of reedswamp as the silts and sands accumulated at Site 2. 5. Freshwater swamp continued to develop at this site accompanied by the formation of peat. 6. Subsequently the sea rose and carse clay began to be deposited over the peat at Site 2 and the surface of the main gravel layer at Site 1. This rise of sea-level was accompanied by the expansion of saltmarsh plants at both locations.

Summary.

Two sites, Dollhouse Site 1 and Site 2, are situated close to the edge of the carse clay lowland in a former embayment south of the river Forth. Pollen and radiocarbon evidence indicate that the deposits at these sites accumulated during the main Post-glacial transgression in the western Forth valley. The following sequence of events probably took place at these sites; 1. At Dollhouse Site 1 coarse gravel and sand were deposited over sandstone bedrock, probably during a river flood, as sea-level was rising. 2. The sea rose and carse clay began to be deposited over the gravel at this site. This event, which took place during the Late-Boreal, shortly after 7,800 B.P., was accompanied by the development of saltmarsh. 3. About the Late-Boreal/Atlantic transition carse clay deposition at Dollhouse Site 1 was interrupted by a major river flood which discharged gravel and sand into the sea. As a result of this flood a thick layer of sand and gravel, the surface of which was above sea-level, stretched from Dollhouse Site 1 to Site 2. 4. This event was followed by the deposition of river-borne silts and sands and the development of freshwater swamp at Site 2. 5. Freshwater marsh continued to develop at Site 2 accompanied by the development of peat at this locatiom. 6. Subsequently sea-level rose and carse clay began to be laid down over the peat at Site 2 and the thick gravel layer at Site 1. This change of site conditions was accompanied by the expansion of saltmarsh at both locations.

4.viii. The Menteith and Kinlochspelve Sites.

The Menteith site (NS 589000) is situated by the shore of the Lake of Menteith and is within the Menteith moraine complex deposited by ice of the Loch Lomond Readvance during Zone III, between about 10,800 B.P. and 10,300 B.P., according to Donner (1957). The moraine in this area is chiefly composed of sand and gravel containing glacier-transported marine clays and shells. Site investigations were carried out at a section where, according to Simpson (1933), 3m of dark grey clay containing marine shells is overlain by about 9m of sand and gravel. A radiocarbon date of 11,800 ± 170 B.P. was obtained from marine shells in the grey clay at this section by Sissons (1967a).

The Kinlochspelve site (NM 656261) is located near Kinlochspelve Farm by Loch Spelve in south-east Mull. At this location are deposits of the Kinlochspelve Moraine which were laid down during a stage of valley glaciation. This valley glaciation was correlated by Charlesworth (1955) and later by Sissons (1967a, 1967b) with the Loch Lomond Readvance at Menteith. At the site investigated the morainic deposits are composed chiefly of clay and stones with ice-transported marine shells. A sample of these shells gave a radiocarbon date of 11,330 ± 170 B.P. (Gray and Brooks, 1972).

The geomorphic and radiocarbon evidence from Menteith is comparable to that from Kinlochspelve and indicates the presence of marine conditions in the western Forth valley and Kinlochspelve area during the Late-glacial Interstadial (Zone II). Thus a major aim of the investigations at these sites was to test the geomorphological and radiocarbon evidence by the independent method of pollen analysis. A further aim was to determine Late-glacial vegetational conditions during the time the marine deposits in the Menteith and Kinlochspelve moraines accumulated before they were scooped up, transported and redeposited by ice. To these ends a sample from the radiocarbon dated marine deposits at each site was analysed. The numbers of pollen and spores from each sample are displayed in Table 13 below.

Table 13.

Pollen and Spores	Kinlochspelve	Menteith
Alnus	3	1
Betula	4	22
Betula nana	14	10
Pinus	23	42
Salix	3	3
Juniperus	3	1
Armeria	1	1
Caryophyllaceae	12	13
Chenopodiaceae	2	5
Compositae	1	1
Cyperaceae	12	5
Dryas octopetela	3	1
Epilobium	0	1
		/Continued

Table 13, continued.

Pollen and Spores	Kinlochspelve	Menteith
Empetrum	20	12
Ericaceae	14	27
Filipendula	47	29
Galium	2	0
Gramineae	51	61
Helianthemum	15	11
Hippophaë rhamnoides	0	1
Plantago maritima	1	1
Ranunculus	11	8
Rumex	1	1
Succisa	1	1
Thalictrum alpinum	4	8
Tilia cordata	0	1
Umbelliferae	4	3
Urtica	10	7
Myriophyllum alterniflorum	1	5
M.spicatum	1	0
Nymphaeaceae	1	0
Potamogeton	1	1
Filicales	7	3
Lycopodium clavatum	2	1
L.selago	11	8
Polypodium vulgare	1	0
Selaginella selaginoides	10	2

/Continued

Table 13, continued.

Pollen and Spores	Kinlochspelve	Menteith
Sphagnum	3	3
Total count	300	300
Arboreal percentage of total count	17	26
Non-arboreal percentage of total count	83	74
Derived Pre-Quaternary spores	71	1525

The arboreal pollen totals in Table 13 consist of small amounts of Pinus and Betula. A few grains of Salix and Alnus are recorded, but pollen of warmth demanding trees and shrubs such as oak, elm and hazel are not represented. Non-arboreal pollen and spore totals, however, are high and include a large number of herbaceous species. In this category, pollen and spores of plants characteristic of open habitat are well represented, particularly Gramineae, Cyperaceae, Caryophyllaceae, Dryas octopetela, Empetrum, Ericaceae, Filipendula, Helianthemum, Ranunculus, Thalictrum alpinum, Lycopodiaceae and Selaginella selaginoides. To this list may be added Betula nana (tentatively identified by pore characteristics) and Juniperus, as pollen of these shade intolerant species are also recorded at both sites.

The pollen and spore assemblages described above are comparable to those from Late-glacial deposits at Scottish sites investigated by other workers (Mitchell, 1952; Donner, 1957, 1958; Kirk and Godwin, 1963; Vasari and Vasari, 1968; Moar, 1969; Newey, 1970; Sissons and Walker, 1974). The pollen evidence presented by these investigators indicates the existence of open vegetational conditions at Scottish sites during the Late-glacial. On this basis it appears that the pollen and spores listed in Table 13 are referable to the Late-glacial period in which herbaceous vegetation predominated as the marine deposits, subsequently incorporated in the Menteith and Kinlochspelve moraines, accumulated.

The predominance of Gramineae, Filipendula, Ericaceae and Empetrum pollen in Table 13 suggests that the Late-glacial flora in the Kinlochspelve and Menteith localities was chiefly composed of grasses and heath communities. These types of vegetation appear to be referable to Zone II, the Alleröd period, as similar grass and heath communities are characteristic components of Zone II vegetation at sites in the research area investigated by Donner (1957) and Vasari and Vasari (1968), and at sites in the south-west lowlands of Scotland investigated by Moar (1969).

Other non-arboreal pollen in Table 13 may also support a Zone II age for the ice-transported marine deposits at Menteith and Kinlochspelve. The relative abundance of Filipendula pollen may be indicative of climatic amelioration which characterised Zone II, as this thermophilous plant is considered to be an indicator of warmer conditions during the Late-glacial (Iversen, 1954).

Records of *Filipendula* pollen from Late-glacial deposits in the research area are, however, sparse; this pollen type being poorly represented and recorded only in Zone II material at Drymen by Donner. The frequencies of *Filipendula* pollen in Table 13, however, can be compared with values of the pollen type in Zones I, II and III at Newey's (1970) site in the eastern Forth valley and Moar's (1969) sites in south-western Scotland. Thus the values of *Filipendula* pollen, 10% and 16% from Menteith and Kinlochspelve respectively, are comparable to the totals of *Filipendula* pollen which do not exceed 12% and 25% in Zone II deposits investigated by Newey and Moar, respectively. In the diagrams presented by these workers, *Filipendula* pollen totals in Zones I and III are below 5%; thus it seems unlikely that the higher pollen values of this plant from Menteith and Kinlochspelve are representative of Zone I or Zone III.

Helianthemum pollen values, below 10%, recorded by Moar and Newey from Zone II material are interpreted as indicating the existence of stable soil conditions during the Allerød period. On this basis the frequencies of *Helianthemum* pollen, which do not exceed 5%, in Table 13 may also be referable to Zone II and suggest the possible presence of stable soil conditions in the Kinlochspelve and Menteith areas during this zone. Soil stability at these locations may also be indicated by the relative abundance of *Empetrum* pollen in Table 13 since unstable soliflucted soils, as in Zone III, were unfavourable for the development of this plant (Vasari and Vasari, 1968; Newey, 1970).

The arboreal pollen counts in Table 13 also favour an interpretation of a Zone II age. The low tree pollen frequencies, 17% and 26% of the total pollen counts, from Kinlochspelve and Menteith respectively, are comparable to arboreal pollen totals of between 10% and 30% from Zone II deposits at other Scottish sites referred to above. In addition, the tree pollen at these sites are represented mainly by Betula, Pinus and Salix with pollen of the shrub Juniperus, as are those from Kinlochspelve and Menteith. The very low counts of Alnus and Tilia in Table 13, however, are uncharacteristic of Late-glacial pollen assemblages and are most likely derived. That or sample contamination probably explains the presence of these pollen in the table.

On the basis of low arboreal pollen counts from Zone II deposits at other Scottish sites, Donner (1957) suggested that during the Alleröd the vegetation was completely open and that Betula and Pinus pollen found in Zone II deposits were derived by wind transport; a view shared by Moar (1969). Thus it is possible that some, or all, of the Betula and Pinus pollen from Kinlochspelve and Menteith may have been similarly derived. Some Pinus pollen, however, may have been transported by the sea as substantial numbers of this pollen type are characteristic of marine deposits at other sites in the research area, as shown earlier. In view of these possibilities, the totals of Betula and Pinus pollen in Table 13 may not be representative of vegetational conditions at Kinlochspelve and Menteith during Zone II.

Pollen of Armeria, Caryophyllaceae (possibly Silene maritima), Chenopodiaceae, Hippophaë rhamnoides and Plantago maritima from Kinlochspelve and Menteith may indicate the influence of the sea on the vegetation at these locations for the following reasons; firstly, these pollen types, particularly Chenopodiaceae, recorded in marine deposits at other sites in the research area are considered to reflect the probable presence of saltmarsh vegetation during periods of high sea-level; secondly, representatives of these taxa are found in coastal situations today (Tansley, 1939). However, they are also characteristic of open habitat; thus it is possible that presence of their pollen in the Kinlochspelve and Menteith samples may have been derived from the open vegetational landscapes which apparently existed in the Kinlochspelve and Menteith areas in Zone II. In view of this possibility, the shells from Kinlochspelve and Menteith, described by Gray and Brooks (1972), are regarded more reliable indicators of marine conditions at these locations during Zone II.

Virtually all of the derived Pre-Quaternary spores recorded from the Menteith sample were identified as Lepidostrobus Jacksoni and L.Oldhamius, as described by Knox (1938) from Productive Coal Measures of the Fife coalfield. As these deposits are not present in the western part of the Forth valley, and since the ice that deposited the Menteith Moraine came from the west, most if not all, of these spores were probably derived from Carboniferous outcrops farther east in the Forth valley and redeposited by the sea during Zone II.

The total number of Pre-Quaternary spores in the Kinlochspelve sample is much smaller than that from Menteith. The two Carboniferous type spores found abundantly in the Menteith sample could not be identified in that from Kinlochspelve. As no Carboniferous deposits have been found on Mull it is suggested that the spores from the Kinlochspelve site may have been derived largely or entirely from adjacent Mesozoic outcrops.

Summary.

Zone III terminal moraines at Menteith in the western Forth valley and at Kinlochspelve in south-eastern Mull are partly composed of ice-transported shelly marine clays. Radiocarbon and pollen evidence indicate that these ice-transported marine deposits are referable to the Late-glacial Interstadial (Zone II). The pollen evidence also suggests the probable existence at these locations of essentially open vegetational conditions, similar to those which characterise Zone II at other Scottish sites.

PART 5.

Discussion.

5.i. Introduction.

The presentation of the data in this thesis follows the rules of geological nomenclature as defined in the Report of the Stratigraphic Code Sub-Committee (1967) and by West (1970). Thus biogenic and minerogenic material from nine Post-glacial sites in the western Forth valley is divided into units, each of which consists of a stratum having characteristic pollen assemblages. Taken together these units illustrate the vegetational development and changing environmental conditions in the research area during the Post-glacial. The type site at Woodend Farm Site 2 is of key importance as the deposits there represent the longest period of Post-glacial time and also allow study of most of the characteristic deposits of the upper Forth basin represented at other sites. The data from the type site thus provide a framework of reference of the chronology and development of vegetation with which data from other locations in the western Forth valley can be correlated. It can also be used, with radiocarbon dates, to date relative changes of land and sea-level in the upper Forth valley during the Post-glacial as shown later.

5.ii. Zonation of the Pollen Diagrams.

It was stated in a previous section (4.i.pp.66-77) that zonation of Post-glacial diagrams from British sites is usually based upon criteria proposed by Godwin (1940, 1956) which are in turn a development of an earlier zonation scheme evolved by von Post (1929, 1930) for pollen diagrams from sites in north-west Europe. By Godwin's zonation system Post-glacial vegetational history is divisible into eight zones and reflect the response of plants to widespread environmental change, in particular an amelioration of climate which progressed to a maximum and was followed by a recession. It was believed that these changes were widespread, resulting in a broad parallelism of vegetational development, thus pollen zones in diagrams from different regions were regarded as being synchronous. Consequently Godwin's zonal system provided a general chronological index for dating Post-glacial vegetational, archaeological and geological events in Britain. It was later recognised, however, that factors including differences in migration rates of plants, especially trees, in response to climatic change may have resulted in differences in vegetational development and that pollen zones at different sites might not be synchronous (Godwin, 1961, 1966).

Radiocarbon dating enabled the synchroneity of pollen zones at British sites and on the continent to be tested. Godwin (1961) compared C^{14} dates of major Post-glacial zones at Scaleby Moss in Cumberland with those from similar horizons at continental sites. The Scaleby dates showed a broad synchroneity with those obtained from sites on the European mainland and therefore British pollen zones could be equated with those of Europe. Subsequent research, however, has shown that the zones are not synchronous and that the actual course of vegetational development differs in different parts of Britain and the continent.

With regard to Scottish pollen diagrams, stages of vegetational history comparable to those at Post-glacial sites in England and Wales are not always distinguishable as demonstrated by Donner (1957, 1962), Moar (1969), Pennington and Lishman (1971) and Birks (1970, 1972). Furthermore, the datings of some zonal divisions at Scottish sites are at variance with those further south. For instance, Pennington and Lishman have shown that the expansion of Alnus at a site in north-western Scotland took place about a thousand years later than in England. On the other hand sequences of vegetation similar to those reflected in diagrams from English sites are recorded in diagrams presented by Durno (1956) and Newey (1966) from sites in the western Forth valley. In addition, the development of vegetation reflected in the type diagram from Woodend Farm Site 2 also corresponds to that which developed at more southerly locations, as shown below.

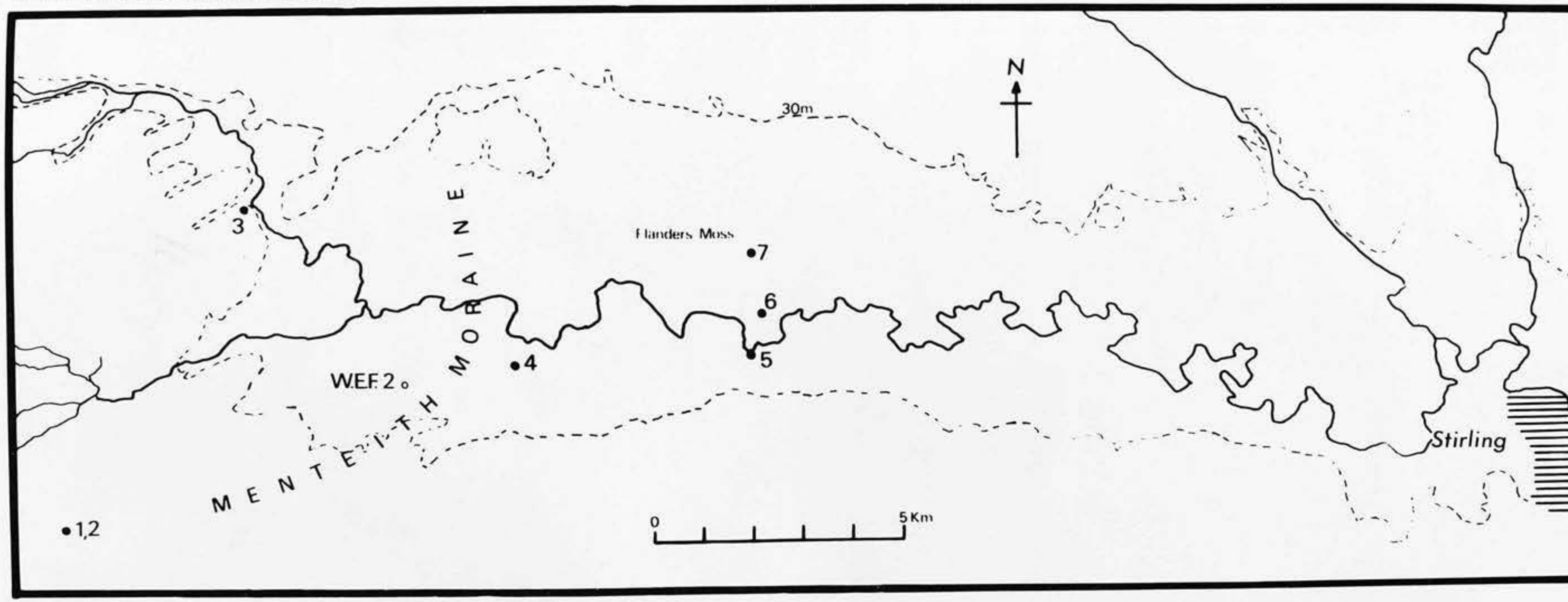
5.iii. Correlation of the Type Diagram from Woodend Farm with Diagrams from Other Sites in the Western Forth Valley.

It may be assumed that most, if not all, of the pollen in the organic and minerogenic material at the type site is derived from sources within the upper Forth basin. This assumption is supported by the work of Turner (1964), Tauber (1965, 1967) and Janssen (1973) whose investigations into pollen dispersal by air currents indicate that most tree pollen does not spread far beyond the site where they are released and that pollen of herbs is often found in close proximity to the parent plant. Faegri and Iversen (1964) consider that a distance between 50 - 100Km is a natural limit of pollen dispersal, most pollen however being deposited long before this limit is reached.

Pollen originating from sources outwith the research area, if present, are impossible to distinguish in the pollen spectra in the type diagram. However, in view of the relatively short distances travelled by airborne pollen, except Pinus, it seems likely that the influence of extra-regional pollen upon spectra in the type diagram is small. The assumption can therefore be made that this diagram provides a record of the vegetation, climatic and other environmental changes during the Post-glacial within the research area.

An interpretation of the pollen and stratigraphy from Woodend Farm Site 2 has been given in an earlier section (4.i.pp.64-77). Attention was drawn to the similarity of vegetational development at this site to that which developed

Location of pollen sites investigated by other workers in the western Forth valley in relation to the type site at Woodend Farm Site 2. (W.E.F.2)



1 and 2 Drymen (Donner, 1957; Vasari and Vasari, 1968)
3 Gartmore (Donner, 1957)
4 Kippen (Newey, 1966)
5 West Flanders Moss (Newey, 1966)
6 " " " (Turner, 1965)
7 East Flanders Moss (Durno, 1956)

Fig 29

at other sites in the western Forth valley. There are of course differences in the development of vegetation at each of these locations, explainable by variable site conditions. Therefore, to establish the validity of the type diagram as a standard reference for Post-glacial vegetational history in the upper Forth valley similarities (and divergencies) of the vegetation which developed at Woodend Farm Site 2 and at other locations in the research area (Fig. 29) merit more detailed discussion.

The Pre-Boreal Period.

The Pre-Boreal period, the earliest part of Post-glacial time is represented by the deposits of three sites, namely Woodend Farm Site 2, Bield and The Homesteads. The pollen assemblages from these deposits have therefore been designated Zone F.V. I. At each site the deposits are associated with the Main Buried Beach surface which existed as a raised shoreline at a period of falling sea-level in the early Post-glacial. The pollen composition illustrates the characteristic vegetation of the period and is shown in detail by the diagrams of the type site and of Bield and The Homesteads. This pollen was derived mainly from landscapes close to each site, but a proportion was doubtless derived from more distant sources and these would include high ground to the north, forming the Highland edge and also elevated land to the south such as the Campsie Fells.

The three diagrams emphasise the dominance of herbaceous plants; these include both species of open and treeless habitats and also those of arctic, sub-arctic or alpine environments. Grasses and sedges were the most prominent plants; genera such as Artemisia and Rumex indicate open conditions and Empetrum, Thalictrum and Dryas exemplify the arctic component. Aquatic pollen such as Myriophyllum and Potamogeton also appear in the diagrams and these indicate the existence of freshwater habitats.

Tree pollen consists only of Betula and Salix. These two genera are prominent today in tundra communities of arctic situations and their presence at these sites suggests a type of tundra vegetation analogous to modern communities. Thus the floral composition that characterises the period represented by this zone suggests the early stage of development of Post-glacial vegetation which accompanied the gradual amelioration of climate which terminated the Loch Lomond Stadial at c. 10,300 B.P.

The pollen in the Main Buried Beach deposits indicates, however, conditions also associated with proximity to sea-water. Both the Bield and The Homesteads sites contain pollen of plants of the Chenopodiaceae which are common in littoral situations and this pollen combined with the frequencies of Gramineae, Cyperaceae, Compositae and the clayey nature of the deposits in which they occur is interpreted as belonging to a saltmarsh habitat, formed by the flat, ill-drained surface of the Main Buried Beach. This beach has only a very gradual slope as numerous bores have shown (Sissons, 1966).

The gradual withdrawal of the sea from the Main Buried Beach as sea-level declined allowed representatives of the mesophytic and hydrophytic plant life of the time to colonise the flat surface of the beach. Consequently the vegetation characteristic of brackish conditions such as saltmarsh was replaced by freshwater swamp and marsh plant communities, in which the common reed, <u>Phragmites</u>, was abundant, with <u>Sphagnum</u> mosses and other bog plants. These types of vegetation, reflected by stratigraphy, pollen and spores in the diagrams, namely The Homesteads and Bield which include this zone, were favoured by poor drainage resulting from both soil and slope conditions and were conducive to peat formation as recorded in the diagrams.

A comparable sequence of events has been recorded at other pollen sites in this area, such as at West Flanders Moss (Newey, 1966) where the deposits are similar stratigraphically and where deposition was contemporaneous with those of the type site namely Zone IV of the English system. The salient feature of Zone IV in these diagrams are a predominance of NAP (including pollen of plants characteristic of the tundra) with <u>Betula</u> then <u>Salix</u> being the main AP representatives. They convey a picture of an essentially herbaceous flora with colonies of birch and willow which bears a striking resemblance to the vegetation at the type site and confirm that Zone F.V.I at Woodend Farm Site 2, The Homesteads and Bield and Zone IV of the English zonation in the research area are indicative of similar conditions.

Radiocarbon dates obtained by Godwin (1957) from a site at Scaleby Moss in northern England indicate that the Pre-Boreal lasted from <u>c</u>. 10,300 - 9.500 B.P. However, dates of this period at sites in the research area are unavailable at present, therefore exact correlation of Zone F.V.I and Zone IV of the English system is not possible.

The Boreal Period.

The Boreal is represented by Zones F.V.2 - F.V.5 in the type diagram (Fig. 8). It is distinguished by changes in floral composition, particularly the immigration into the western Forth valley of woodland species in response to climatic, edaphic and other environmental factors.

The opening of the Boreal is characterised by the sudden and sustained rise of *Corylus* and the consistent increase of *Ulmus* pollen totals and reductions in the values of *Betula* and *Salix* pollen in Zone F.V.2 in the diagrams from Woodend Farm Site 2, The Homesteads and Bield. This evidence indicates development of deciduous genera, namely the rapid immigration into the region of hazel accompanied by elm. As these taxa advanced, birch and willow being light demanding plants presumably declined, although *Betula* remained an important constituent of the vegetation.

Zone F.V.2 is essentially one of rapid transition between the open early Post-glacial landscape and the later thickly wooded or forested landscape. As *Corylus* and *Ulmus* spread, the plants of open, treeless habitats declined together with those of arctic or arctic/alpine environments. This is most clearly shown in The Homesteads and Bield diagrams where, for example, *Empetrum*, *Plantago*, *Rumex*, *Artemisia*, Lycopodiaceae and *Selaginella* all have decreasing pollen frequencies. These vegetational changes were produced by the development of a closed cover of trees and shrubs and also by the rapid amelioration of climate in that area.

<u>Pinus</u> may also have been present at Woodend Farm as its pollen increases in frequency in Zone F.V.2 in the type diagram. However, it is well known that pine pollen can travel long distances by air currents, therefore most <u>Pinus</u> pollen recorded in Zone F.V.2 at Woodend Farm could have originated from sources outwith the western Forth valley. Hence they must be regarded as unrepresentative of the actual presence of pinewood. Frequencies of pine pollen in Zone F.V.2 in The Homesteads diagram are also considered unrepresentative as some of them at least were probably transported from afar by water currents as explained earlier (Section 4.v.pp.93-99).

The early Boreal represented in Zone V diagrams from other sites in the research area, namely Drymen and Gartmore (Donner, 1957), West Flanders Moss and Kippen (Newey, 1966) and East Flanders Moss (Durno, 1956) is also characterised by sharp increases in <u>Corylus</u> and reductions in <u>Betula</u> pollen totals. <u>Ulmus</u> pollen values, however, do not usually show a clear, consistent rise as those in the type diagram, although they indicate an expansion of elm during this period as birch declined and hazel swiftly advanced. Non-arboreal pollen ratios in these diagrams also fall, indicating the suppression of herbaceous plants by the expanding woodland. Thus it may be assumed that Zone V at these sites and Zone F.V.2 at Woodend Farm, Bield and The Homesteads are equivalent.

There is little doubt that the development of woodland during Zone F.V.2 was in response to changes in environmental conditions in the upper Forth valley. According to Walker (1966) the expansion of Corylus during the Boreal was favoured by rising temperatures (mean summer temperatures probably exceeding 15°C) and the almost total eradication of late spring frosts, as hazel flowers early and its stigmas are sensitive to frost (Godwin, 1956). The absence of sharp cold spells would also be favourable for elm as late spring frosts are detrimental to the development of this species according to Godwin. Thus comparable climatic conditions probably favoured the expansion of hazel and elm in the upper Forth basin during Zone F.V.2. Other factors, however, may also have assisted the spread of these taxa, such as maturing soils and lack of competition from other trees, particularly oak. Freedom from competition from high forest trees is particularly important for the development of Corylus as this species flowers best in relatively open conditions whereas understory hazel flowers sparsely (Faegri, 1966).

At English sites the early Boreal was also the time when Corylus began its rapid advance accompanied by the expansion of Ulmus, as signified by the frequencies of these pollen types in diagrams from these locations. However, pine exceeded birch in amount, particularly in the south of England than at more northerly sites.

As the expansion of hazel and elm at English sites is also attributed to improving climatic and edaphic conditions (Godwin, 1956) it seems probable that the climate and vegetation in England and the western Forth valley during the early Boreal were broadly similar. Thus Zone F.V.2 in the upper Forth valley can be correlated with Zone V in England.

Correlation of these zones may also be possible by radiocarbon evidence. Dates presented by Godwin et al (1957) from Scaleby Moss indicate that the Boreal began c. 9,500 B.P. and ended between c. 9,000 - 8,800 B.P. A date of 8,690 ± 140 B.P. obtained by Newey (1966) from Zone V (F.V.2) deposits at Kippen is relatively close to the upper dates of the early Boreal at Scaleby, although its apparent age may have been reduced by contamination of the material obtained for radiocarbon assay by younger material e.g. roots of trees (Sissons, 1966). Thus it is likely that Zone F.V.2 in the western Forth valley is synchronous (or approximately synchronous) with Zone V in England.

The boundary between Zones F.V.2 and F.V.3 is defined by the increase of Quercus and by the reduction in the frequencies of Corylus and Betula in the type diagram. Though hazel attains its maximum at the start of the zone it declines thereafter in response to the changing environment brought about by the dominance of tall, broad-leaf taxa, notably Quercus and Ulmus; the competition of these plants reduced Corylus and Betula to the role of subordinates, though Betula was still present in quantity, presumably occupying more open spaces in the woodland where its demands for light were fulfilled. Corylus continued as an understory shrub species in the forest, a role which it occupies at the present time. This zone thus marks an important stage in the development of a mature broad-leaf deciduous forest.

Arboreal pollen spectra in the diagrams from The Homesteads and Bield and those of early Zone VI from Drymen and Gartmore (Donner, 1957), West Flanders Moss and Kippen (Newey, 1966) and East Flanders Moss (Durno, 1956) are comparable to AP totals in Zone F.V.3 in the type diagram from Woodend Farm. They convey a picture of the development of broad-leaf forest, notably oak and elm, and the decline of pioneer species such as hazel and birch, similar to that at Woodend Farm. It may be assumed therefore, that the development of this forest was also in response to changes in climate and soil conditions and the inability of pioneer plants such as Corylus and Betula to compete successfully against the advancing layer dominants.

The characteristics of woodland development which distinguish Zone F.V.3 in the western Forth valley are not usually apparent in diagrams from Highland sites (including those investigated by Durno, 1956, 1958; Donner, 1957, 1962; Vasari and Vasari, 1968; Moar, 1969; Birks, 1970, 1972; Pennington and Lishman, 1971). Comparison of arboreal pollen evidence from these areas indicates that Post-glacial woodland history in northern Scotland differed from that in the Forth basin. In the former region oak and elm, although present in small amounts, were subordinate to birch or, in parts of north-west Scotland, to pine, whereas the reverse was the case in the Forth valley. Similar differences in arboreal vegetation exist between these regions at the present day.

The pine frequencies shown in the type diagram are presumably the result of over-representation. They may, however, represent actual stands of _Pinus_ in the vicinity of the type site, since the soils of the area varied considerably as a result of glaciation. Areas of outwash sands and gravels are present (Simpson, 1933; Sissons, 1966, 1967b) and they would develop strongly podsolised soils in which _Pinus_ associations may have occurred whereas the heavier, more base rich soils were more favourable for _Quercus_ and _Ulmus_. Dollhouse and Drymen appear to be cases where local stands of pine occurred.

The _Pinus_ frequencies recorded at The Homestead and Bield sites were associated with the deposition of carse clays produced by marine incursion. Pollen of _Pinus_ is common in such deposits as a result of inwash and concentration of floating pollen as discussed elsewhere (Sections 4.ii.pp. 80-83 and 4.vi.pp.100-110).

The status of pine is therefore doubtful in the Forth area and the pollen evidence for its widespread presence is not conclusive. This contrasts with the situation in contemporaneous English zones as in Breckland, East Anglia, where a preponderance of pine occurred in Zones V and VI (Godwin, 1956).

However, despite the contrasts in the status of _Pinus_, forest development in the research area was generally analogous to that in southern England where _Quercus_ and _Ulmus_ also advanced and _Corylus_ and _Betula_ declined.

Further correlation of Zone F.V.3 in the research area and early Zone VI at sites in England is given by radiocarbon evidence. Dates from Scaleby Moss indicate that Zone VI began between c. 9,000 - 8,800 B.P. and ended c. 7,500 B.P. From Kippen in the western Forth valley dates of 8,690 ± 140 B.P. and 8,270 ± 160 B.P. from Zone V (F.V.2) and early Zone VI (F.V.3) deposits, respectively, signify that Zone VI in this area opened sometime between c. 8,700 - 8,300 B.P. which is relatively near the lower date for Zone VI at Scaleby. This suggests that Zone F.V.3 in the upper Forth valley and early Zone VI at English sites may be synchronous.

A further stage in the evolution of forest in the western Forth valley is represented in Zone F.V.4 in the type diagram by rising values of Quercus (which exceed those of Ulmus), Alnus and increases in Corylus and Pinus. Conversely, Betula frequencies fall, but more sharply than in the previous zone. This evidence indicates that oak became predominant in the forest and Alnus began its immigration into the region. Betula, unable to compete against the advancing layer dominants declined rapidly, although presumably with Corylus it remained an understory species in the forest. Pinus may also have expanded in the Woodend Farm area although it is highly likely that its representation is over-emphasised.

The changes in forest composition in the neighbourhood of Woodend Farm were also accompanied by a change in site conditions. Freshwater marsh and peat which developed at Woodend Farm during the preceding zone were replaced by saltmarsh communities as sea-level rose and carse clays began to accumulate at this site, as confirmed by stratigraphy and pollen evidence in the type diagram.

Whether the changes in forest composition, described above, were influenced by the prevailing marine conditions or other environmental factors is difficult to assess. It is a possibility that the rapid decline of birch may, in part, be attributed to destruction of marginal woodland by the rising sea. This is supported by stratigraphic evidence consisting of a layer of birchwood immediately beneath the carse clays, indicating that Betula was present at Woodend Farm just before the sea rose and began to deposit carse clays. A consistent fall in AP ratios at the level of these minerogenic deposits may also indicate the recession of coastal woodland as sea-level rose. The development of other woodland genera could also have been affected by the rising sea. For instance, water-table levels would rise and produce wet situations favourable for Alnus. Thus the rise of alder during Zone F.V.4 at Woodend Farm can be explained by favourable site conditions for its development, namely, low lying clay soils, a level topography and a high water-table.

Short diagrams from other sites in the research area can be correlated with the type diagram from Woodend Farm. Pollen and stratigraphy from Easter Offerance indicate the presence of mixed oakwood as carse clays were laid down at this site by a rising sea. Tree pollen totals, especially Quercus and Ulmus, in the diagram (Fig. 13) from this location broadly resemble those of woodland genera which characterise the Boreal in the type diagram. Thus the pollen spectra and carse clays represented in the Easter Offerance diagram are also referable to the Boreal. Further correlation cannot be expected as the pollen frequencies from Easter Offerance are from a small number of samples from a thin layer of carse clay.

Pollen and stratigraphy represented in the diagram (Fig. 16) from Newburn also convey a picture of broad-leaved forest development as sea-level rose and carse clays began to be deposited at this site; events which accord with those which took place at Woodend Farm during Zone F.V.4. However, the rise of sea-level and deposition of carse clay at these sites could have occurred at different times as explained later (Section 5.vi.pp.169-190) therefore exact correlation may not be possible. Nevertheless, zonal determination of the Newburn diagram may be possible by radiocarbon datings.

Radiocarbon evidence presented earlier (Section 4.v. pp.93-99) indicates that carse clays began to accumulate at Newburn shortly before c. 8,000 B.P. when mixed oakwood was present. Similar vegetational and marine conditions existed during the mid-Boreal (VIb) at Newey's (1966) site at Kippen, a short distance east of Newburn, and have been dated at c. 8,270 ± 160 B.P.. As these dates are relatively close it may be assumed that the events at Newburn also took place during VIb. The frequencies of tree pollen, particularly oak and elm, which characterise VIb at Kippen and Zone F.V.4 in the type diagram are remarkably similar and can therefore be correlated. In the light of this evidence it can be concluded that the development of broad-leaved deciduous forest and the deposition of carse clays at Newburn also took place during Zone F.V.4.

In contrast to the Newburn diagrams, those from Drymen and Gartmore (Donner, 1957) and East Flanders Moss (Durno, 1956) reflect a longer period of Post-glacial vegetational history which can be compared more easily with that at Woodend Farm. Arboreal pollen totals in mid-Zone VI represented in these diagrams indicate a development of broad-leaf deciduous woodland comparable to the development of forest in the vicinity of Woodend Farm during Zone F.V.4. There are of course differences in AP frequencies in the diagrams from these sites. For instance, oak and alder were more frequent in the Woodend Farm area than at East Flanders Moss, Drymen and Gartmore. These differences are not entirely unexpected as these sites are situated some distance from the type site and account has to be taken of probable differences in site conditions and their influence upon vegetational development.

Nevertheless, the AP totals from Woodend Farm, Drymen, Gartmore and East Flanders Moss are in general similar, indicating an overall similarity of forest development. Therefore, it may be assumed that Zone F.V.4 at Woodend Farm and mid-Zone VI at other sites in the research area are equivalent. Furthermore, the vegetation and radiocarbon dates from the mid-Boreal in the upper Forth basin and those at English sites are also in accord and can therefore be correlated.

The Late-Boreal (Zone F.V.5) is represented at Woodend Farm by a further rise of <u>Alnus</u> and a change in stratigraphy which reflect more changes in regional and local environmental conditions. The most outstanding of these changes is furnished by stratigraphy. At 400cm Phragmites/Carex/Sphagnum peat is replaced by Eriophorum sp. peat indicating that plants characteristic of freshwater marsh and swamp were superseded by raised moss communities. This change in vegetation is confirmed by rising totals of Sphagnum spores and Ericaceae pollen in the type diagram.

The development of raised moss is explained by the level, waterlogged surface of the carse clay at Woodend Farm which would provide a suitable habitat for the spread of Sphagnum mosses together with other calcifuge plants such as Ericaceae and Eriophorum. Comparable stratigraphic and pollen evidence is presented by Godwin (1955) from the Somerset Levels where reedswamp was replaced by raised moss which developed upon flat, saturated marine clays of Late-Boreal age.

Local environmental conditions would also tend to favour the spread of Alnus as indicated by very high values of its pollen which depress those of other woodland genera in the type diagram. Presumably alder was colonising the ill-drained carse clays present in that area. It is probable, therefore, that the development of Alnus at Woodend Farm during Zone F.V.5 was in response to favourable environmental conditions at local and regional levels.

The poorly drained carse clay soils at Woodend Farm would also be a suitable habitat for Betula, as this plant is commonly present in areas where drainage is impeded. This would account for the increases in birch pollen totals in Zone F.V.5 in the type diagram. However, on higher and well-drained land in the region mixed-oakwood would predominate;

the presence of this forest in the area being indicated by consistent counts of Quercus and Ulmus pollen in the type diagram.

Mixed oak-wood comparable to that at Woodend Farm also developed at Easter Mye and Dollhouse Site 1, as indicated by the similarity of pollen totals of oak and elm in the diagrams from these sites. Betula however did not expand although it is highly likely that with Corylus it was an understory species of the forest at Easter Mye and Dollhouse. Pinus was also present on freely drained soils in the vicinity of Easter Mye as explained in a previous section (4.iv.pp.89-92).

In contrast to the type site, Easter Mye and Dollhouse Site 1 were inundated by the sea during a major marine transgression into the Forth valley during Zone F.V.5. This event was accompanied by the deposition of carse clay and the development of saltmarsh at these sites as demonstrated by stratigraphy and pollen evidence. The rise of sea-level produced by the marine transgression may have influenced woodland development at these locations. For instance, water-table levels would rise resulting in increased soil moisture favourable for Alnus. This might account for the rise in frequency of alder pollen in the Easter Mye and Dollhouse Site 1 diagrams. However, the increased totals of this pollen type could also reflect the response of Alnus to regional environmental conditions, as dates of 7,840 ± 125 B.P, and 7,480 ± 125 B.P. from Dollhouse Site 1 and Easter Mye respectively correspond to dates of 7,354 ± 146 B.P. and 7,425 ± c. 350 B.P. when Alnus began to expand during the late-Boreal (VIc) at Scaleby.

Correlation of Zone F.V.5 vegetation at the type site and that which developed at Gartmore, Drymen, East Flanders Moss and West Flanders Moss during the Late-Boreal can also be attempted. Frequencies of AP from these locations indicate that late Zone VI was characterised by mixed-oakwood and an expansion of *Alnus* similar to the development of identical taxa at Woodend Farm. Furthermore, ombrogenous mire also developed at Gartmore, Drymen and East Flanders Moss as indicated by rising totals of *Sphagnum* spores and Ericaceae pollen in the diagrams from these sites. However, at West Flanders Moss raised bog did not develop because the site area was flooded as sea-level rose.

In the light of the above evidence it can be concluded that Zone F.V.5 at Woodend Farm and upper Zone VI at other sites in the upper Forth valley are the same. The forest in this area bears a close resemblance to that which characterises the Late-Boreal in England. This evidence and the closeness of the radiocarbon dates from Dollhouse Site 1, Easter Mye and Scaleby indicates that Zone F.V.5 in the western Forth valley and late Zone VI at English sites are also equivalent.

The Atlantic Period.

According to Godwin (1956) Atlantic time is characterised by the Climatic Optimum in which temperatures and rainfall increased. Manley (1964) has suggested that annual precipitation at that time may have been 25-50% above that at the present day. Mean summer temperatures rose to about 2.5°C higher than they now are and winters were perhaps 2°C warmer than at present.

In these climatic conditions alder attained its maximum development; it would be present in the mixed forests of the area forming associations in moist habitats too wet for _Quercus_ e.g. along streams. At this time peat bogs developed in many parts of Britain; blanket bogs developing on flat upland surfaces with high rainfall and raised moss in moist lowland areas with impeded drainage, for example on valley floors. Doubtless the western Forth valley formed an ill-drained area with a moist climate during Zone F.V.6 similar to these conditions at the present day, producing conditions conducive for the development of _Alnus_ and ombrogenous mires; the latter gave rise to the Ericaceae and _Sphagnum_ represented in the type diagram and their presence is confirmed by stratigraphy.

The frequencies of _Quercus_ and _Ulmus_ in this diagram signify that these taxa were also present; the likelihood is that these plants predominated on well drained soils in the type area as in the previous zone.

The presence of high forest, _Alnus_ and raised moss development in the Woodend Farm area during the Atlantic period is confirmed by comparable frequencies of AP and NAP together with stratigraphy in the short diagrams (Figs. 10,11) from Woodend Farm Site 1, situated a short distance northwards of the type site, although for a time ombrogenous bog did not develop at Woodend Farm Site 1 as the site area was flooded by the sea, when carse clays were deposited and saltmarsh developed at this site as demonstrated by stratigraphy and frequencies of Chenopodiaceae pollen. Presumably the prevailing marine conditions were locally unfavourable for alder as this genus is intolerant of saltwater (Buxton, 1939; Ranwell, 1972).

The carse clays at this site contain substantial amounts of <u>Pinus</u> pollen; however, they are unrepresentative of the presence of pinewood as it is almost certain that they were transported from afar by the sea as explained earlier (Section 4.ii.pp.78-83).

Subsequently the sea retreated from Woodend Farm Site 1 and saltmarsh was replaced by freshwater marsh and swamp and then by raised moss communities which with <u>Alnus</u> developed upon the surface of the carse clay abandoned by the sea; this change in vegetation being confirmed by pollen, spores and stratigraphy and the disappearance of Chenopodiaceae pollen. A radiocarbon date of the carse clay/peat junction at this site, presented by Sissons and Brooks (1971) indicates that this event took place at <u>c</u>. 6,500 B.P.

A development of mixed-oakwood and alder, comparable to the development of identical taxa at Woodend Farm during Zone F.V.5, is discernible in pollen diagrams (Figs. 24,26) from the Dollhouse sites situated in the eastern extremity of the research area. Stratigraphic evidence presented in Fig. 23 shows that these sites were influenced by the rising sea and periodic river flooding. Such conditions would produce wet soils favourable for alder in addition to moist climatic conditions as explained earlier. The likelihood is that the development of <u>Alnus</u> at Dollhouse was in response to local and regional environmental conditions during Zone F.V.6

The vegetation at these sites and at Woodend Farm matches the development of mixed-oakwood, alder and ombrogenous mire at the sites at Drymen and Gartmore (Donner, 1957), East Flanders Moss (Durno, 1956) and Turner's (1965) site at West Flanders Moss during sub-Zone VIIa, as the pollen, spore and stratigraphic evidence from these sites and the type site are similar. Therefore it can be concluded that VIIa and Zone F.V.6 in the western Forth valley are equivalent.

Correlation of Zone F.V.6 vegetation in the research area with Post-glacial plant development at other Scottish sites may not be possible as the rise of <u>Alnus</u> began at different times in different places. For instance, at a site at Loch Scionascaig in north-west Scotland, alder began its expansion at <u>c</u>. 6,250 $\pm$ 140 B.P. (Stuiver, 1969), nearly one thousand years later than at Scaleby in northern England. This date is close to a date of 6,490 $\pm$ 125 B.P. obtained for the rise of <u>Alnus</u> at Woodend Farm Site 1 by Sissons and Brooks (1971) who suggest that the zonal divisions in the Forth valley may not be exactly synchronous with those in England. However, the AP frequencies in Zone F.V.6 in the type diagram are strikingly similar to those which characterise the Atlantic period at English sites. Furthermore, the date from Zone F.V.6 deposits at Woodend Farm Site 1 and a date of 5,490 $\pm$ 130 B.P. obtained from equivalent deposits at Turner's site at West Flanders Moss, fall within the Atlantic period dated from <u>c</u>. 9,000 - 5,000 B.P. at Scaleby. Thus Zone F.V.6 in the upper Forth valley and VIIa in England are probably synchronous.

The Sub-Boreal Period.

The Atlantic/Sub-Boreal (F.V.6/F.V.7) transition in the type diagram is set where Ulmus pollen values fall. They mark the decline of this species and the possible onset of human activity upon forest development in the research area as explained below. Other changes in forest composition also distinguish the Sub-Boreal from the previous zone, namely the revival of Betula and Corylus as signified by increases in their pollen totals. However, those of Quercus and Alnus maintain their previous levels, indicating that these taxa maintained their position during the Sub-Boreal.

Pollen evidence in VIIb diagrams from Drymen (Donner, 1957) East Flanders Moss (Durno, 1956) and West Flanders Moss (Turner, 1965) show a development of forest similar to that at Woodend Farm during Zone F.V.7. Thus Zone F.V.7 and VIIb in the western Forth valley can be correlated. Zone F.V.7 can also be correlated with the Sub-Boreal represented in English pollen diagrams which are also characterised by AP frequencies closely resembling those in the type diagram. Further correlation is given by radiocarbon evidence; dates from Scaleby show that the Sub-Boreal began c. 5,000 B.P. and ended c. 2,500 B.P. These dates are close to those of 5,014 ± 120 B.P. and 5,192 ± 120 B.P. and 2,712 ± 120 B.P. for the lower and upper boundaries respectively of VIIa (F.V.7) in Turner's diagram from West Flanders Moss.

The elm decline which characterises the Sub-Boreal at many sites in Britain and the mainland of Europe is generally accepted as being the consequence of forest clearance by

Neolithic agriculturalists, as the fall in elm pollen values in many diagrams is accompanied by pollen of plants of open habitat including weed species such as Plantago lanceolata (Iversen, 1949). Support is given by archaeological evidence at the level of the elm decline at sites investigated by Godwin (1956) and Troels-Smith (1960). However, other explanations for the fall in elm pollen production have been put forward. These include the selective exploitation of elm by primitive farmers; disease such as Dutch Elm disease; climatic factors, for instance decreasing temperatures (Iversen, 1941, 1960); wet and dry periods which resulted in fluctuating water-table levels unsuitable for the development of elm (Tauber, 1965); a declining soil base status caused by leaching of soils in response to increasing precipitation (Pennington, 1972); a combination of climatic and human factors (Dimbleby, 1964; Sims, 1973).

Evidence that the decline of elm in Scotland was connected with early forest clearance is strong at some sites, particularly those investigated by Durno (1965) in Perthshire and Lanarkshire, where the Sub-Boreal is characterised by increases in NAP including Plantago pollen at the level of the elm decline. At other Scottish sites, however (including those investigated by Donner, 1957 and Pennington, et al 1973) the connection between forest clearances denoted by the elm decline and early farming practices is not established. The main discrepancy concerns the timing of the clearances with the elm decline which do not take place at the same level in many diagrams. For instance, at sites in north-west Scotland human interference upon forest development began c. 3,500 B.P., long after elm began to decline (Pennington, 1973). It is possible therefore, that the elm decline was produced by causes other than human influence. Donner (1957) considered that the effects of environmental conditions during the previous zone (the Atlantic period), such as increased rainfall, progressive leaching and acidification of soils and development of peat bogs were largely responsible for the diminution of forested areas in Scotland. Similar views have been expressed by Durno (1956) although he also believed that anthropogenic influence upon vegetation increased from the beginning of the Sub-Boreal.

With reference to the Ulmus decline in the western Forth valley, soil impoverishment in nutrients would certainly occur during the moist Atlantic period as a result of increased leaching. Such soil change would be unfavourable to Ulmus which requires soils of adequate base-status. Hence the pollen counts of elm would fall. These effects, however, would become apparent only in the Sub-Boreal which experienced a drier climate as suggested by other evidence e.g. the drying out of peat bog surfaces (Godwin, 1956), and the development of Eriophorum sp. peat (Tallis, 1964). Thus the development of Eriophorum peat at Woodend Farm during the Sub-Boreal, as demonstrated by stratigraphy, also suggests some tendency towards lessened humidity in the western Forth valley at this time. The drier conditions of the Sub-Boreal would not restore Ulmus to its former status as the soil change would be irreversible over a short period.

The evidence for human influence upon forest composition in the type diagram is less clearly indicated than in diagrams from some other parts of Britain. The other sites in the research area moreover, are investigations of aspects of environmental change of earlier date than that of the Ulmus decline and hence can yield no supporting evidence. Other workers, however, have made contributions to the subject of anthropological influence upon vegetation in the upper Forth region, and their conclusions may be cited as supporting evidence (Durno, 1956; Donner, 1957; Turner, 1965).

With reference to the Woodend Farm Site 2 sample diagram, continuous frequencies of Plantago lanceolata appear above the level of the Ulmus decline, although isolated grains were recorded just below it. This herb became a consistent, yet small, component of the pollen rain during this zone and the following zone, perhaps indicating some small clearings in the forest, although the presence of other weeds of cultivation is not recorded. On the whole, the composition of the forest was, apart from the absence of Ulmus, not affected although there are fluctuations in the frequencies of Betula and Corylus, perhaps indicating the restoration of birch and hazel scrub after clearances had been abandoned by early farmers. In the case of birch, however, it is more likely that its expansion during Zone F.V.7 was associated with the development of Sphagnum moss and a moist climate as Betula develops well in such conditions (Kinnaird, 1974).

Archaeological work has shown that in Scotland the human inhabitants during the Neolithic formed primitive communities subsisting by hunting, fishing and food gathering (Piggott, 1958) and retained for a considerable time the characteristics of the Mesolithic (Lacaille, 1954). Later, Bronze Age communities, who derived their food from nomadic pastoralism and grazing animals would make some impact upon forest composition (Turner, 1965). Thus it is possible that small clearings and perhaps selective exploitation of elm during the Neolithic and Bronze Ages may have taken place in the western Forth valley although this has yet to be established.

In the light of the above evidence it seems possible that human disturbance of the forest in the upper Forth basin during the Sub-Boreal was on a very small scale and may have been connected with early farming practices. However, environmental factors such as leaching and acidification of soils and the spread of raised moss in response to a moist climate may have been more important causes responsible for the decline of forest in the western Forth valley during Zone F.V.7, and may explain the presence of _Plantago lanceolata_ and increases in _Betula_ and _Corylus_ after elm began to decline in this area.

The Sub-Atlantic Period.

The Sub-Atlantic, Zone F.V.8, at Woodend Farm is distinguished by changes in stratigraphy and pollen totals which reflect the continued effect of climate and other environmental factors and the probable intensification of human activity upon the vegetation.

The most outstanding of these changes at the type site is the replacement of dark, highly humified, fibrous _Eriophorum_ sp. peat by paler Sphagnum peat of low humification. This stratigraphic change is accompanied by rising values of Ericaceae pollen and Sphagnum spores and represents a further development of raised moss. A similar change in stratigraphy usually characterises the Sub-Boreal/Sub-Atlantic transition at other sites in the western Forth valley and elsewhere in Britain and is called a recurrence surface or Grenzhorizont. It is generally accepted that the poorly humified Sphagnum peat of the Sub-Atlantic reflects a rapid growth of oligotrophic vegetation and peat formation in response to climatic deterioration when temperatures fell c. 2°C and rainfall increased. It is evident that such climatic conditions must have existed in the upper Forth valley during the Sub-Atlantic and favoured the rapid development of raised bog in this area.

Radiocarbon evidence from Scaleby shows that the Sub-Atlantic began c. 2,500 B.P. which agrees with a date of 2,712 ± 120 B.P. for the Sub-Boreal/Sub-Atlantic transition at Turner's (1965) site at West Flanders Moss. This confirms that the rapid development of raised moss in the western Forth valley and in England during the Sub-Atlantic was contemporaneous.

As ombrogenous mire developed at Woodend Farm the forest steadily decreased as indicated by the fall in AP ratios in the type diagram. During this time elm was poorly represented and alder was less frequent than in the previous zone. Betula, however, continued to expand accompanied by increases in Quercus and Corylus. A similar picture of vegetation during the Sub-Atlantic is conveyed by pollen, spore and stratigraphic evidence in the diagrams from Drymen (Donner, 1957), West Flanders Moss (Turner, 1965) and East Flanders Moss (Durno, 1956), and in diagrams from Highland sites (including those investigated by Durno, 1956; Donner, 1957; Vasari and Vasari, 1968).

It is generally accepted that in Scotland forest had rapidly declined as a result of natural processes (i.e. development of peat bogs, progressive acidification and leaching of soils connected with climatic deterioration) by the beginning of the Sub-Atlantic, and that the decrease of forest during Zone VIII was caused mainly by the continuation of these processes and the intensification of human activity. These factors doubtless influenced the vegetation of the research area.

It is difficult however, to gauge the impact of man upon the forest in the upper Forth basin from the type diagram as the Sub-Atlantic is not fully represented. According to Turner (1965) large scale clearance of the forest in this area took place from c. 80 AD during the Roman occupation. These clearances are represented by increases in Gramineae pollen totals (above 80%) and those of Plantago and Pteridum in upper Zone VIII in her diagram from West Flanders Moss. It is possible, however, that small clearings were made in the forest prior to the Roman period i.e. during the Iron Age. This is suggested by increases in Gramineae and low, consistent totals of Plantago lanceolata pollen frequencies in the type diagram and early Zone VIII at Drymen and East Flanders Moss.

On the other hand, archaeological evidence of human occupation in the western Forth valley during the Iron Age is much stronger. Evidence presented by Feacham (1963) shows that high ground near Stirling was occupied at this time, and an Iron Age crannog (a lake/marsh dwelling) recorded by the Ordnance Survey on Flanders Moss (at NS 569988) indicates that the mossy, ill-drained floor of the upper Forth valley was also inhabited. That Iron Age man actually cleared forest in the research area has yet to be established, although Turner (1965) has suggested that small clearings, connected with semi-nomadic pastoralism, were probably made in the forest during the Iron Age.

The course of vegetational history in the upper Forth valley during the late stages of the Sub-Atlantic is not represented in the type diagram as explained earlier (Section 4.i.pp.64-77). However, raised moss continued to develop and forest declined as recorded in the diagrams from West Flanders Moss (Turner, 1965) and East Flanders Moss (Durno, 1956). All of the primeval woodland and most of the raised moss have been cleared for agriculture; the reclamation of peat moss began in 1776 and at the present time much of the remaining area is planted with coniferous trees.

The evidence presented in this section establishes that the course of Post-glacial forest history at Woodend Farm Site 2 is representative of Post-glacial vegetational development in the upper Forth basin and can therefore be used as a standard reference for the Post-glacial in that area. Furthermore, it has been shown that radiocarbon dates from Post-glacial sites in the research area generally fall within the major divisions of the Post-glacial dated at Scaleby. The assumption can therefore be made that the chronological index of Post-glacial vegetational history at Scaleby is relevant as a temporary guide to date major sequences of vegetational development in the western Forth valley during the Post-glacial.

5.iv. Interpretation of Pollen Frequencies in Marine Deposits in the Western Forth Valley.

Studies have been made of flotation and long distance transport capabilities of pollen grains, in particular *Pinus*, and the effect of these factors upon pollen spectra from water-borne minerogenic material. Early work by Erdtman (1943) has shown that pine pollen is particularly subject to long distance transport by sea currents. Hopkins (1970) later demonstrated, under laboratory conditions, that pollen once wetted acts as any other fine clastic particle and is thus transported as part of the washload. Muller (1959) however, was among the first to investigate, under field conditions, relationships between the sedimentation of pollen and marine deposits. His researches show that the deposition of pollen in marine sediments is closely related to water currents and is dependent upon relationships between pollen size, specific gravity and water current patterns. Similar relationships between the sedimentation of pollen and fine mineral particles in marine depositional environments have been demonstrated by Cross and Shaefer (1965) and Traverse and Ginsburg (1967). This work shows that high *Pinus* pollen frequencies are a feature of fine surface muds associated with sluggish water movement, in contrast to low concentrations of this pollen type in sandy sediments associated with turbulent sea currents. The distribution of pollen in marine sediments is, therefore, a function of sediment types and sedimentation characteristics.

It was established earlier that the fine grained deposits which characterise the Main and Low Buried Beaches and carse clays in the research area are indicative of gentle sedimentation associated with the conditions prevailing at the head of an estuary in a lowland situation. During periods of high sea-level, the upper Forth formed a sheltered estuary with an absence of strong wave action and therefore unlikely to be subject to rapid erosion and deposition of coarse deposits. Thus calm conditions prevailed as the estuarine muds and clays of the buried beaches and carse clays accumulated in the western Forth valley. Pollen accumulated in these deposits as they were laid down, derived from landward and/or seaward sources and carried to the sites by river, tidal action or air currents. Pollen preservation was good owing to the fine grained, anaerobic character of the deposits.

Whether the pollen in these deposits is representative of vegetational development contemporaneous with the prevailing high sea-levels is of major importance. Walker (1966) considered that in the interpretation of pollen frequencies from marine laid mineral matter account has to be taken of possible pollen selectivity by the movement of sea-water, conditions of sedimentation and reworked pollen from older material.

Although pollen selectivity is possible it seems unlikely that this would account for the pollen in the buried beaches and carse clays, particularly AP as they usually accord (with the exception of Pinus) with AP frequencies in peats overlying these marine deposits.

That pollen present in the buried beaches and carse clays are reworked from older material also seems unlikely as the deposits reflect gentle sedimentation. Furthermore, no corroded or broken pollen grains - indicators of reworked pollen (Birks, 1969), were observed in the samples analysed for pollen. The only evidence of recycled material in these deposits are adventitious Pre-Quaternary spores. They consist mainly of Lepidostrobus Jacksonii and L.Oldhamius, members of the Lycospora, which are common in Carboniferous rocks (Butterworth, pers.comm.) and have also been found in rocks of Devonian age by Chaloner (1967). Carboniferous and Devonian rocks are predominant in the western Forth valley, therefore it is almost certain that the Lycospores (and other spore types) in the buried beaches and carse clays in that area were derived from these strata. It is likely that these spores were released by the erosion of these rocks by rivers which transported them into the sea.

Account must also be taken of the transportation and deposition of pollen into the sea by rivers. For instance, Alnus pollen in the carse clays at Dollhouse could have been derived from alder present in streamside situations in that locality and transported by streams and deposited in the carse clays as they were laid down by the sea. However, no marked changes in the pollen counts characterise the marine and fluviatile material at the Dollhouse sites and the conclusion may therefore be safely made that these counts are a continuing indication of the regional vegetational development.

Support is given by evidence from regions outwith the Forth valley. Groot (1966) has compared recent pollen grains suspended with fine clastic material in the Delaware River in the United States with those in fossil marine sediments in the Delaware basin. He found that they were similar and concluded that the pollen in the marine deposits reflected vegetation comparable to that in the Delaware basin at the present day.

5.v. Vegetational Response to Sea-Level Changes in the Western Forth Valley.

From the pollen and stratigraphic evidence presented in this thesis, sequences of vegetation associated with changes of sea-level are apparent and merit further discussion.

The most abundant pollen and macrofossils in the buried beaches and carse clays are those of grasses, especially the common reed Phragmites, and sedges. They are accompanied by pollen of Chenopodiaceae, Plantago maritima and Compositae. Representatives of these plants are characteristic of flora in present day saltmarshes in the Forth valley (Foord and Kidston, 1890; Martin, 1934; Chapman, 1941), the Tay estuary (Smith, 1905) and at other coastal estuaries in Britain (Chapman, 1938; Gillham, 1957; Ranwell, 1972).

Consequent upon the regression of the sea from the buried beaches and carse clays saltmarsh was usually replaced by freshwater marsh and swamp, particularly at sites close to the shorelines of the buried beaches and carse clays. The fall in sea-level would result in a lowering of water-table levels which may have stimulated the expansion of reedswamp at these locations. This interpretation is supported by the work of Salisbury (1970) which shows that a lowering of water-table level may enhance the vigour of reedswamp and extend its zone. At some locations however, namely The Homesteads and Turner's (1965) site at West Flanders Moss, communities of raised moss developed in suitable ill-drained situations on the buried beaches and carse clays and have continued to develop to the present day. In other parts of the Forth valley the carse clays were colonised by oak, as evidenced by historical records of its presence in these deposits (Sissons and Brooks, 1971).

As the vegetational changes described above are related to changes in sea-level they are of use in the dating of Post-glacial sea-level changes in the upper Forth valley as shown in the next section (5.vi).

5.vi. Dating of Relative Land and Sea-Level Changes in the Upper Forth Valley during the Late - and Post-glacial Periods.

Pollen zonation and radiocarbon datings of organic and minerogenic material at the sites investigated provide a chronological framework which, supported by geomorphological evidence, can be of use firstly, to date relative changes of sea-level in the western Forth valley during the Post-glacial; secondly, to cast some light upon eustatic and isostatic movements in this region, with particular reference to possible influence of land uplift upon the early rise of the main Post-glacial marine transgression. However, before this is attempted some recapitulation of Late-glacial land and sea-level changes in the Forth valley, as determined by geomorphological, radiocarbon and pollen evidence, seems to be required in order to place Post-glacial isostatic and eustatic movements in the research area in the sequence of Late-Quaternary events which occurred in the Forth valley as a whole.

Geomorphological evidence presented by Sissons (1969) shows that during the later part of the Late-glacial, the sea transgressed into the central lowlands of Scotland. This marine transgression began later than c. 13,000 - 12,500 B.P., when the last British ice sheet finally wasted away in response to a rapid rise of temperatures, as indicated by C^{14}, stratigraphic and Coleopteran evidence summarised by Sissons and Walker (1974). The transgression probably culminated at about 10,300 B.P.

For a considerable period this Late-glacial sea-level in the central Forth valley stood at or slightly above its present level in relation to the land. During this time the Buried Gravel Shoreline and related features were formed, Late-glacial clays being extensively planated. Subsequently, sea-level rose to about 6m OD and then became stable; this rise being associated with further planation of Late-glacial clays in the central Forth lowlands. Sissons (1974a) has correlated this period of marine erosion and the formation of the Main Late-glacial Shoreline, which he has renamed the Main Late-glacial Shoreline, with Late-glacial marine erosional features on part of the west coast of Scotland.

That the sea was present in the upper Forth valley c. 11,800 B.P. is indicated by pollen, radiocarbon and shell evidence from ice-transported marine sediments in the Menteith moraine (Gray and Brooks, 1972). The dated marine sediments were transported by ice of the Loch Lomond Re-advance as it moved down the western Forth valley and were deposited, together with other morainic material, in the Menteith moraine, which marks the limit of this readvance in the Forth valley. The level of the sea in relation to the land during the Late-glacial Interstadial was perhaps partly related to downwarping of the land as ice of the Loch Lomond Readvance began to advance into the western Forth valley. This event took place during a more continental climate than now, when mean July temperatures probably fell to about 7^{o}C (Sissons, 1974b).

It is generally considered that the Loch Lomond Stadial lasted between c. 10,800 - 10,300 B.P. However, evidence reviewed by Sissons (1974c) suggests that glaciers of the Loch Lomond Readvance in Scotland existed before 10,800 B.P. and that deglaciation took place after 10,300 B.P. In addition, variations in topography and precipitation may also have caused glacier ice to develop at different times in different localities. Thus until more C^{14} datings become available, the dates conventionally assigned to the stadial must be viewed with caution. Nevertheless, in the context of sea-level changes in the Forth valley, geomorphological evidence indicates that the maximum of the Loch Lomond Readvance in this area corresponds to the culmination of the Late-glacial marine transgression represented by the High Buried Beach, when sea-level was about 12m OD by the Menteith moraine.

Subsequently, the sea fell relative to the land, but at approximately 9,000 B.P. there was probably a slight rise when the Main Buried Beach, located at about 10m OD immediately outside the Menteith moraine, was formed. By this time glacier ice had disappeared from the Forth valley (and perhaps from other parts of Scotland) and the sea transgressed to the western extremity of this region. This event is confirmed by the presence of Main Buried Beach material at Woodend Farm Site 2, situated close to the western margin of the Forth valley. The buried beach deposits accumulated at this site during Zone F.V.4 (Zone IV of the English zonation) and are of equivalent age to the Main Buried Beach, represented by identical minerogenic material, at Newey's (1966) site at West Flanders Moss and farther east at Bield and The Homesteads sites as stated previously. Although no radiocarbon datings of the Main Buried Beach are available at present, the pollen and stratigraphic evidence from these sites indicate that the sea probably transgressed rapidly westwards and was not significantly retarded by isostasy.

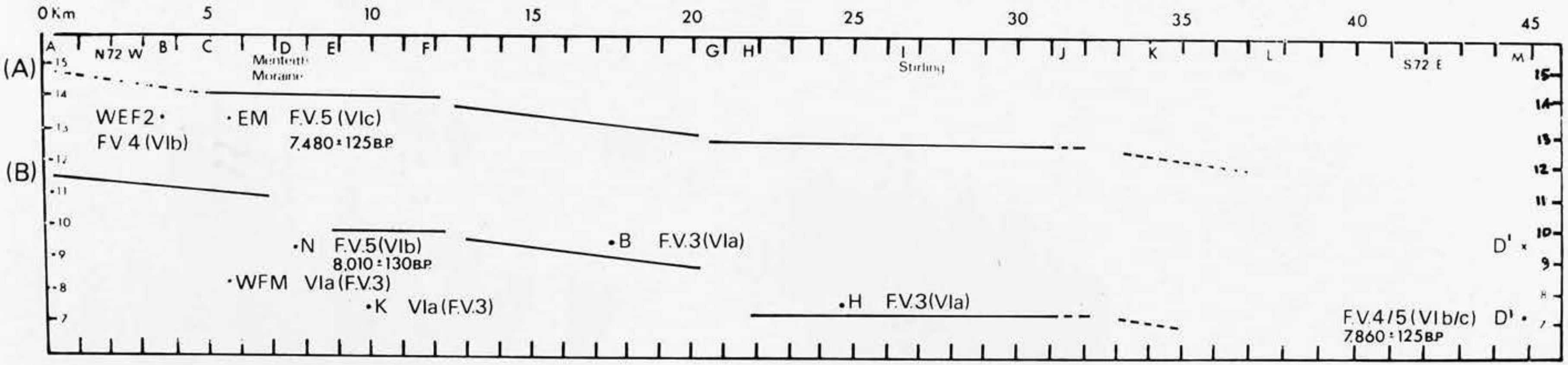
Subsequent to the formation of the Main Buried Beach, sea-level fell to nearly 7m OD when the Low Buried Beach was formed. This feature was probably associated with a minor marine transgression as this buried beach, like the Main Buried Beach, is extensively developed both inside and outside the Menteith moraine, as shown by geomorphological evidence presented by Sissons (1966). The level of the sea then dropped further, probably reaching a minimal level at about 8,500 B.P. when it became restricted to the buried estuary.

Around or shortly after 8,500 B.P., the sea began to rise rapidly in relation to the land (Fig. 3) and carse clay began to accumulate over the buried beaches and the peat resting upon them. This transgression (the principal Post-glacial marine transgression in the Forth valley) was caused by a world wide eustatic rise of sea-level in response to the disintegration of the world's ice sheets (1.iii.pp.29-39). The main Post-glacial marine transgression culminated in the western extremity of the Forth valley at c. 6,500 B.P., as indicated by radiocarbon evidence from peat immediately above the carse clay surface at Woodend Farm Site 1.

As the main Post-glacial sea transgressed into the western Forth valley isostatic recovery of the land was decreasing (p.36; Fig. 5). However, a major objective of the thesis was to attempt to determine whether the early rise of this transgression was retarded by land uplift, as stated. Of use to this investigation are the data from the following sites; Dollhouse Site 1, The Homesteads, Bield, Newburn, Easter Mye, Easter Offerance and Woodend Farm Site 2, together with Newey's (1966) sites at West Flanders Moss and at Kippen, because at most of these sites the base of the carse clay is accessible and has been dated by pollen. In addition, radiocarbon dates from Dollhouse Site 1, Kippen, Newburn and Easter Mye assist in dating the early stages of this marine transgression. It should be pointed out, however, that the sites are isolated points on the carse clay and distributed over a distance of about 38Km, and that the carse slopes not only down-valley but also towards the centre of the Forth valley (i.e. at right angles to the carse shoreline). Thus the altitudinal measurements of the carse clay base at the sites investigated need to be discussed.

Height measurements, pollen and available radiocarbon datings of the base of the carse clay at these locations are plotted on a height/distance diagram (Fig. 30) in order to show the location of these sites, and the data from them, in relation to the gradients of the surfaces of the Main Post-glacial and Main Buried Beach Shorelines in the research area.

This diagram shows that both shorelines slope down-valley



Altitudes of the Main Post-glacial Shoreline A, the Main Buried Shoreline B, the carse clay base at five sites[1] located close to the Main Post-glacial Shoreline and at three sites[2] situated north of this shoreline. Pollen dating of the base of the carse clay at each site is in Forth valley (F.V.) zones and equivalent zones of the English zonation. Radiocarbon datings of the carse clay base are also displayed.

[1] WEF2 = Woodend Farm Site 2, EM = Easter Mye, B = Bield, H = The Homesteads, D' = Dollhouse Site 1.

[2] WFM = West Flanders Moss, N = Newburn, K = Kippen.

× Denotes carse clay surface at site.

• " " " base " " .

Fig 30

The Main Buried Shoreline reaches its highest altitude of about 11.5m OD in the west and its lowest, at c. 7m OD, at a point approximately 9Km east of Stirling. Likewise, the gradient of the Main Post-glacial Shoreline also declines down-valley, from a maximum altitude of nearly 15m OD in the westernmost part of the Forth valley, to about 10m OD at Dollhouse Site 1 in the eastern extremity of the research area.

The Main Post-glacial Shoreline is dislocated at points F and G (Fig. 30) and these dislocations correspond to two dislocations of the Main Buried Shoreline. However, the latter feature has two abrupt changes of altitude not represented in the carse shoreline. One of these dislocations is at the Menteith moraine, between points D and E in the diagram, and may have been caused by the weight of ice west of the moraine operating in the reverse sense during and after the removal of the ice load. The other dislocation, between G and H, may have been caused by faulting, as a major fault, the Abbey Craig Fault, crosses this buried shoreline at H. Apart from these dislocations, the Main Buried and Main Post-glacial Shorelines are essentially parallel and slope in sympathy with each other, indicating that in the period of approximately 2,500 - 3,000 years between the formation of these features there was no differential uplift of the land in the area. That is to say, that during this period the area was uplifted as three units without detectable tilting, these units being separated by the dislocations described above. Thus where gradients now exist in the shorelines, they are the result of tilting since the Main Post-glacial Shoreline was formed, and the greater overall gradient of the Main Buried Shoreline is a consequence of the dislocations at D - E and G - H which have produced over half the overall slope of this shoreline.

In the extreme west (section A - C in Fig. 30) information on the altitude of the Main Post-glacial Shoreline is sparse, since almost everywhere this shoreline is covered or replaced by peat. In this section is situated Woodend Farm Site 2, where the base of the carse clay, at 13.4m OD, corresponds to the boundary between Zones F.V.3 and F.V.4 (Vla/Vlb transition).

In the area between C and D, within the Menteith moraine, the surface of the carse clay is essentially horizontal. In this section are located the sites of Easter Mye, Newey's (1966) site at West Flanders Moss and Easter Offerance. These are situated on the carse surface at various distances from the carse shoreline. Easter Mye is located close to the shoreline where the altitude of the base of the carse clay is at 13.34m OD. Pollen and radiocarbon evidence indicate that carse clay began to accumulate at this site during Zone F.V.5 (Vlc) at about 7,500 B.P. Approximately 0.5Km north of Easter Mye is Newey's (1966) site at West Flanders Moss. Here the height of the carse clay base is at 10.67m OD, and pollen and radiocarbon data signify that carse clay began to be laid down at this location close to the Vla/Vlb junction (Zone F.V.3/F.V.4 transition) at

c. 8,300 B.P. About 0.5Km north of this site is that at Easter Offerance where a thin band of peat is sandwiched between carse clays. Although only three samples were analysed from the minerogenic deposits beneath this peat layer, pollen and stratigraphic evidence suggest that the peat and lower minerogenic material at this station are of Late-Boreal age and accumulated during the main Post-glacial transgression. This evidence, however, does not help to date the transgression at this site, although it may be of some value in the interpretation of eustatic and isostatic movements in the western Forth valley during the Late-Boreal as shown later.

East of the Menteith moraine the Main Post-glacial Shoreline has a slight down-valley gradient. This eastward slope of the shoreline is probably largely or entirely due to the western measurements of the shoreline, located in an embayment between the Menteith moraine and Arnprior, being higher than those farther east. These differences may in part be due to the build-up of the carse shoreline by local site conditions, such as deposition of stream-borne terrestrial minerogenic material. However, if the measurements between C and F are analysed together, the shoreline is not significantly different from horizontal.

In the section D - F are located the Newburn site and Newey's (1966) site at Kippen. The former site is situated at the mouth of a buried meltwater channel immediately east of the Menteith moraine. The stratigraphy at Newburn consists of a lower mineral layer, presumed to be carse clay (4.v.pp.93-99). This is overlain by a thin bed of peat which in turn is buried beneath carse clay. A date of 8,010 ± 130 B.P. obtained from the top of the peat indicates that shortly after this date this organic layer began to be covered by carse clay. According to pollen evidence this event probably took place during Zone F.V.4 (V1b), although the stratigraphy at this site suggests that the pollen and radiocarbon data from this location are of little use in dating the initial rise of the main Post-glacial transgression as the base of the carse clay was not reached. The above evidence, like that from Easter Offerance may, however, be of use in the interpretation of land and sea-level factors operative in the research area during the Late-Boreal. About 3Km east of Newburn is Newey's (1966) site at Kippen. At this site, also situated at a point north of the Main Post-glacial Shoreline, the base of the carse clay is at 7.69m OD. This horizon is just below the V1a/V1b transition (Zone F.V.3/F.V.4 boundary) at Kippen. A date of 8,270 ± 160 B.P. obtained from peat immediately beneath the carse clay signifies that the latter material began to be laid down at this location about this time.

Over a distance of nearly 8Km, between F and G, the surface of the Main Post-glacial Shoreline has a down-valley gradient of 0.109m/Km. The Bield site is located at a point close to the shoreline in this section where the base of the carse clay is at 9.46m OD and rests upon peat. According to pollen data the carse clays began to cover the peat at this site during Zone F.V.3 (V1a).

The Homesteads site is located at a point between H and I where the carse overlies peat. The peat/carse clay contact is at 8.19m OD and has also been pollen dated at Zone F.V.3.

Between K and L the Main Post-glacial Shoreline has been lowered by coal mining subsidence and the majority of measurements of the altitude of the carse surface are from an embayment into which several streams flow. Thus a meaningful shoreline gradient for this section of the shoreline cannot be calculated. Nevertheless, these measurements indicate that the shoreline has a definite down-valley gradient from about 12.5 to 11.5m OD.

It is likely that the eastward tilt of the carse clay surface from L to M is continued, for at Dollhouse Site 1, situated in the easternmost part of the research area, the top of the carse clay is at 9.60m OD. At this site, located close to the carse shoreline in an embayment, the early rise of the main Post-glacial transgression may well be expressed by coarse sands and gravels beneath the carse clay (4.vii.pp. 111-121). The base of this sand and gravel layer is at 7.14m OD. Resting upon its surface are minerogenic deposits consisting of carse clays, river-borne sands and thin bands of gravel. These deposits probably began to accumulate over the sand and gravel layer after c. 7,800 B.P. as indicated by a date of 7,860 ± 125 B.P. obtained from wood, probably transported, resting upon the buried surface of this gravel at 7.31m OD.

As stated earlier, each site is an isolated point on the carse clay over a distance of approximately 38Km. Only five of these sites (Dollhouse Site 1, The Homesteads, Bield, Easter Mye and Woodend Farm Site 2) are situated close to the Main Post-glacial Shoreline, and of these, two (Dollhouse Site 1 and The Homesteads) are located in embayments and one (Easter Mye) in a small re-entrant valley. It is possible, therefore, that the measurements of the altitudes of the carse clay base at these locations are unrepresentative of this horizon in the research area, as they may reflect local variations in conditions at each site before, during and after the main Post-glacial transgression. These local variables might include the compaction of peat by the weight of overlying carse clays; a possible explanation for the highly compacted peat beneath carse clays at The Homesteads site. There may also have been differential rates of sedimentation associated with different types of sediment, as at Dollhouse Site 1, where stream-borne deposits probably accumulated rapidly in relation to carse clays laid down by the rising sea. Similarly, local factors may also explain the difference in altitude of the peat/ carse clay junction at Newey's (1966) sites at Kippen and West Flanders Moss, which are situated at points north of the Main Post-glacial Shoreline.

It seems unlikely that the differences in altitude of the base of the carse clay are due to erosion of peat by the sea as carse clays began to be laid down because firstly, at sites where peat is present (e.g. The Homesteads, Bield, Easter Mye and Woodend Farm Site 2), remains of plants pass vertically from the peat into the carse clays; secondly, the latter deposits are generally fine grained and indicative of gentle sedimentation. A further possibility is that tidal variation along the length of the Forth estuary may have influenced the height measurements of the shorelines under consideration, although this factor would not explain the changes in the gradients of the shorelines, particularly those between D - E and G - H. That the constrictions of the Forth estuary at the Stirling gap and at Menteith affected tidal conditions is also improbable, as the Main Post-glacial and Main Buried Shorelines are essentially horizontal on both sides of the Stirling gap, while the former shoreline is also horizontal on either side of the Menteith gap.

The measurements of the carse clay base at the sites examined indicate firstly, a down-valley slope from west to east, from the western margin of the Forth valley to Stirling, and from north-west to south-east, east of that city; secondly, that the base of the carse clay also declines in altitude towards the centre of the Forth valley. This evidence is in accord with the comparable slopes of the carse clay and Main Buried Beach surfaces.

That the land was rising as the sea deposited carse clays in the upper Forth valley is indicated by the two dislocations of the Main Buried Beach, between G - H and D - E, as they are not represented in the Main Post-glacial Shoreline and were probably a result of uplift, but not tilting, of the land, as stated. Downwarping of the land towards the centre of the Forth valley, although possible, is considered unlikely (Sissons, 1972).

The possibility exists that isostatic recovery may have retarded the advance of the main Post-glacial sea into the upper Forth valley. This possibility can be tested by pollen and radiocarbon evidence from the sites investigated. East of the Menteith moraine, the sea began to deposit carse clays at The Homesteads and Bield sites during Zone F.V.3 (Vla). Farther west, at Kippen, deposition of identical minerogenic material commenced almost at the end of Vla (Zone F.V.3), at about 8,300 B.P. Within the Menteith moraine, carse clays began to accumulate at Newey's (1966) site at West Flanders Moss towards the close of Vla and at Woodend Farm Site 2, located in the westernmost part of the Forth valley, at the beginning of Zone F.V. 4 (Vlb). These dates, from between upper Zone F.V. 3 and the beginning of Zone F.V.4, cover a short period of the Late-Boreal and indicate that the sea transgressed relatively swiftly into the western Forth valley. Thus retardation of this transgression by land uplift was probably insignificant.

There are, however, differences in the times when the sea began to deposit carse clays at Easter Mye, Newburn and Dollhouse Site 1, which may be explained by local variations of site conditions. At Easter Mye, located within the Menteith moraine, deposition of carse clay began during Zone F.V. 5 (Vlc), around 7,500 B.P. whereas at Woodend Farm Site 2, situated farther west, identical deposits began to accumulate at the beginning of Zone F.V. 4 as stated. This difference is probably not attributable to differences in altitude, as the base of the carse clay at Woodend Farm Site 2 is only slightly higher (c. 6cm) than that at Easter Mye. As the latter site is located in a small re-entrant valley (Sissons, 1966. Fig. 1), it seems possible that local conditions at this site favoured the accumulation of peat which temporarily exceeded the level of the rising sea. Support is provided by the fact that peat bogs in the region of East Flanders Moss, investigated by Sissons, Cullingford and Smith (1965), were not inundated by the main Post-glacial transgression, as they developed rapidly in relation to the rising sea. In addition, the arrival of the sea at Easter Mye during Zone F.V. 4 may, in part, be related to a possible slowing down of the rate of sea-level rise resulting, perhaps, from diminution of meltwater flow into the oceans from decaying ice sheets in the world.

Another possibility is that land uplift may have delayed the sea reaching Easter Mye until Zone F.V. 4. About 0.5Km north of this site is Newey's (1966) site at West Flanders Moss where carse clay began to accumulate towards the close of VIa (Zone F.V. 3). Farther north is the site at Easter Offerance where carse clays also began to be laid down during the Late-Boreal, but deposition of this material was temporarily halted and peat developed. This organic layer was subsequently buried beneath carse clay. The stratigraphic evidence from Easter Offerance suggests that the formation of peat at this site might have resulted from a temporary stillstand of the sea or that the land rose and for a short time was above the level of the sea. The former possibility is unlikely as there is no evidence that the rise of the sea-level was temporarily halted; the latter possibility also seems improbable because there is no peat layer between the carse clays at Newey's site, located about 0.5Km south of Easter Offerance, nor at other sites within the Menteith moraine. Furthermore, the presence of peat between the carse clays at Easter Offerance indicates that downwarping of the land in this part of the Forth valley is unlikely, as this site would have been covered by the sea and peat would have been unable to develop. Thus the arrival of the sea at Easter Mye may well have been delayed by local factors, unconnected with land uplift; the most important probably being that peat development temporarily exceeded the rate of sea-level rise. Subsequently, the sea rose and the peat was covered with carse clay.

The development of peat at Easter Offerance may also be attributed to local conditions. As stated earlier (4.iii.pp. 84-88), this site is situated in a small river channel and the peat in the section examined is part of an organic layer which probably extends the length of this channel. In addition, it was established that the peat is *in situ*, as stems of *Phragmites* and *Carex* sp. pass vertically from the lower carse clay layer into the peat and from this organic material into overlying carse clay. The presence of macro-remains of reed in the lower carse clays indicates that representatives of this plant must have been present as these minerogenic deposits accumulated at this site. As *Phragmites* is a silt-trapper *par excellence* (Tansley, 1939) it is a probability that this plant assisted in the silting up of this site with carse clays and possibly fine river-borne minerogenic material (although the latter, if present, could not be distinguished from the carse clays). Consequently the level of these deposits was raised above the sea and thereby created conditions favourable for the development of freshwater marsh and peat. Later, plants and peat were buried beneath carse clays laid down by the rising sea.

A comparable sequence of events may also have occurred at Newburn, situated near the mouth of an abandoned melt-water channel immediately east of the Menteith moraine, where carse clays are separated by peat as at Easter Offerance. Furthermore, the peat at Newburn is also in situ, being part of a peat layer which has been traced for a considerable distance up-valley by Sissons, Cullingford and Smith (1965). Pollen and stratigraphic evidence from the section examined indicate that plants characteristic of reedswamp were also present as the lower carse clays accumulated at this location. Thus, as at Easter Offerance, these minerogenic deposits and possibly fine river-transported sediments were probably trapped by reeds and raised above sea-level, creating an environment suitable for the growth of freshwater marsh and peat. Subsequently, this organic material was overtaken by the rising sea and covered with carse clays. This event took place at about 8,010 ± 130 B.P., the date obtained from the upper peat/carse clay junction at this site (4.v.pp.93-99).

It is also possible that the conditions which gave rise to the development of vegetation and peat at Newburn may in part have been caused by land uplift raising the lower carse clays above sea-level, as close to this site the Main Buried Beach is dislocated, this dislocation possibly resulting from isostatic readjustment during the main Post-glacial transgression as explained. However, isostatic influence upon events at Newburn whilst possible seems unlikely, because there is no peat band between carse clays at Kippen, situated about 3Km east of Newburn, nor at other sites investigated outside the Menteith moraine to substantiate the view that land uplift exceeded sea-level rise during the Late-Boreal.

Furthermore, although the land was rising (Fig. 5), the rate of this rise was almost certainly slower than that of the sea. This is signified by pollen, stratigraphic and radiocarbon evidence from Newburn and Kippen. At the latter site, carse clay began to be laid down almost at the end of VIa (Zone F.V. 3) at about 8,270 ± 160 B.P. This date is slightly older than that of 8,010 ± 130 B.P. from the upper peat/carse clay contact at Newburn, which is of Zone F.V. 4 age. The initial accumulation of carse clay at this site, however, began earlier than c. 8,000 B.P. as indicated by carse clays below the dated peat. Although the base of the carse clay layer was not reached, it is probable that the initial deposition of carse clay at Newburn began shortly after identical mineral deposits began to be laid down at Kippen, as the radiocarbon dates from these sites are relatively close.

It is also probable that local factors influenced the deposition of carse clays at Dollhouse Site 1, situated at the head of an embayment in the eastern extremity of the research area. At this site, however, the early rise of the main Post-glacial transgression is not expressed by the replacement of peat by carse clays as at other sites investigated. Instead, the lower stratigraphy consists of a layer of coarse sand and gravel overlain by carse clays. The boundary between these two layers has been radiocarbon dated at 7,860 ± 125 B.P. and reflects a change in sedimentation conditions which, according to pollen evidence, took place in the Late-Boreal, probably during Zones F.V.4/ F.V.5 (Vlb/Vlc). Doubtless this change of sedimentation was connected with the rise of the main Post-glacial sea in the western Forth valley from Zone F.V.3 to the early part of Zone F.V.6.

From the stratigraphic evidence under consideration it is not clear which minerogenic layer represents the initial rise of the main Post-glacial transgression at Dollhouse Site 1. It is almost certain that the sands and gravels were deposited at this site by river action as explained earlier (4.vii.pp.111-121). For this material to have been transported from inland sources river flow at Dollhouse Site 1 must have increased. This may have resulted in part from raised water tables in response to the rising sea, and partly from increasing surface run-off resulting from increasing regional precipitation; the latter being reflected by the development of raised bogs in the western Forth valley during the Late-Boreal.

In addition, marine and climatic influences described above could have been associated with occasional river floods which led to the deposition of sands and gravels in the sea. A major flood, at about the Late-Boreal/Atlantic transition, resulted in the accumulation of a thick band of sands and gravels (the main gravel layer) in the sea at the Dollhouse sites. Consequently, the level of this gravel layer was probably raised above sea-level until the sea subsequently rose and began to cover this material with carse clay, as explained in a previous section (4.vii. p.120). It is probable, therefore, that the lower sands and gravels beneath the main gravel layer at Dollhouse Site 1, were similarly discharged into the sea by a river flood (thereby preventing deposition of carse clays) and built up above sea-level. Then after about 7,800 B.P. the sea rose and carse clays began to accumulate over this gravel bed.

As the lower and main gravel layers at Dollhouse Site 1 were, at separate times, above sea-level, it might be expected that peat would accumulate upon them, comparable to the development of organic material over similar sands and gravels at Dollhouse Site 2 and Easter Mye. That this was not the case at Dollhouse Site 1 may relate in part to the sands and gravels, subject to free drainage, being unsuitable for peat development, and partly to possible continuous deposition of the former deposits, followed by the accumulation upon them of carse clays, thereby preventing plant growth and the formation of peat. At Dollhouse Site 2, however, the deposition of sands and gravels (the main gravel layer) was not immediately followed by that of carse clays; instead, the former material was replaced by river-borne silts and sands and then by peat. The absence of comparable deposits over the main gravel layer at Dollhouse Site 1 indicates that the main gravel bed at Dollhouse Site 2 was possibly above sea-level for a longer period of time than that at the former location; or that the silts and sands at Dollhouse Site 2 produced moisture-retentive soils favourable for plant growth and the formation of peat until sea-level rose and began to cover this organic material with carse clays. At Easter Mye a different situation existed in that the sands and gravels at this location are part of the Menteith moraine. Thus there was a considerable time for vegetation to become established and for peat to develop at this site.

The deposition of the lower sands and gravels into the sea at Dollhouse Site 1 and their build up above sea-level, may account for the initial accumulation of carse clays at this site being later than at most other sites investigated. Furthermore, as the sands and gravels were laid down during a river flood connected with the rising sea, it seems possible that the base of the lower gravel layer at Dollhouse Site 1 may reflect the early rise of the main Post-glacial transgression at this location.

The influence of local variations in site conditions appears to have been more important than that of isostatic readjustment upon the early rise of the main Post-glacial marine transgression in the western Forth valley, as discussed above. However, this is not apparent from the data in the height/distance diagram (Fig. 30) which indicate a thinning out of the carse clays in a westerly direction, particularly within the Menteith moraine, implying that land uplift steadily increased westwards as carse clays were laid down in the upper Forth valley. This implication is misleading as only two sites, Easter Mye and Woodend Farm Site 2, are situated close to the Main Post-glacial Shoreline west of the moraine. Furthermore, the advance of the main Post-glacial sea into the western Forth valley took place within a relatively short period of time and was not significantly retarded by land uplift, as explained above.

There are also apparent differences in the thickness of the carse clay at sites situated outside the Menteith moraine, but these differences are also probably unrepresentative as firstly, not all of the sites in Fig. 30 are situated on the carse clay shoreline; secondly, the carse clay also slopes and increases in thickness towards the centre of the Forth valley; thirdly, the sites are isolated points upon the carse; fourthly, the altitude of the carse clay base at some locations may have been influenced by local factors such as compaction of peat by overlying carse clay or the presence of streams, particularly at sites situated in embayments. In view of these possibilities, more height measurements of the base of the carse clay are required before meaningful comments about possible differences in thickness of the carse clay can be made.

In conclusion, the investigation into the possible influence of isostatic readjustment upon the advance of the main Post-glacial sea into the western Forth valley has shown that the effect of land uplift upon the early rise of this transgression was probably insignificant. On the other hand local variables, related to differences in site conditions and location, were probably more important factors which influenced this transgression, resulting in the deposition of carse clays at some sites at different times. In addition, this study has focussed attention upon some of these local variables and the difficulties they present in attempting to correlate isolated fragments of the Main Post-glacial Shoreline. Similar detailed investigations in other coastal areas may reveal comparable or additional complications. However, comparisons between eustatic and isostatic movements in the Forth valley and those in other areas must be approached with caution, as fluctuations of sea and land in other regions may also relate to local factors different from those in the research area. Nevertheless, it is hoped that the data presented in this thesis may be of use as a basis for further research into problems related to changes of Post-glacial sea and land levels, particularly in the Forth valley.

PART 6.

Summary of Discussion.

Summary of Discussion.

Organic and minerogenic material from the sites investigated are divisible into biostratigraphic units, each being distinguished by characteristic pollen assemblages. Eight of these are recognised in the type diagram from Woodend Farm Site 2 and reflect stages of Post-glacial vegetational development equivalent to those interpreted from pollen diagrams, zoned according to the English zonation, from other sites in the western Forth valley.

The earliest pollen zone in the type diagram, Zone F.V. 1, relates to the Pre-Boreal, when immature soils and probably sub-arctic climatic conditions existed in the central Scottish lowlands. At this time the flora was predominantly herbaceous and included pioneer scrub species of *Betula* and *Salix*. These taxa declined during Zone F.V.2, the early Boreal, as *Corylus* and *Ulmus* migrated into the area in response to maturing soils and climatic amelioration. At the beginning of Zone F.V. 3 hazel attained its maximum extension and *Quercus* began to migrate into the region; the latter species steadily increased in frequency throughout this zone whereas hazel declined. *Pinus* may have been present locally, but in general this species was poorly represented in the Forth valley during the Post-glacial. In Zone F.V. 4 mixed broad-leaf deciduous woodland continued to expand, the representation of oak exceeding that of elm, and *Alnus* began to immigrate into the research area. A feature of Zone F.V. 5 is the consistent spread of alder, particularly where this plant was colonising ill-drained carse clays. There seems little doubt that the expansion of Alnus was also favoured by increases in regional precipitation and temperatures, the former being reflected by the growth of raised bogs in the upper Forth valley. Zone F.V. 6, the Atlantic period, was the time of the climatic optimum when rainfall increased and mean summer temperatures rose 2°C higher than at present. Under these conditions Alnus quickly attained its maximum expansion, particularly on poorly drained lowland. On higher and well drained land, however, mixed broad-leaf deciduous forests reached their maximal development. The wet climate and the presence of extensive surfaces of level relief floored by moisture-retentive clays favoured the development of raised bogs during this zone. Zone F.V. 7, the Sub-Boreal, is characterised by the elm decline, which began c. 5,000 B.P., and a revival of Betula. The recession of Ulmus was probably in part associated with the beginning of forest destruction by early farming communities who derived their livelihood from pastoral agriculture, and partly by the extension of raised bogs, acid soils and soil leaching; conditions which favoured the expansion of birch. Zone F.V. 8, the Sub-Atlantic, is marked by the further development of raised mosses and the acidification and leaching of soils in response to climatic deterioration. These factors and the intensification of farming practices resulted in the continued destruction of forest trees, except birch which steadily expanded during this zone.

Radiocarbon dates from the type site are unavailable at present. However, dates from other Post-glacial sites in the western Forth valley fall within dated pollen zones at Scaleby Moss in northern England, suggesting that Forth valley pollen assemblage zones may be synchronous (or approximately synchronous) with those at Scaleby. Hence zonal divisions at the latter location may be useful as a temporary chronological index for dating Forth valley pollen zones until these are radiocarbon dated.

Broad trends of Post-glacial forest history reflected in the type diagram are divisible into three chronozones. The earliest of these cover the immigration of trees into the region during Zones F.V. 1 - 5; the second relates to the maximum development of mixed broad-leaf deciduous forests and the growth of raised bogs during the climatic optimum in Zone F.V. 6; the third covers the period of probable human influence upon woodland destruction in Zones F.V. 7 and F.V. 8. The main use of these chronozonal divisions may well be to provide a broad chronological framework of major Post-glacial vegetational events in the upper Forth valley by which other pollen diagrams from this area can be compared and assessed.

Factors such as pollen selectivity by moving water, especially sea currents, and reworked pollens from older deposits upon pollen spectra from the Main Buried Beach and carse clays are considered unimportant, as pollen frequencies from these minerogenic layers are comparable to those from organic deposits at the type site and at other locations which were not subjected to marine influence. Thus pollen counts from marine deposits of Zone II age (the Late-glacial Interstadial) are considered to be representative of vegetational conditions at this time. They indicate the existence of an essentially herbaceous flora similar to that interpreted from pollen spectra from terrestrial material of equivalent age at other Scottish sites.

Changes in relative levels of land and sea in the area during the Post-glacial gave rise to variations in soil conditions. These were associated with changes in plant assemblages which can be reconstructed from pollen and statistical data. Falling sea-levels produced local vegetational successions from halophytic species characteristic of saltmarshes to freshwater marsh and swamp or raised moss communities; this sequence was followed by retrogression as the level of the sea rose again.

As these changes took place the land was isostatically readjusting from glacial unloading; the amount of isostatic recovery increasing westwards in the Forth valley. A major objective of this thesis was to attempt to determine whether the rising land retarded the advance of the sea, particularly the early rise of the main Post-glacial marine transgression, into the western Forth valley. Pollen evidence indicates that during the formation of the Main Buried Beach in Zone F.V. 1 the sea rose more quickly than the land and reached the western margin of the Forth valley by the end of this zone. Likewise, the early rise of the main Post-glacial sea was relatively rapid in relation to the land, pollen data indicating that the sea rose in Zone F.V. 3 and was at the westernmost part of the Forth valley at the beginning of Zone F.V. 4. However, the sea reached some sites at later times because of probable local variations in site conditions. These include the development of peat and deposition of river-borne minerogenic deposits above sea-level; the accumulation of carse clays and possibly fine stream transported sediments above the sea and the development upon them of peat until the sea subsequently rose and covered these deposits with carse clays.

These local variables focus attention on some of the difficulties of attempting to correlate isolated fragments of relict marine features in the western Forth valley, but it is hoped that the data presented in this thesis may be of use as a basis for further research into problems relating to Post-glacial land and sea-level changes, particularly in the central Scottish lowlands.

A correlation table (Fig. 31) showing the main characteristics and chronology of vegetation, climate, soils and relative changes in the levels of land and sea in the western Forth valley during the Late - and Post-glacial periods, as described above, is presented below.

FIG 31. CORRELATION TABLE SHOWING THE CHRONOLOGY OF THE MAIN EVENTS IN THE WESTERN FORTH VALLEY DURING THE LATE-AND POST-GLACIAL PERIODS. (A provisional table)

C14 DATES (Years B.P.)		CHRONO-ZONES	POLLEN ZONES		CHARACTERISTICS OF VEGETATION	CULTURE	RELATIVE CHANGES OF LAND AND SEA LEVELS	CLIMATE AND SOILS	BLYTT-SERNANDER CLIMATIC PERIODS	
Scaleby[1]	Forth Valley[2]	Forth Valley	Forth Valley	English[3]						
	1858±110 1765±110 1731±120	PG3	8	VIII	Accelerated development of peat forming vegetation Progressive recession of forest resulting in part from extension of ombrogenous mires, acidification and leaching of soils and partly from large scale clearances from c.200A.D Betula however steadily rises In 1776 peat bogs began to be cleared and land beneath them reclaimed for agriculture Drainage and reafforestation of raised mosses in progress at present	Roman Period Iron Age	LAND UPLIFT DOMINANT	Climatic deterioration ie increased precipitation and lower temperatures continued leaching and development of acid soils gleys and peats	SUB-ATLANTIC	POST-GLACIAL
4925±134	2712±120 4120±125 5492±130 5192±120	PG3	7	VIIb	Ulmus declines from the beginning of this zone and Betula expands Anthropogenic influence upon forest composition evident Small clearances, connected with Neolithic and Bronze Age farming practises, possibly existed in the region	Bronze Age Neolithic		Increasing wetness acidification and leaching of soils	SUB-BOREAL	
7425±c350	5014±120 6135±105 6494±106	PG2	6	VIIa	Alnus attains its maximal development and raised bogs begin to develop. Maximum development of mixed oak forest		Culmination of main Post-glacial marine transgression c 6,500 B.P	Climatic optimum temperatures c.2°C higher than they are now Wet Gleying widespread Increasing rainfall	ATLANTIC	
	7480±125	PG1	5	VIc	Expansion of broad leaved deciduous trees. Alnus steadily spreads and Pinus is present locally. Betula and Corylus may increase but are minor constituents of the woodland	Mesolithic	LAND RISING	Mature Brown Forest Soils	BOREAL	
	7860±125 8010±130	PG1	4	VIb	Betula decreases in frequency as deciduous forest advances; Ulmus is subordinate to Quercus, Alnus immigrates into the area. Pinus is present on a local scale. Corylus recovers some ground but is less important than previously.		Sea reaches westernmost part of Forth Valley by beginning of Zone FV4			
9002±194	8270±160 8411±157	PG1	3	VIa	Betula maintains its position as the dominant tree Ulmus continues to expand and Quercus migrates into the region Pinus is possibly present in small amounts At the opening of this zone Corylus attains its maximum development Later, this plant declines as deciduous forest spreads		Beginning of main Post-glacial marine transgression and deposition of carse clay			
9557±209	8690±140	PG1	2	V	Predominance of Betula; Salix is less frequent than in previous zone. Corylus and Ulmus immigrate into the area		Sea-level rises and Low Buried Beach formed Later, the level of the sea fell reaching a minimal level c 8,500 B.P			
10,257±c350		PG1	1	IV	Recession of herbaceous flora, landscape colonised by Betula and Salix.		Main Buried Beach formed c 9,600 B.P during a period of high sea-level Subsequently sea-level dropped	Temperatures begin to rise Soils immature	PRE-BOREAL	
10,698±207				III	Herbaceous vegetation		Loch Lomond Readvance of ice, culmination of the main Late-glacial marine transgression formation of the High Buried Beach.	Cold mean summer temperatures c 7°C Solifluxion	UPPER DRYAS	LATE-GLACIAL
	11700±170 11800±170			II	Open landscape, grasses and sedges predominant, with dwarf shrubs of Betula and Salix.		Sea present in upper Forth valley c 11,800 B.P	Decreasing temperatures more stable soils	ALLERÖD	
				I	Vegetation essentially herbaceous		Sea level high in central Forth lowlands	By c 13,000 B.P temperatures rose and were probably comparable to those at present Intense solifluxion	LOWER DRYAS	

[1] GODWIN, H., WALKER, D and WILLIS, E.H. (1957).

[2] GODWIN, H. and WILLIS, E.H. (1961, 1962); SISSONS, J.B (1966, 1967a); SISSONS, J.B and BROOKS, C.L (1971)

[3] GODWIN, H (1940, 1956)

REFERENCES.

References.

AITON, W. 1811. A Treatise on the Origin, Qualities and Cultivation of Moss-Earth. Ayr.

ANDERSON, A.L. 1967. A History of Scottish Forestry. 1. From the Ice Age to the French Revolution. London.

BAILEY, E.B. et al 1924. The Tertiary and post-Tertiary geology of Mull, Loch Aline and Oban. Mem. geol. Surv. U.K.

BALD, R. 1811. On the coal formation of Clackmannanshire. Mem. Wernerian. Soc., 1, 479-503.

BIRKS, H.H. 1970. Studies in the vegetational history of Scotland. 1. A pollen diagram from Abernethy forest, Inverness-shire. J. Ecol., 58, 827-846.

BIRKS, H.H. 1972. Studies in the vegetational history of Scotland. 2. Two pollen diagrams from the Galloway Hills, Kirkcudbrightshire. J. Ecol., 60, 183-217.

BIRKS, H.J.B. 1969. Inwashed spectra at Loch Fada, Isle of Skye. New Phytol., 69, 807-820.

BIRSE, E.L., and ROBERTSON, L. 1970. Assessment of Climatic Conditions in Scotland. 1. Based on accumulated temperature above 5.6°C and potential water deficit. 1 : 625,000. The Macaulay Institute for Soil Research. Aberdeen.

BIRSE, E.L., and ROBERTSON, L. 1970. Assessment of Climatic Conditions in Scotland. 2. Based on exposure and accumulated frost. 1 : 625,000. The Macaulay Institute for Soil Research. Aberdeen.

BISHOP, W.W. 1963. Late-glacial deposits near Lockerbie, Dumfriesshire. Trans. J. Proc. Dumfries. Galloway nat. Hist. Antiq. Soc., 40, 117-132.

BISHOP, W.W., and DICKSON, J.H. 1970. Radiocarbon dates related to the Scottish Late-glacial sea in the Forth of Clyde. Nature. Lond., 227, 480-482.

BLACKADDER, A. 1824. On the superficial strata of the Forth district. Mem. Wern. nat. Hist. Soc., 5, 424-439.

BLYTT, A. 1876. Essay on the immigration of the Norwegian flora during alternating rainy and dry seasons. Christiana.

BRINKMANN, P. 1934. Zur Geschichte der Moore, Marschen und Wälder Nordwestdeutschlands. Bot. Jb., 66, 369-445.

BROOKS, C.L. 1972. Pollen analysis and the Main Buried Beach in the western part of the Forth valley. Trans. Inst. Br. Geogr., 55, 161-170.

BRYSON, R.A. et al 1969. Radiocarbon isochrons on the disintegration of the Laurentide ice sheet. Arctic Alpine Res., 1, 1-14.

BUIST, G. 1841. Outline of the geology of the south-east district of Perthshire. Trans. R. Highland agric. Soc. Scott., 13, 17-49.

BUXTON, A. 1939. The Norfolk sea floods February 1938. 1. General effects of the flood seen in 1939. Trans. Norfolk Norwich Nat. Soc., 15, 22-40.

BUXTON, A. 1942. The Norfolk sea floods. General effects of the February 1938 flood seen in 1942. Trans. Norfolk Norwich Nat. Soc., 15, 332-341.

CALLOW, W.J., and HASSALL, G.I. 1970. National Physical Laboratory Radiocarbon Measurements Vll. Radiocarbon, 12, 181-186.

CARMICHAEL, J. 1832. Essay on draining and levelling the clay-lands. Trans. R. Highl. agric. Soc. Scot., 9, 34-39.

CHALONER, W.G. 1967. Spores and land evolution. Rev. Palaeobotan. Palynol., 1, 83-93.

CHAMBERS, R. 1848. Ancient Sea Margins. London.

CHAPMAN, V.J. 1938. Studies in saltmarsh ecology, I-III. J. Ecol., 26, 144-179.

CHAPMAN, V.J. 1941. Studies in saltmarsh ecology. 8. J. Ecol., 29, 69-82.

CHARLESWORTH, J.K. 1955. The Late-glacial history of the Highlands and Islands of Scotland. Trans. R. Soc. Edinb., 62, 769-928.

CHISHOLM, J.I. 1971. The stratigraphy of the Post-glacial marine transgression in north-east Fife. Bull. geol. Surv. Gt. Br., 37, 91-107.

CROSS, A.T., and SHAEFER, B.L. 1965. Palynology of modern sediments, Gulf of California and environs (Resume). Bull. Am. Soc. Petrol. Geologists., 49, 337.

CULLINGFORD, R.A., and SMITH, D.E. 1966. Late-glacial shorelines in eastern Fife. Trans. Inst. Br. Geogr., 39, 31-51.

CURRAY, J.R. 1965. Late-Quaternary history, continental shelves of the United States. In The Quaternary of the United States, Wright, E., and Grey, D.G. (eds) Princeton, 723-735.

DICKSON, J.H. 1971. Flanders Moss, Perthshire. In Newsletter of the Botanical Society of Edinburgh, October 1971, No. 5., 6.

DIMBLEBY, G.W. 1964. Post-glacial changes in soil profiles. Proc. R. Soc., B, 161, 355-362.

DINHAM, C.H. 1927. The Stirling District. Proc. geol. Ass., 38, 483-491.

DONNER, J.J. 1957. The geology and vegetation of Late-glacial retreat stages in Scotland. Trans. R. Soc. Edinb., 63, 221-264.

DONNER, J.J. 1958. Loch Mahaick, a late-glacial site in Perthshire. New Phytol., 57, 183-186.

DONNER, J.J. 1959. The Late - and Post-glacial raised beaches in Scotland. Ann. Acad. Sci. fenn., A.111, Geol-Geogr., 53, 1-25.

DONNER, J.J. 1962. On the post-glacial history of the Grampian Highlands of Scotland. Soc. sci. Fenn. Comm. Biol., 24, 5-29.

DONNER, J.J. 1963. The Late - and Post-glacial raised beaches in Scotland, II. Ann. Acad. Sci. fenn., A.111, Geol-Geogr., 68, 1-13.

DONNER, J.J. 1970. Land/sea level changes in Scotland. In Studies in the vegetational history of the British Isles, Walker, D., and West, R.G. (eds) Cambridge, 23-39.

DRUMMOND, H.H. 1824. Notice regarding fossil bones of a whale discovered in the district of Monteith. Mem. Wern. nat. Hist. Soc., 5, 440-441.

DURNO, S.E. 1956. Pollen analysis of peat deposits in Scotland. Scott. geogr. Mag., 72, 177-187.

DURNO, S.E. 1957. Certain aspects of vegetational history in north-east Scotland. Scott. geogr. Mag., 73, 176-184.

DURNO, S.E. 1958a. The dating of the Forth valley carse clay : a note. Scott. geogr. Mag., 74, 47-48.

DURNO, S.E. 1958b. Pollen analysis of peat deposits in eastern Sutherland and Caithness. Scott. geogr. Mag., 74, 127-135.

DURNO, S.E. 1958c. Pollen analysis of peat deposits in the eastern Grampians. Scott. geogr. Mag., 75, 102-111.

DURNO, S.E. 1959. Pollen analysis of peat deposits in the eastern Grampians. Scott. geogr. Mag., 75, 102-111.

DURNO, S.E. 1965. Pollen analytical evidence of "Landnam" from two Scottish sites. Trans. bot. Soc. Edinb., 40, 13-19.

EARP, J.R. *et al* 1962. Discussion of J.B. Sissons' paper on Late-glacial shorelines. Trans. geol. Soc. Edinb., 19, 216-220.

ERDTMAN, G. 1928. Studies in the post-arctic history of the forests of north-western Europe. 1. Investigations in the British Isles. Geol. Fören. Stockh. Förh., 50, 123-192.

ERDTMAN, G. 1943. An Introduction to Pollen Analysis. Waltham, Mass.

ERDTMAN, G., BERGLUND, B. and PRAGLOWSKI, J. 1961. An Introduction to a Scandinavian Pollen Flora. 1. Stockholm.

ERDTMAN, G., BERGLUND, B. and PRAGLOWSKI, J. 1963. An Introduction to a Scandinavian Pollen Flora. 2. Stockholm.

FAEGRI, K. 1966. Some problems of representivity in pollen analysis. Palaeobotanist., 15, 135-140.

FAEGRI, K., and IVERSEN, J. 1964. Textbook of Pollen Analysis, Copenhagen.

FAIRBRIDGE, R.W. 1961. Eustatic changes in sea-level. Phys. and Chem. of the Earth, 4, 99-185.

FEACHAM, R. 1963. Prehistoric Scotland. London.

FOORD, A.H., and KIDSTON, R. 1890. Notes on the flora and fauna of Pleistocene beds of the carse of Stirling. Trans. Stirling Fld. Club and Nat. Hist. and Archaeol. Soc., 1889-1890, 91-97.

FRANCIS, E.H. et al 1970. The geology of the Stirling District. Mem. geol. Surv. Scotl.

GEIKE, J. 1881. Prehistoric Europe. London.

GEIKE, J. 1894. The Great Ice Age. London. 3rd. ed.

GILLHAM, M.E. 1957. Vegetation of the Exe estuary in relation to water salinity. J. Ecol., 45, 735-756.

GODWIN, H. 1940. Pollen analysis and forest history of England and Wales. New Phytol., 39, 370-400.

GODWIN, H. 1943. Coastal peat beds of the British Isles and North Sea. J. Ecol., 31, 199-247.

GODWIN, H. 1955. Botanical and geological history of the Somerset Levels. Advmt. Sci., 12, 319-322.

GODWIN, H. 1956. The History of the British Flora. Cambridge.

GODWIN, H. 1961. Radiocarbon dating and Quaternary history in Britain. Proc. R. Soc., B, 153, 287-320.

GODWIN, H. 1966. Introductory address. In World Climate from 8,000 to 0 BC. Sawyer, J.S., et al (eds) Royal Meteorological Society, 3-14.

GODWIN, H., and SWITZUR, V.R. 1966. Cambridge University Natural Radiocarbon Measurements Vlll. Radiocarbon, 8, 390-400.

GODWIN, H., and WILLIS, E.H. 1961. Cambridge University Natural Radiocarbon Measurements III. Radiocarbon, 3, 60-76.

GODWIN, H., and WILLIS, E.H. 1962. Cambridge University Natural Radiocarbon Measurements IV. Radiocarbon, 4, 57-70.

GODWIN, H., SUGGATE, R.P., and WILLIS, E.H. 1958. Radiocarbon dating of the eustatic rise in ocean levels. Nature., 181, 1518.

GODWIN, H., WALKER, D., and WILLIS, E.H. 1957. Radiocarbon dating and post-glacial vegetational history : Scaleby Moss. Proc. R. Soc., B, 147, 352-366.

GRAY, J.M., and BROOKS, C.L. 1972. The Loch Lomond Readvance moraines of Mull and Menteith. Scott. J. Geol., 8, 95-103.

GREEN, F.H.W. 1958. The Moray floods of July and August 1956. Scott. geogr. Mag., 74, 48-50.

GROOT, J.J. 1966. Some observations on pollen grains in suspension in the estuary of the Delaware River. Marine Geol., 4, 409-416.

HIBBERT, F.W., SWITZUR, V.R., and WEST, R.G. 1971. Radiocarbon dating of Flandrian pollen zones at Red Moss, Lancashire. Proc. R. Soc., B, 177, 161-176.

HOPKINS, J.S. 1950. Differential flotation and deposition of coniferous and deciduous tree pollen. Ecology, 31, 633-641.

HUNTER, T. 1883. Woods, Forests and Estates of Perthshire. Perth.

HYDE, H.A., and ADAMS, K.F. 1958. An Atlas of Airborne Pollen Grains. London.

IVERSEN, J. 1941. Landnam i Danmarks Stenalder. Danm. Geol. Unders., Ser. II., 66, 1-68.

IVERSEN, J. 1949. The influence of prehistoric man on vegetation. Danm. Geol. Unders., Ser. IV., 3, 1-25.

IVERSEN, J. 1954. The Late-glacial flora of Denmark and its relation to climate and soil. Danm. Geol. Unders., Ser II, 80, 87-119.

IVERSEN, J. 1960. Problems of the early post-glacial forest development in Denmark. Danm. Geol. Unders., Ser. IV., 4, 1-32.

JACK, R.L. 1875. Notes on a till or boulder clay with broken shells in the lower part of the River Endrick, near Loch Lomond, and its relation to certain other glacial deposits. Trans. geol. Soc. Glasg., 5, 1-25.

JAMIESON, T.F. 1865. On the history of the last geological changes in Scotland. Quart. J. geol. Soc., 21, 161-203.

JAMIESON, T.F. 1906. On the raised beaches of the Geological Survey of Scotland. Quart. J. geol. Soc. Lond., 21, 161-203.

JAMIESON, T.F. 1908. On changes of level and the production of raised beaches. Geol. Mag., 53, 22-25.

JANSSEN, C.R. 1973. Local and regional pollen deposition. In Quaternary Plant Ecology, Birks, H.J.B. and West, R.G. (eds) Oxford, 31-42.

JELGERSMA, S. 1961. Holocene sea-level changes in the Netherlands. Med. van de Geologische Stichting., C, 6, 1-100.

JELGERSMA, S. 1966. Sea-level changes during the last 10,000 years. In World climate 8,000 to 0 B.C., Sawyer, J.S., et al (eds) Royal Meteorological Society.

KEMP, D.D. 1971. The stratigraphy and sub-carse morphology of an area on the northern side of the River Forth between the Lake of Menteith and Kincardine-on-Forth. Unpublished Ph.D thesis, University of Edinburgh.

KINNAIRD, J.W. 1974. Effect of site conditions on the regeneration of birch. J. Ecol., 62, 462-472.

KIRK, W., and GODWIN, H. 1963. A late-glacial site at Loch Droma, Ross and Cromarty. Trans. R. Soc. Edinb., 65, 225-249.

KNOX, E.M. 1938. The spores of Pteridophyta, with observations on the microspores in coals of Carboniferous age. Trans. bot. Soc. Edinb., 32, 438-466.

KUPRIANOVA, L.A. 1965. *The Palynology of the Amentiferae.* Academy of Sciences, USSR.

LACAILLE, A.D. 1954. *The Stone Age in Scotland.* Oxford.

LEARMONTH, A.T.A. 1950. The floods of 12th August, 1948 in south-east Scotland. *Scott. geogr. Mag.*, 66, 147-153.

MANLEY, G. 1964. The evolution of the climatic environment. In *The British Isles : A Systematic Geography*, Watson, J.W., and Sissons, J.B. (eds) Edinburgh, 152-170.

MARTIN, I.H. 1934. *The Field-Club Flora of the Lothians.* Edinburgh.

McVEAN, D.N., and RATCLIFFE, D.A. 1962. Plant communities of the Scottish Highlands. *Monogr. Nature Conservancy*, No. 1., London.

MILNE-HOLME, D. 1871. *The estuary of the Forth and adjoining districts viewed geologically.* Edinburgh.

MITCHELL, G.F. 1952. Late-glacial deposits at Garscadden Mains, near Glasgow. *New Phytol.*, 50, 277-286.

MOAR, N.T. 1969. Late Weichselian and Flandrian pollen diagrams from south-west Scotland. *New Phytol.*, 68, 433-467.

MORAN, J.M., and BRYSON, R.A. 1969. The contribution of Laurentide ice wastage to the eustatic rise of sea-level, 10,000 - 6,000 B.P. *Arctic Alpine Res.*, 1, 97-104.

MÖRNER, N-A. 1969. The Late Quaternary history of the Kattegat Sea and the Swedish west coast. *Sveriges geol. Unders.* C.640.

MÖRNER, N-A. 1971. The Holocene eustatic sea-level problem. *Geol. en Mijnb.*, 50, 699-702.

MORRIS, D.B. 1892. The raised beaches of the Forth valley. *Trans. Stirling Fld. Club and Nat. Hist. and Archaeol. Soc.*, 1892-1893, 18-48.

MULLER, J. 1959. Palynology of Recent Orinoco delta and shelf sediments. *Micropaleontology.*, 5, 1-32.

NEWEY, W.W. 1965. Post-glacial vegetational and climatic changes in part of south-east Scotland as indicated by the pollen analysis and stratigraphy of some of its peat and lacustrine deposits. Ph.D thesis, University of Edinburgh.

NEWEY, W.W. 1966. Pollen analysis of sub-carse peats of the Forth valley. Trans. Inst. Br. Geogr., 39, 53-59.

NEWEY, W.W. 1970. Pollen analysis of Late-Weichselian deposits at Corstorphine, Edinburgh. New Phytol., 69, 1167-1177.

PATERSON, I.B. 1973. The supposed Perth Readvance in the Perth district. Scott. J. Geol., 10, 53-66.

PEACOCK, J.D. 1970. Some aspects of the glacial geology of west Inverness-shire. Bull. geol. Surv. Gt. Brit., 33, 43-56.

PEACOCK, J.D. 1971. Marine shell radiocarbon dates and the chronology of deglaciation in western Scotland. Nature (Phys. Sci.) Lond., 230, 43-45.

PENNINGTON, W. 1973. Absolute pollen frequencies in the sediments of lakes of different morphometry. In Quaternary Plant Ecology, Birks, H.J.B., and West, R.G. (eds), Oxford, 79-104.

PENNINGTON, W., and LISHMAN, J.P. 1971. Iodine in lake sediments in northern England and Scotland. Biol. Rev., 46, 279-313.

PENNINGTON, W., et al 1972. Lake sediments in northern Scotland. Phil. Trans. R. Soc., B, 264, 191-294.

PIGGOT, S. 1958. Scotland before History. London.

POST von, L. 1929. Die Postarktische Geshnichte der europaischen wälder nach den vorliegenden Pollendiagrammen. Geol. Fören. Stockh. Förh., 51, 1-27.

POST von, L. 1930. Problems and working lines in the post arctic forest history of Europe. Proc. 5th Int. Bot. Congr. Cambridge.

RAMSAY, J. 1801. The Ochertyre Manuscripts. MS. 1644. Natn. Libr. Scotl.

RANWELL, D.S. 1972. Ecology of Salt Marshes and Sand Dunes. London.

READ, W.A. 1959. The economic geology of the Stirling and Clackmannan Coalfield, Scotland : Area south of the River Forth. Geol. Surv. U.K.

Recommendations on stratigraphical usage. Proc. geol. Soc. Lond., 1969, No. 1650, 139-166.

Report of the Stratigraphical Code Sub-Committee. Proc. geol. Soc. Lond., 1967. No. 1638, 75-87.

RICHARDSON, S.D. 1955. Effects of sea-water flooding on tree growth in the Netherlands. Quart. J. For., 49, 22-28.

SALISBURY, E. 1970. The pioneer vegetation of exposed muds and its biological features. Phil. Trans. R. Soc., B., 259, 207-255.

SCHOFIELD, J.C. 1964. Post-glacial sea-levels and isostatic uplift. N.Z. J. Geol. Geophys., 7, 330-359.

SERNANDER, R. 1908. On the evidence of post-glacial change of climate furnished by the peat mosses of northern Europe. Geol. Fören. Stockh. Förh., 30, 262-268.

SHEPARD, F.P. 1963. Thirty-five thousand years of sea-level. In Essays in marine geology in honor of K.O. Emery, Clements, T. (ed) Los Angeles, 1-10.

SIBBALD, R. 1707. History and description of Stirlingshire, ancient and modern. Edinburgh.

SIMPSON, J.B. 1933. The late-glacial readvance moraines of the Highland border west of the River Tay. Trans. R. Soc. Edinb.,57, 633-645.

SIMS, R.E. 1973. The anthropogenic factor in East Anglian vegetational history. In Quaternary Plant Ecology, Birks, H.J.B., and West, R.G. (eds) Oxford, 223-236.

SINCLAIR, J. 1792-1796. The Old Statistical Accounts of Scotland. Edinburgh. 7, 139-142; 8, 546-552; 18, 317-357; 20, 40-92.

SISSONS, J.B. 1962a. A re-interpretation of the literature on late-glacial shorelines in Scotland with particular reference to the Forth area. Trans. Edinb. geol. Soc., 19, 83-99.

SISSONS, J.B. 1963a. Scottish raised shoreline heights with particular reference to the Forth valley. Geogr. Annlr., 45, 180-185.

SISSONS, J.B. 1965. Quaternary. In The Geology of Scotland, Craig, G.Y. (ed), Edinburgh, 467-503.

SISSONS, J.B. 1966. Relative sea-level changes between 10,300 and 8,300 B.P. in part of the Carse of Stirling. Trans. Inst. Br. Geogr., 39, 19-29.

SISSONS, J.B. 1967a. Glacial stages and radiocarbon dates in Scotland. Scott. J. Geol., 3, 375-381.

SISSONS, J.B. 1967b. The Evolution of Scotland's Scenery. Edinburgh.

SISSONS, J.B. 1969. Drift stratigraphy and buried morphological features in the Grangemouth - Falkirk - Airth area. central Scotland. Trans. Inst. Br. Geogr., 48, 19-50.

SISSONS, J.B. 1972. Dislocation and non-uniform uplift of raised shorelines in the western part of the Forth valley. Trans. Inst. Br. Geogr., 55, 145-159.

SISSONS, J.B. 1974a. A late-glacial ice-cap in the central Grampians, Scotland. Trans. Inst. Br. Geogr., 62, 95-114.

SISSONS, J.B. 1974b. Late-glacial marine erosion in Scotland. Boreas. 3, 41-48.

SISSONS, J.B. 1974c. The Quaternary in Scotland : a review. Scott. J. Geol., 10, 311-337.

SISSONS, J.B., and BROOKS, C.L. 1971. Dating of early post-glacial land and sea-level changes in the western Forth valley. Nature (Phys. Sci.) Lond., 234, 124-127.

SISSONS, J.B., and SMITH, D.E. 1965a. Raised shorelines associated with the Perth Readvance in the Forth valley and their relation to glacial isostasy. Trans. R. Soc. Edinb., 66, 143-168.

SISSONS, J.B., and SMITH, D.E. 1965b. Peat bogs in a post-glacial sea and a buried beach in the western part of the Carse of Stirling. Scott. J. Geol., 1, 247-255.

SISSONS, J.B., and WALKER, M.J.C. 1974. Late-glacial site in the central Grampian Highlands. Nature Lond., 249, 822-824.

SISSONS, J.B., CULLINGFORD, R.A., and SMITH, D.E. 1965. Some pre-carse valleys in the Forth and Tay basins. Scott. geogr. Mag., 81, 115-124.

SISSONS, J.B., SMITH, D.E., and CULLINGFORD, R.A. 1966. Late-glacial and post-glacial shorelines in south-east Scotland. Trans. Inst. Br. Geogr., 39, 9-18.

SMITH, D.E. 1965. Late - and post-glacial changes of shoreline on the north side of the Forth valley and estuary. Unpublished Ph.D thesis, University of Edinburgh.

SMITH, D.E. 1968. Post-glacial shorelines in the surface of the carse clay on the north bank of the River Forth in Scotland. Z. Geomorph., 12, 388-408.

SMITH, S.M. 1972. Palaeoecology of post-glacial beaches in East Lothian. Scott. J. Geol., 8, 31-49.

SMITH, W. 1905. Botanical survey of Scotland III and IV. Scott. geogr. Mag., 21, 4-23; 58-83.

STEELE, A. 1826. The natural and agricultural history of peat moss or turf-bog. Edinburgh.

STEVEN, H.M., and CARLISLE, A. 1959. The native pinewoods of Scotland. Edinburgh.

STUIVER, M. 1969. Yale Natural Radiocarbon Measurements IX. Radiocarbon, 11, 589.

SUGDEN, D.E. 1970. Landforms of deglaciation in the Cairngorm mountains, Scotland. Trans. Inst. Br. Geogr., 51, 201-219.

TAIT, C. 1974. An account of the peat mosses of Kincardine and Flanders in Perthshire. Trans. R. Soc. Edinb., 3, 266-279.

TALLIS, J.H. 1964. Studies on southern Pennine peats. 2. The pattern of erosion. J. Ecol., 52, 333-344.

TANSLEY, A.G. 1939. The British Islands and their Vegetation. Cambridge.

TAUBER, H. 1965. Differential pollen dispersion and the interpretation of pollen diagrams. Danm. Geol. Unders., Ser II, 89, 1-69.

TAUBER, H. 1967. Investigations of the mode of pollen transfer in forested areas. Rev. Palaeobotan. Palynol., 3, 277-286.

TOOLEY, M.J. 1969. Sea-level changes and the development of coastal plant communities during the Flandrian in Lancashire and adjacent areas. Unpublished Ph.D thesis, University of Lancaster.

TOOLEY, M.J. 1974. Sea-level changes during the last 9,000 years in north-west England. Geogrl. J., 140 (1). 18-42.

TRAVERSE, A., and GINSBURG, R.N. 1966. Pollen and associated microfossils in the marine surface sediments of the Great Bahama Bank, as related to water movement and sedimentation. Marine Geol., 4, 417-459.

TROELS-SMITH, J. 1960. Ivy, Mistletoe and Elm : Climatic indicators - fodder plants. Danm. Geol. Unders., Ser.IV, 4, 1-32.

TURNER, J. 1964. Surface sample analysis from Ayrshire, Scotland. Pollen Spores, 6, 583-592.

TURNER, J. 1965. A contribution to the history of forest clearance. Proc. R. Soc., B, 161, 343-354.

TURNER, W. 1869. On the bones of a seal found in red clay near Grangemouth with remarks on the species. Proc. R. Soc. Edinb., 7, 105-114.

THOMPSON, K.S.R. 1972. The last glaciers in western Perthshire. Unpublished Ph.D thesis, University of Edinburgh.

VASARI, Y., and VASARI, A. 1968. Late - and post-glacial macrophytic vegetation in the lochs of northern Scotland. Acta. bot. fenn., 80, 1-120.

WALKER, D. 1966. The Late-Quaternary history of the Cumberland lowland. Phil. Trans. R. Soc., B, 251, 1-210.

WEST, R.G. 1968. Pleistocene Geology and Biology. London.

WEST, R.G. 1970. Pollen zones in the Pleistocene of Great Britain and their correlation. New Phytol., 69, 1179-1183.

WODEHOUSE, R.P. 1935. *Pollen Grains*. New York.

WRIGHT, W.B. 1914. *The Quaternary Ice Age*. London.

APPENDIX.

PUBLISHED PAPERS.

The Loch Lomond Readvance moraines of Mull and Menteith

J. M. Gray and C. L. Brooks
Department of Geography, University of Edinburgh

Synopsis

A radiocarbon date of 11 330±170 B.P. for shells from the Kinlochspelve Moraine on the Isle of Mull indicates that a readvance of ice took place there during Zone III. The ice apparently scooped up marine deposits laid down during the preceding Zone II (Alleröd) climatic amelioration.

Analysis of pollen from clays in both the Kinlochspelve and Menteith moraines substantiates this opinion and together with radiocarbon dates and geomorphological evidence enables correlation of both moraines with the Loch Lomond Readvance. On Mull the mapping of moraines and thick drift deposits indicates that an ice cap and several separate glaciers existed on the island at this time.

Introduction

In the Geological Survey memoir for Mull (Bailey *et al.* 1924) a local valley glaciation on the island was described and correlated with the 'Valley' or 'Moraine Glaciation' of the West Highlands. Similarly Charlesworth (1955) described the former valley glaciers of Mull and correlated this stage with the 'Moraine Glaciation', his Stage M. With this stage he also correlated the lobes at Menteith and Loch Lomond previously mapped and described by Simpson (1933). From pollen studies inside and outside the limit of this readvance in the Oban and Menteith areas, Donner (1957) inferred that it took place during the Zone III cold phase* or between about 10 800 and 10 300 B.P.

Synge (1966) suggested that Charlesworth's Stage M actually consists of two readvances in the vicinity of Oban. The earlier one was said to be represented by the Oban–Ford Moraine south of Oban. The younger one, at Loch Etive and Loch Creran north of Oban and represented by the Connel Moraine, was believed to have taken place during Zone III. Synge, however, could find no representative of this younger stage on Mull, believing that the ice had retreated into the corries by this time; and instead he correlated the ice-limits of the Mull valley glaciation with his Oban–Ford Moraine. Similar views were expressed in a later paper (Synge and Stephens 1966).

Sissons (1967a, 1967b) correlated the valley glaciation of Mull and the ice-limits at Loch Etive and Loch Creran, with Simpson's (1933) Loch Lomond

* For brevity the terms Zone I, Zone II etc. are used in a chronological sense though it is realized that strictly these are not time correlatives.

Readvance at Menteith and Loch Lomond. Radiocarbon dating at the latter sites has confirmed Donner's (1957) Zone III dating (Sissons 1967a), and at Loch Creran has enabled the readvance there to be correlated with the Loch Lomond Readvance (Peacock 1971).

The Menteith Moraine

Extending for 20 km (12 miles) in an arcuate loop from 10 km (6 miles) west of Buchlyvie to Port of Menteith, the Menteith Moraine complex encloses the western part of the Forth lowlands. On the lower ground it is largely composed of ridges and mounds of sand and gravel and areas of glacier-transported marine clay and shells. Simpson (1933) described a section in the moraine on the banks of the Lake of Menteith where 3 m (10 ft) of dark grey clay containing fragments of *Mytilus edulis* is overlain by about 9 m (30 ft) of sand and gravel. Radiocarbon dating of shells from this section has yielded a date of 11 800 ± 170 B.P. and shells from a sand pit at Drymen in the Loch Lomond Moraine complex were dated as 11 700 ± 170 B.P. (Sissons, 1967a). It has therefore been concluded that the sea had access to Loch Lomond and the western part of the Forth lowlands during Zone II (Alleröd Interstadial) and that subsequently the glaciers advanced across the marine clay and shells and redeposited them during Zone III.

The molluscan fauna collections from Menteith and Drymen have been identified recently from photographs taken before the shells were radiocarbon dated. The shells are listed approximately in order of decreasing abundance as far as this can be established from the photographs.

Menteith [NN 589000]	Drymen [NS 483880]
Mytilus edulis L.	*Arctica islandica* (L.)
Nuculana pernula (Müller)	*Tridonta montagui* (Dillwyn)
Littorina littorea (L.)	*Trophonopsis clathratus* (L.)
Littorina littoralis (L.)	*Tridonta elliptica* (Brown)
Buccinum undatum L.	*Littorina littorea* (L.)
Chlamys sp.	*Littorina littoralis* (L.)
Macoma sp.	*Tridonta borealis?* (Schumacher)
	Nucella lapillus (L.)
	Chlamys islandica (Müller)
	Lunatia pallida? (Broderip and Sowerby)
	Macoma calcarea? (Gmelin)

Although the number of species collected from Menteith is small, both assemblages indicate that sea temperatures were lower during Zone II than they are today. The fauna from both moraines can be described as constituting boreal to sub-arctic assemblages.

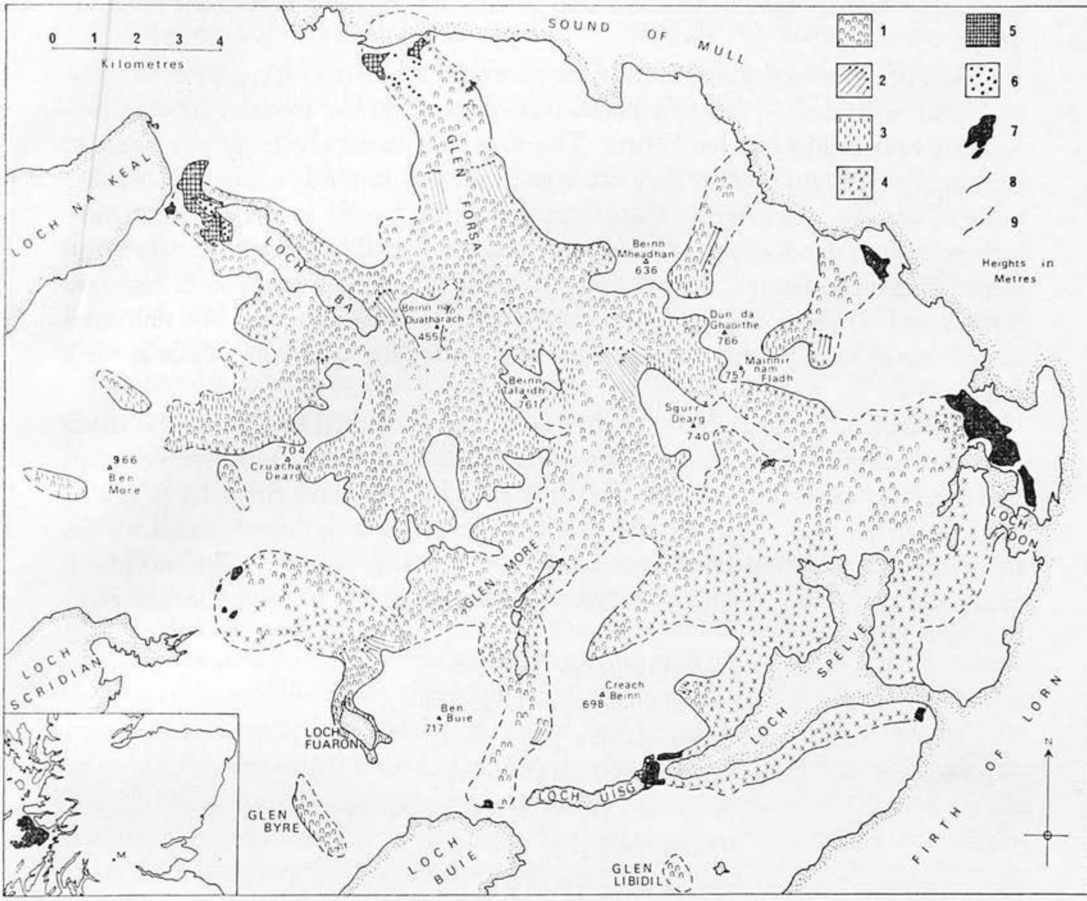


FIG. 1. The moraines, thick drift deposits and ice-limits of Mull. 1. Hummocky moraines. 2. Fluted moraines. 3. Deeply gullied drift. 4. Drift plastered rock. 5. Outwash. 6. Kames, kettle holes and eskers. 7. Terminal moraines. 8. Upper limit of thick drift where this is clearly defined. 9. Upper limit of thick drift where this is not clearly defined. The inset map shows the position of Mull (shaded) and Menteith (M).

The Kinlochspelve Moraine

At the head of Loch Spelve on eastern Mull (Fig. 1) there is a group of morainic ridges here collectively termed the Kinlochspelve Moraine. These ridges clearly represent the terminal point of a readvance of ice along Loch Spelve from the north-east and were interpreted as such by previous writers (Bailey *et al.* 1924; Synge 1966; Synge and Stephens 1966). Evidence of a readvance is observable in a section in the moraine [NM 656259] near Kinlochspelve Farm which shows grey and orange varved clay with cross-bedded sand above, both truncated by overlying sand and gravel. This depositional succession in this location indicates ice readvance into an ice dammed lake or sea loch reduced in salinity by meltwater.

Most of the material constituting the morainic ridges is a blue-grey or brown-grey clay with stones. Shell material was observed in the moraine at only two sections near Kinlochspelve Farm. The shell fragments are fairly abundant in certain layers, though often they are weathered and crumble easily, while other parts of the clay are barren. Contrasting with the poorly preserved fragments, however, are the occasional, almost unweathered lamellibranchs with valves still joined at the ligament, a characteristic particularly noted in the species *Nuculana pernula* and *Tridonta elliptica*. The clay is usually homogeneous, but thin sand lenses occur locally and these contain concentrations of small, washed, shell fragments.

A collection of about 180 g of the better preserved shell fragments was made from a small pit dug on the west side of the track leading to Kinlochspelve Farm, where it crosses the eastern end of a large morainic ridge, at about 25 m (82 ft) O.D. [NM 656261]. The scarcity of unweathered shells is demonstrated by the fact that about 60 hours were required to collect this weight. The molluscan fauna is listed approximately in order of decreasing abundance, the last eight species being rare:

Tridonta elliptica (Brown)
Tridonta montagui (Dillwyn)
Arctica islandica (L.)
Nuculana pernula (Müller)
Portlandia (*Yoldiella*) *phillipiana* (Nyst)
Mya truncata (L.)
Littorina littoralis (L.)
Acanthocardium sp.
Trophonopsis clathratus (L.)
Buccinum undatum L.
Littorina saxatilus (Olivi)
Littorina littorea (L.)
Tellinacea
Arenomya arenaria? (L.)
Lunatia pallida? (Broderip and Sowerby)
Trochidae

This list, though longer than that contained in Bailey *et al.* (1924), is similar to it and confirms that the molluscan fauna contained in the Kinlochspelve Moraine constitutes a marine assemblage of boreal to sub-arctic character. The fauna bears a marked resemblance to the Menteith and Drymen assemblages, especially to the latter, no significant temperature differences being indicated.

A radiocarbon date of 11 330 ± 170 B.P. (I-5308) has been obtained for the Kinlochspelve shell sample. Although this date is slightly younger than those from Menteith and Drymen, it still falls within the Alleröd climatic amelioration. The situation at Loch Spelve thus appears to be similar to that at Menteith and Loch Lomond. During Zone II the sea had access to Loch Spelve, but ice later advanced over the marine clays and shells, redepositing them at the Kinlochspelve Moraine during the Zone III cold phase.

The last glaciation of Mull

Fig. 1 shows the moraines, thick drift deposits and ice-limits of Mull. The mapping was done on Ordnance Survey 1:63 360 maps from 1:10 560 aerial photographs and most of the area, except the high corries, was checked in the field. In addition the coastal ice-limits were mapped at the 1:10 560 scale.

Usually it is possible to delimit the vertical extent of the thick glacial deposits in each valley as the upper limit of deeply gullied drift or drift plastered rock, but places where the mapping of this limit is less certain are shown by a broken line on Fig. 1.

The valleys of Mull contain a well developed system of hummocky moraines. The moraines are particularly clear in the valley draining northwards from Loch Fuaron into Glen More, locally termed ' the valley of the hundred hills ', though in fact several hundred of these mounds exist in this area. At the point where this valley joins Glen More there is evidence of lineation of the hummocks, but this phenomenon is best developed on the spur north-west of Sgurr Dearg. In this area the convergent nature of the lineations indicates convergent glaciers (Pl. 1). Linear drift accumulations are present elsewhere in the valleys of central Mull and are particularly common in the corries. Elsewhere in the west Highlands drift lineations have been described by Peacock (1967) and Sissons (1967b), the latter referring to them as fluted moraines.

The Kinlochspelve Moraine is a terminal feature of the Mull valley glaciation, and other important ice-limits include the Loch Don Sand Moraine and the outwash spreads at Glen Forsa and Loch Ba. Fig. 1, which compares well with the map published in the Mull memoir (Bailey *et al.* 1924, fig. 64) showing the morainic drift on part of Mull, is considered to indicate the approximate extent of the last glaciation of Mull. The Kinlochspelve date indicates that this glaciation took place during Zone III and is the Mull equivalent of the Loch Lomond Readvance, despite Synge's (1966) statement that such a correlation cannot be upheld. It appears that a small ice cap existed on Mull at this time, Sgurr Dearg, Beinn Talaidh and Beinn na Duatharach protruding as nunataks. Separate corrie glaciers existed in the vicinity of Ben More and in Glen Byre and Glen Libidil, while two major valley glaciers were present on the Sound of Mull coastline. In the east of the island confluent glaciers occupied the Loch Spelve and Loch Don basin. During this readvance glaciers were apparently able to form as low as 200 m (650 ft) O.D. and in many cases the glaciers descended to sea level.

Pollen analysis

Samples of glacier-transported shelly marine clay were obtained from the Kinlochspelve Moraine [NM 656261] and the Menteith Moraine [NN 589000]. The samples, each weighing 2 g, were deflocculated with 10% KOH and siliceous matter was removed by 40% HF, as described by Faegri and Iversen (1964). Slides were made by mounting the samples in safranin-stained glycerine jelly. A total of 300 pollen grains and spores, excluding derived pre-Quaternary spores, were counted from each sample. The table below compares the pollen and spores from the two sites.

	Kinlochspelve	Menteith
Alnus	3	1
Betula nana	14	10
Betula	4	22
Pinus	23	42
Salix	3	3
Juniperus	3	1
Armeria	1	1
Caryophyllaceae	12	13
Chenopodiaceae	2	5
Compositae	1	1
Cyperaceae	12	5
Dryas octopetala	3	1
Epilobium		1
Empetrum	20	12
Ericaceae	14	27
Filipendula	47	29
Galium	2	
Gramineae	51	61
Helianthemum	15	11
Hippophaë rhamnoides		1
Plantago maritima	1	1
Ranunculus	11	8
Rumex	1	1
Succisa	1	1
Thalictrum alpinum	4	8
Tilia cordata		1
Umbelliferae	4	3
Urtica	10	7
Myriophyllum alterniflorum	1	5
M. spicatum	1	
Nymphaeaceae	1	

	Kinlochspelve	Menteith
Potamogeton	1	1
Filicales	7	3
Lycopodium clavatum	2	1
L. selago	11	8
Polypodium vulgare	1	
Selaginella selaginoides	10	2
Sphagnum	3	3
Total count	300	300
Derived pre-Quaternary spores	71	1525
Arboreal percentage of total count	17	26
Non-arboreal percentage of total count	83	74

The very low arboreal pollen percentages do not include pollen of warmth demanding trees such as oak and elm. Of the pollen present, *Betula nana* (tentatively identified by pore characteristics), *Salix* and *Juniperus* are commonly found in Late-glacial deposits. Some of the *Betula* and *Pinus* pollen in these glacier-transported marine deposits are likely to be of secondary origin and both are known to be subject to long distance wind transport. The presence of small numbers of *Alnus* and *Tilia* pollen may be the result of sample contamination. The major components of the non-arboreal pollen, particularly Gramineae and Cyperaceae, together with Caryophyllaceae, *Dryas*, *Empetrum*, *Filipendula*, *Helianthemum*, *Ranunculus*, *Thalictrum*, *Lycopodium clavatum*, *L. selago* and *Selaginella* belong to plants of open habitat. The high totals of these non-arboreal pollen and spores compared with those of the arboreal pollen are indicative of open and relatively treeless vegetation which suggests a Late-glacial age for the deposits.

The pollen assemblages in the table, although from isolated samples, favour an interpretation of a Zone II age. That from the Menteith Moraine is comparable with the Zone II pollen assemblages recorded by Vasari and Vasari (1968) from a site only 15 km away. A Zone II age for the deposits at both Menteith and Kinlochspelve is indicated by the radiocarbon dates of shells from these sites.

No pollen investigations of morainic material in Britain have been published with which the pollen results from Kinlochspelve and Menteith can be compared. The pollen and spore assemblages are comparable however, to those found in other Zone II pollen sites in Scotland by Donner (1957, 1958), Moar (1969) and Newey (1970). The arboreal pollen content from these sites varies between 10 and 30% of the pollen totals and consists of *Betula*, *Pinus*, *Salix* and *Juniperus*. The dominant components of the non-arboreal pollen are mainly Gramineae and Cyperaceae together with pollen of taxa which are found in present-day open habitats. The low arboreal pollen content from these sites is interpreted as indicating open vegetation. Vegetation of this type has been described by Moar

(1969) from a Zone II deposit, dated by radiocarbon at 11 580 ± 180 B.P. and 11 820 ± 180 B.P. (Godwin and Willis 1964).

The presence of marine shells in the Kinlochspelve and Menteith deposits indicates that both localities were influenced by a marine incursion during Zone II. Pollen of *Armeria*, Caryophyllaceae, Chenopodiaceae, *Hippophaë* and *Plantago maritima* found in the samples may represent the influence of marine conditions on the vegetation at these sites, as these taxa are found in coastal situations today (Tansley 1949). On the other hand these plants are also found today in open habitats; hence their pollen in the deposits could have been derived from similar environments in Late-glacial times.

Virtually all of the derived pre-Quaternary spores found in the Menteith sample were of the *Lepidostrobus Jacksoni* and *L. Oldhamius* types described by Knox (1938) from the Productive Coal Measures of the Fife Coalfield. Since the ice that deposited the Menteith Moraine came from the west, most or all of these spores were probably derived from the Carboniferous outcrops farther east in the Forth Valley and redeposited by the Alleröd sea.

The total number of derived pre-Quaternary spores found in the Kinlochspelve sample is much smaller than in the Menteith sample. The two Carboniferous spore types found abundantly in the latter could not be identified in the sample from Mull and it is suspected that the spores from the Mull site have been derived largely or entirely from adjacent Mesozoic outcrops.

Conclusions

The radiocarbon date, pollen analyses and geomorphological evidence presented in this paper indicate that the Kinlochspelve Moraine, like the Menteith and Loch Lomond Moraine complexes, was deposited by a readvance of ice during Zone III. A small ice cap and several separate valley glaciers existed on Mull at this time, and the readvance is confirmed to be the Mull equivalent of the Loch Lomond Readvance at Menteith, Loch Lomond and Loch Creran.

The ice-limit correlations of Charlesworth (1955) and Sissons (1967a, 1967b) are, therefore, upheld with certain modifications, but those of Synge (1966) and Synge and Stephens (1966) are not.

The Kinlochspelve date is the first relating to glacial limits to be obtained for the Western Isles of Scotland. It is possible that a glacial readvance on Skye, Rhum, Jura, Islay, Arran and Harris can also be correlated with the Loch Lomond Readvance but detailed evidence is not available for these islands.

Acknowledgements

The authors gratefully acknowledge the help and advice given by Dr J. B. Sissons, Dr W. W. Newey and Dr J. D. Peacock during the preparation of this

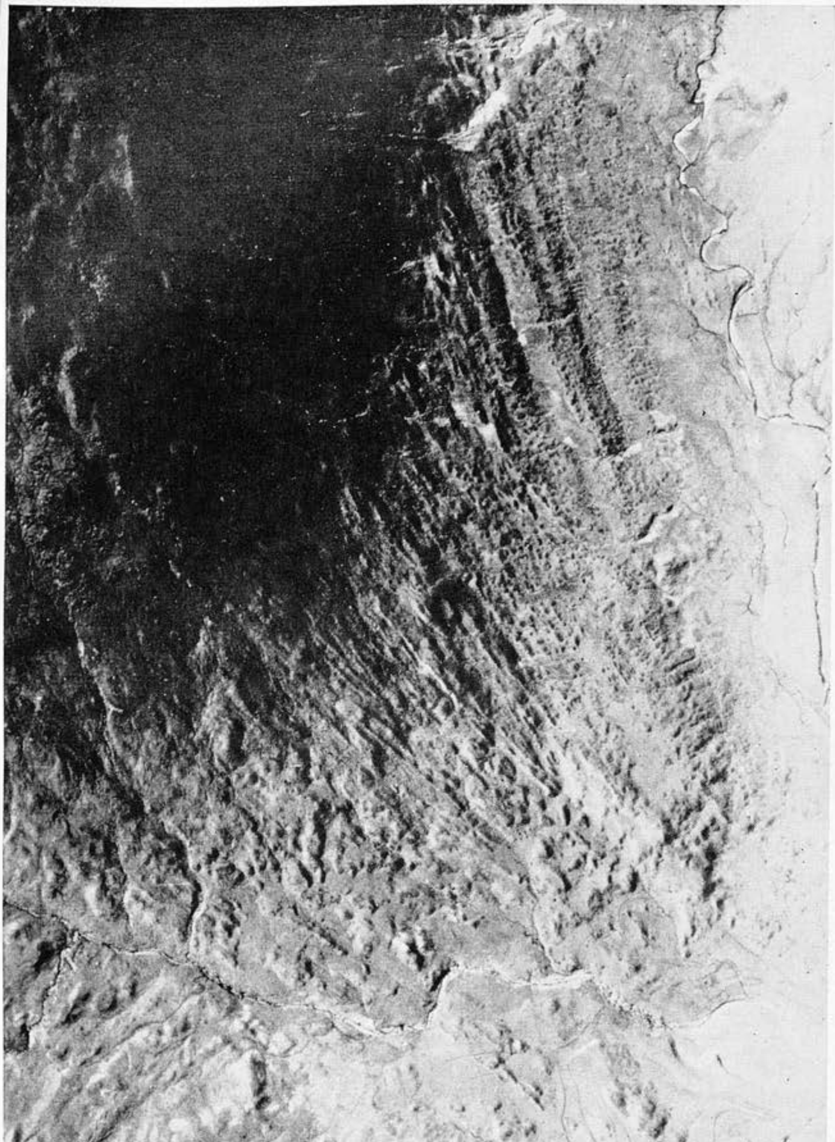


PLATE 1. Convergent drift lineations on the north-west spur of Sgurr Dearg, Isle of Mull. Convergent glaciers moved towards the lower right from the valley of the Abhainn an t-Sratha Bhàinn (lower left) and Glen Forsa (upper right). Between the dark area of outcropping rock on Sgurr Dearg (upper left) and Glen Forsa the fluted moraine consists of lineated hummocky moraines rather than the continuous morainic ridges of the central part of the photograph. The area shown is about 2·2 × 1·7 km. Ministry of Defence (Air Force Department) photograph, Crown Copyright Reserved.

paper. Dr Shelagh M. Smith very kindly identified all the listed shells. The cost of the radiocarbon date was met out of a grant from the Carnegie Trust. The work of one of us (J. M. G.) is being carried out during the tenure of a Natural Environment Research Council studentship.

References

BAILEY, E. B. 1924. The Tertiary and post-Tertiary geology of Mull, Loch Aline and Oban. *Mem. geol. Surv. U.K.*

CHARLESWORTH, J. K. 1955. The late-glacial history of the Highlands and Islands of Scotland. *Trans. R. Soc. Edinb.* **62,** 769–928.

DONNER, J. J. 1957. The geology and vegetation of late-glacial retreat stages in Scotland. *Trans. R. Soc. Edinb.* **63,** 221–264.

—— 1958. Loch Mahaick, a late-glacial site in Perthshire. *New Phytol.* **57,** 183–186.

FAEGRI, K. and IVERSON, J. 1964. *Textbook of Pollen Analysis.* Copenhagen.

GODWIN, H. and WILLIS, E. H. 1964. Cambridge University natural radiocarbon measurements, VI. *Radiocarbon* **6,** 116.

KNOX, E. M. 1938. The spores of Pteridophyta, with observations on the microspores in coals of Carboniferous age. *Trans. Bot. Soc. Edinb.* **32,** 438–466.

MOAR, N. T. 1969. Late-Weichselian and Flandrian pollen diagrams from south-west Scotland. *New Phytol.* **68,** 433–467.

NEWEY, W. W. 1970. Pollen analysis of Late-Weichselian deposits at Corstorphine, Edinburgh. *New Phytol.* **69,** 1167–1177.

PEACOCK, J. D. 1967. West Highland morainic features aligned in the direction of ice flow. *Scott. J. Geol.* **3,** 372–373.

—— 1971. Marine shell radiocarbon dates and the chronology of deglaciation in western Scotland. *Nature, Physical Science* **230,** 43–45.

SIMPSON, J. B. 1933. The late-glacial readvance moraines of the Highland border west of the River Tay. *Trans. R. Soc. Edinb.* **57,** 633–645.

SISSONS, J. B. 1967a. Glacial stages and radiocarbon dates. *Scott. J. Geol.* **3,** 375–381.

—— 1967b. *The Evolution of Scotland's Scenery.* Edinburgh.

SYNGE, F. M. 1966. The relationship of the raised strandlines and main end-moraines on the Isle of Mull and in the district of Lorn, Scotland. *Proc. Geol. Ass.* **77,** 315–328.

—— and STEPHENS, N. 1966. Late- and Post-glacial shorelines and ice-limits in Argyll and north-east Ulster. *Trans. Inst. Br. Geogr.* **39,** 101–125.

TANSLEY, A. G. 1949. *The British Islands and their Vegetation.* Cambridge.

VASARI, Y. and VASARI, A. 1968. Late- and Post-glacial macrophytic vegetation in the lochs of northern Scotland. *Acta bot. fenn.* **80,** 1–120.

MS received 30*th May* 1971
Revised MS received 29*th September* 1971

Pollen analysis and the Main Buried Beach in the western part of the Forth valley

C. L. BROOKS

Research student, Department of Geography, University of Edinburgh

Reprinted from
Transactions, March 1972
Publication No. 55

THE INSTITUTE OF BRITISH GEOGRAPHERS

Pollen analysis and the Main Buried Beach in the western part of the Forth valley

C. L. BROOKS
Research student, Department of Geography, University of Edinburgh

Revised MS received 2 March 1971

ABSTRACT. Pollen diagrams of the Main Buried Beach and associated deposits at two sites in the western part of the Forth valley are discussed and compared with pollen evidence from similar deposits at two other sites in the same area. At three of these sites the buried beach deposits ceased to accumulate at the end of Zone IV while at the fourth site it is very probable that the beach ceased to form at this time. Pollen analysis thus supports the geomorphological evidence indicating that the dislocated and variably uplifted Main Buried Shoreline is an essentially synchronous feature.

IN the western part of the Forth valley in central Scotland there are extensive deposits of estuarine silts and clays which form wide tracts of almost level land known as carse. Beneath a considerable part of these deposits is a layer of peat of variable thickness. The peat usually rests on gently sloping marine surfaces referred to as the High, Main and Low Buried Beaches, which were formed at the close of Late-glacial and in early Post-glacial times (J. B. Sissons, 1966).

The objects of this investigation were to study vegetational changes during changes of sea level, to determine the approximate time of these changes and to compare results with other pollen studies related to the Main Buried Beach deposits in the Forth valley west of Stirling. A particular object was to determine by pollen analysis whether the feature described in the preceding paper by Sissons in this volume (pages 145–59) as the Main Buried Beach is an approximately synchronous feature or whether it is, in fact, composed of beaches of different ages. Since palynological studies related to the Main Buried Beach had already been made at two sites in the Forth valley, respectively 16 and 22 km west of Stirling (S. E. Durno, 1956; W. W. Newey, 1966), this investigation was concerned with sites nearer Stirling, these being located on either side of the pronounced dislocation in the Main Buried Shoreline.

Radiocarbon dating of the peat was not attempted since, with the equipment available, sufficiently large samples could have been obtained only by putting down numerous closely spaced bores and the risk of contamination was therefore high. It should be added that the buried peat that rests on the Main Buried Beach is nowhere exposed in the area investigated.

At Bield (Grid Reference NS 696947), situated 10 km west of Stirling, the buried beach surface is at 9·04 m O.D., while at The Homesteads (NS 778932), located 2 km west of Stirling, it is at 7·44 m O.D. At each site samples were taken at intervals of 5 cm from the top of the buried beach deposits, from the overlying peat and from the base of the carse deposits. Samples 10 cm apart were analysed initially for pollen, intervening 5 cm samples being analysed later where more information was required. Samples were obtained using a Hiller borer with a 50 cm chamber. The sites were located close to the southern margin of the carse within 10 m of the southern edge of the Main Buried Beach deposits at points where the buried peat layer was known to be well developed. The surface heights at the two sites were levelled from Ordnance Survey bench marks.

In the laboratory pollen was extracted from peat by boiling 1 g of the sample in 10 per cent KOH followed by acetolysis. Mineral matter when present was removed by boiling the sample in HF acid, as described by K. Faegri and J. Iversen (1964). Slides were prepared by mounting treated samples in safranin-stained glycerine jelly. The arboreal and non-arboreal pollen diagrams were constructed on a basis of 150 arboreal pollen grains, except at 420 cm in The Homesteads diagrams, where the percentages are based on a count of 100 arboreal pollen grains.

The zonal division of the diagrams follows the system used by H. Godwin (1956). Scottish pollen diagrams, particularly those of upland or northerly areas, do not consistently show the same trends of vegetational development as those of parts of England. Thus J. J. Donner (1957, 1962) in his diagrams of Highland sites does not differentiate between Zones V and VI, and N. T. Moar (1969) in work in south-west Scotland uses an independent system of sub-division, based upon changes indicated in that locality. In this paper, however, which refers to lowland sites in central Scotland, the pollen assemblages accord with those shown by Godwin as characteristic of each zone and his criteria of division and sub-division are indicated in the diagrams.

THE HOMESTEADS SITE

The samples from the buried beach deposits at this site contained abundant remains of *Phragmites communis* and *Carex* spp., which were replaced in the peat by *Sphagnum* leaves. Some *Phragmites* and *Carex* plant remains were observed in the sample at 390 cm, above which *Sphagnum* became dominant. From 375 to 365 cm the *Sphagnum* samples contained much silt and at about 360 cm *Phragmites* and *Carex* reappeared. Above 360 cm to about 340 cm *Sphagnum* remains were abundant. The basal carse clay samples, from 330 to 320 cm contained abundant remains of *Phragmites* and *Carex*.

The pollen diagrams (Figs. 1 and 2) permit a general interpretation of the forest cover of the locality and also of the vegetation that grew in the immediate vicinity of the site. Samples from the buried beach deposits contained high frequencies of Gramineae and Cyperaceae pollen which, together with pollen of *Artemisia*, Caryophyllaceae, Compositae, Chenopodiaceae and *Plantago maritima*, are characteristic of saltmarsh vegetation (V. J. Chapman, 1964). This pollen decreases in the basal peat from about 400 to 380 cm during which relatively high frequencies of Gramineae and *Carex* pollen continue. From about 375 to 365 cm pollen of saltmarsh vegetation reappears accompanied by an increase in Gramineae counts. Between these levels *Sphagnum* spores also increase and reach very high values which continue to about 340 cm. In the carse deposits pollen assemblages indicative of saltmarsh communities reappear together with high counts of Gramineae and, to a lesser extent, *Carex* pollen.

An upward sequence of vegetational change is indicated by the changing values of the non-arboreal pollen and spores at this site. It appears that saltmarsh vegetation developed

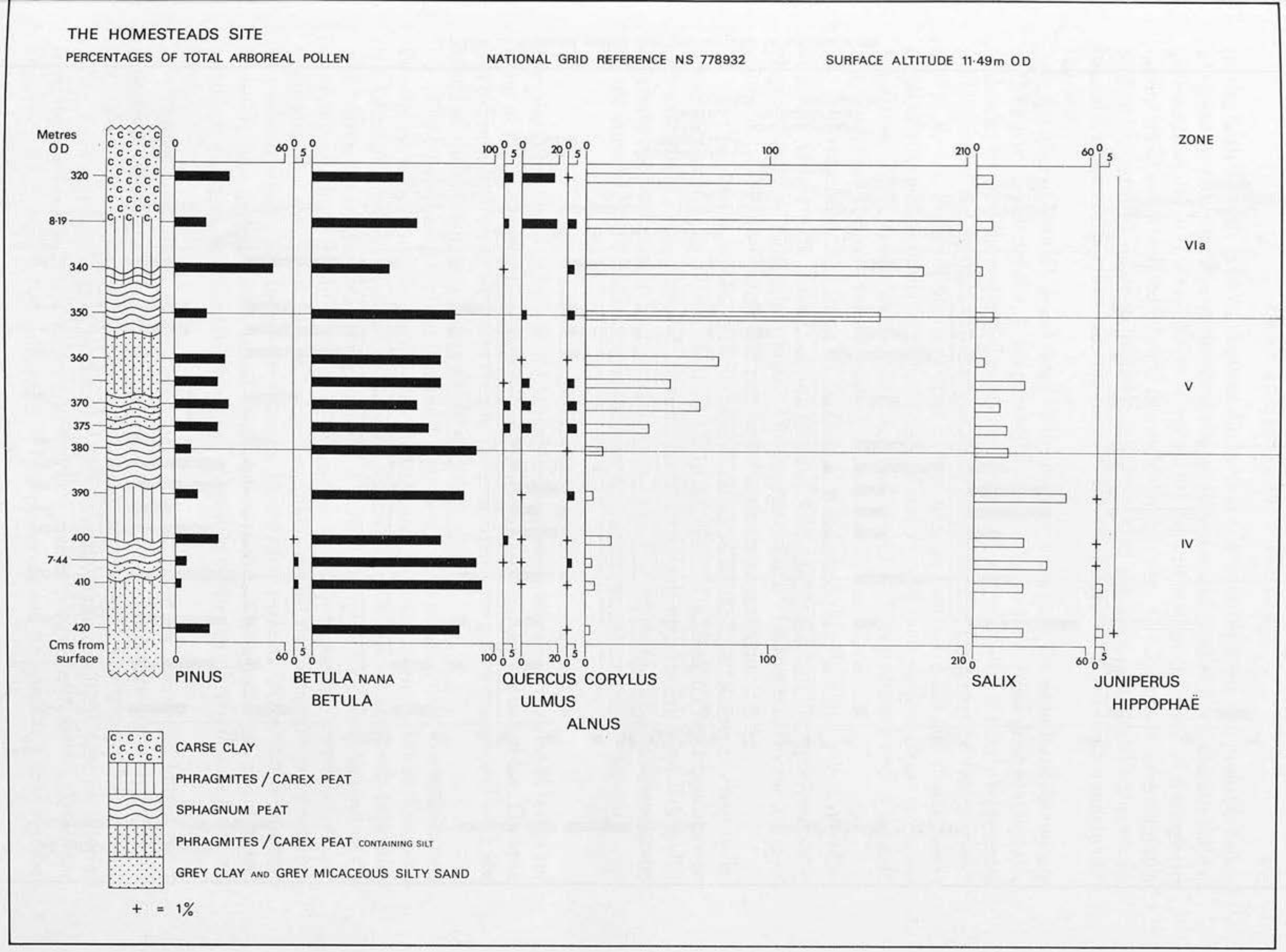


FIGURE 1. Non-arboreal pollen diagram for The Homesteads site

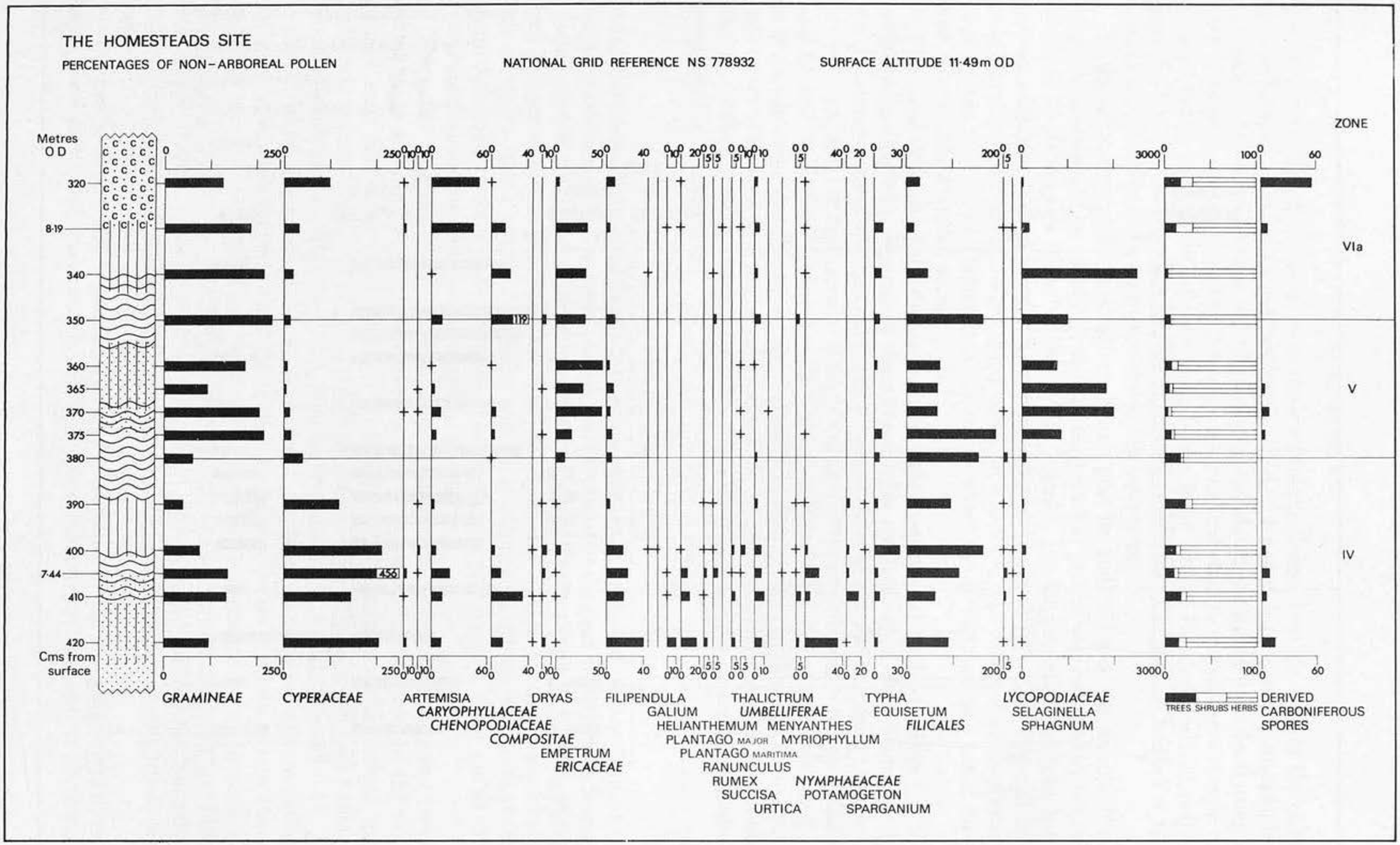


FIGURE 2. Arboreal pollen diagram for The Homesteads site

on the buried beach. The consequent diminution of marine influence and probable lack of adequate surface drainage encouraged the growth of raised moss. Pollen characteristic of saltmarsh occurs in this vegetation at 375 to 365 cm and may be the result of a temporary marine incursion which redeposited this pollen in the moss. The *Sphagnum* moss continued to flourish until the influence of the rising sea level of the main post-glacial transgression caused a reversion to saltmarsh conditions as the carse deposits began to accumulate over the peat.

A dating of Zone IV is indicated by the pollen spectra from the deposits of the top part of the buried beach deposit. It is apparent that the deposit was formed prior to the period of development of the warmth-demanding forest trees as their pollen is poorly represented in this part of the diagram. The only arboreal pollen present in substantial frequencies is that of *Betula*. Pollen of plants of open habitat such as *Rumex*, *Galium* and *Helianthemum* together with pollen of plants characteristic of tundra conditions such as *Dryas octopetela*, *Empetrum*, *Thalictrum alpinum*, *Saxifraga* and spores of Lycopodiaceae and *Selaginella selaginoides* are also well represented.

The transition from Zone IV to Zone V is indicated by substantial values of pollen of *Betula* and a rise in that of *Corylus*, together with a diminution in the representation of plants of open and mountain habitats. The passage to Zone VI is suggested by the increased values of *Ulmus* and *Quercus* and very high *Corylus* representation.

At this site the arboreal pollen diagram shows substantial frequencies of *Pinus* pollen occurring from 375 to 360 cm and from 340 to 320 cm. Although high *Pinus* frequencies are characteristic of Zones V and VI, the evidence at these levels suggests that some of the pollen may have been redeposited by the sea (Godwin, 1943; P. Brinkmann, 1934), as demonstrated by the curves of derived Carboniferous spores.

THE BIELD SITE

Samples from 480 to 445 cm in the buried beach deposits contained remains of leaves and stems of *Phragmites* and *Carex* which became very abundant from 440 to 436 cm. The same macroscopic fragments were also seen in the peat layer from 436 to 400 cm and were also found in the overlying carse deposits from 390 to 385 cm.

The buried beach deposits contained high counts of Cyperaceae and, to a lesser extent, Gramineae which, together with pollen of *Artemisia*, *Armeria*, Caryophyllaceae, Compositae, Chenopodiaceae and *Plantago maritima*, indicate the presence of saltmarsh vegetation which grew on the beach in the vicinity of this site (Fig. 3). This pollen dies out in the overlying peat layer in which counts of Gramineae and Cyperaceae remain relatively high, suggesting that the diminution of marine conditions caused the saltmarsh to be replaced by freshwater grass and sedge communities. In the carse deposits Gramineae frequencies increase; this, together with small counts of *Artemisia*, Chenopodiaceae and *Plantago maritima*, indicates the re-establishment of saltmarsh vegetation in response to rising sea level.

The arboreal pollen frequencies (Fig. 4) indicate that the top of the buried beach deposits at this site was formed in pollen Zone IV. *Betula* counts are relatively high with low values of *Corylus*. *Ulmus* is represented by only one pollen grain while *Quercus* pollen is not represented at all in this zone. Cool climatic conditions at this time are inferred from the presence of *Betula nana* (identified by apparent pore characteristics), *Empetrum*, *Dryas* and *Thalictrum* pollen and spores of Lycopodiaceae and *Selaginella*. These, together

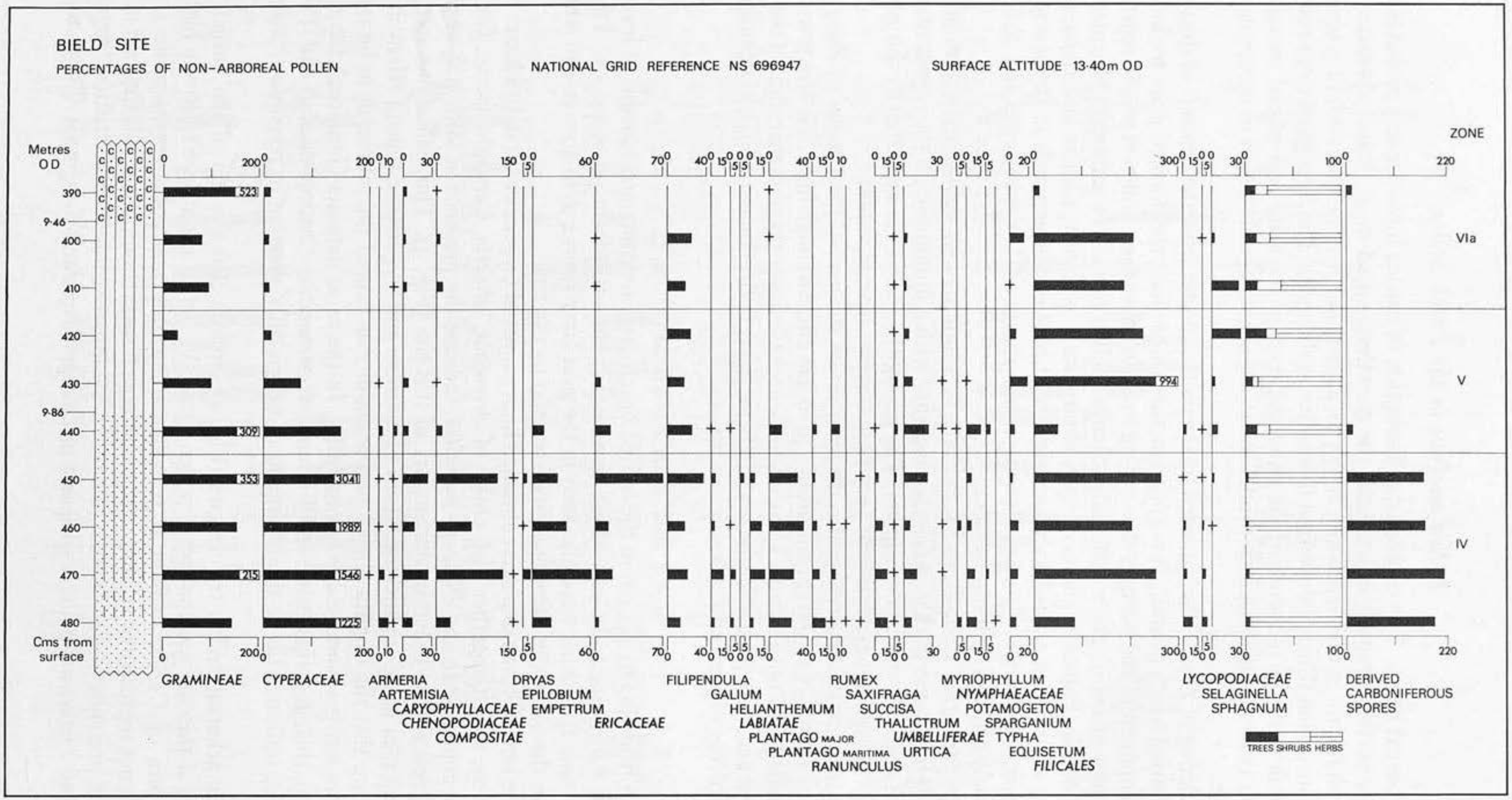


FIGURE 3. Non-arboreal pollen diagram for the Bield site

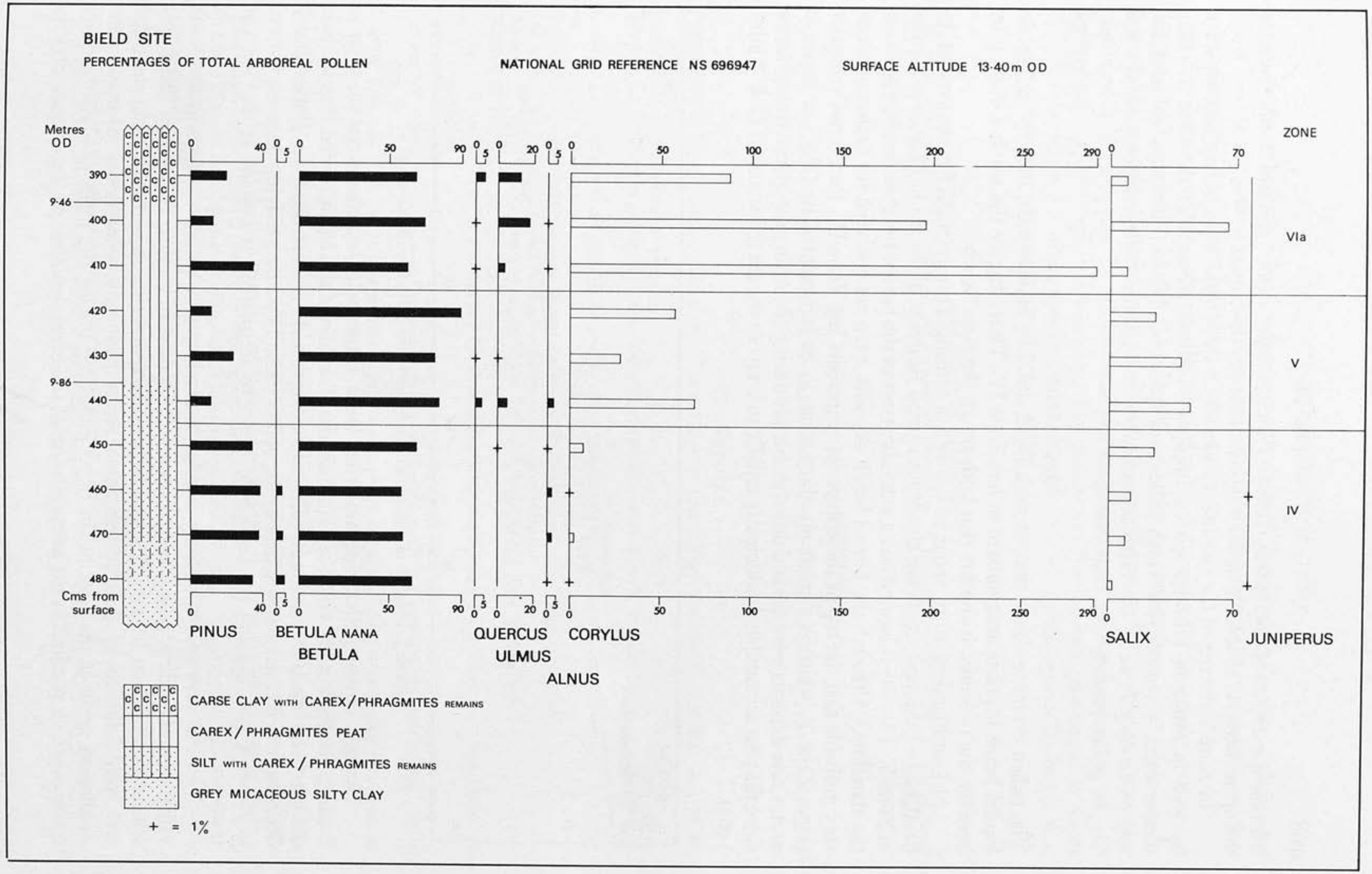


FIGURE 4. Arboreal pollen diagram for the Bield site

with the occurrence of *Filipendula*, *Galium*, *Plantago major*, *Ranunculus* and *Rumex*, indicate the open character of the vegetation that characterizes this zone.

In Zone V the rise of *Corylus* and, to a lesser extent, *Ulmus* and *Quercus*, accompanied by high increases in Filicales spores, imply a woodland advance in response to rising temperature, in accord with which pollen and spores of plants of mountain habitats disappear. In early Zone VI the expansion of *Ulmus* and *Quercus* pollen values continues and *Corylus* pollen reaches very high values.

DISCUSSION

The pollen evidence shows that, at both Bield and The Homesteads, the top part of the buried beach deposits accumulated in late Zone IV. Thus, despite the marked dislocation between the two sites, it appears that both are on the same beach.

At East Flanders Moss, about 16 km west of Stirling, Durno (1956) has shown that the basal part of the peat overlying the Main Buried Beach at about 10 m O.D. was formed in Zone V. This site is located on an extensive tract of the buried beach some distance from the shoreline.[1] Although the buried beach deposits were not analysed for pollen, it seems very probable that the top of these deposits represents late Zone IV, for Durno's diagram shows Zone V, which is a relatively short zone, to be represented by fully one metre of peat. Carse deposits were not laid down at this site during the main post-glacial transgression since the peat accumulated sufficiently rapidly to keep out the sea (Sissons and D. E. Smith, 1965).

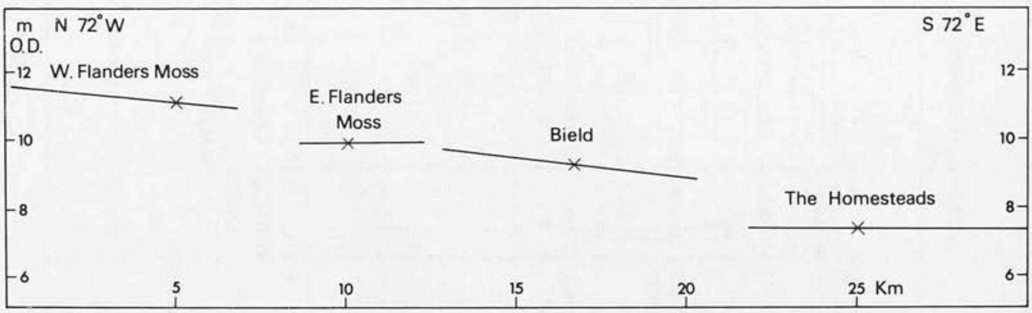


FIGURE 5. Location of pollen sites in relation to the Main Buried Shoreline

Newey's (1966) pollen diagram from West Flanders Moss, about 22 km west of Stirling, relates to a site about 0·5 km from the shoreline of the Main Buried Beach where the beach surface is at about 10 m O.D. His diagram shows that the Main Buried Beach deposits ceased to accumulate here at the end of Zone IV. The overlying peat was formed in Zones V and VIa and the carse mud began to accumulate at the site at the VIa/VIb transition.

Thus, at sites spaced at fairly regular intervals over a 20 km distance in the Forth valley west of Stirling, pollen analyses provide a consistent picture. At three of these sites, saltmarsh conditions have been shown to have existed as the sea withdrew from the beach and were followed by peat accumulation under freshwater conditions, saltmarsh later developing again as the sites began to be inundated during the main post-glacial transgression which resulted in the accumulation of the carse deposits. At these three sites the pollen evidence indicates that the buried beach deposits ceased to accumulate at the end of Zone IV. At the fourth site (East Flanders Moss) pollen evidence is incomplete but it is very probable that the beach ceased to form at this time.

The location of the four sites in relation to the Main Buried Shoreline is shown in Figure 5. The sites investigated by Durno and Newey, situated on the surface of the buried beach some distance from its shoreline, are marked at the appropriate shoreline positions on the diagram. It will be noted that each site is on a different section of this dislocated and variably uplifted shoreline. The conclusion from geomorphological evidence that the shoreline is a single synchronous (or approximately synchronous) feature is thus supported by the independent method of pollen analysis.

ACKNOWLEDGEMENTS

The writer acknowledges with gratitude the help in this research of Dr J. B. Sissons and Dr W. W. Newey of the Department of Geography, University of Edinburgh. He also thanks the Carnegie Trust for the Universities of Scotland for a grant towards the cost of illustrations.

NOTE

1. The National Grid Reference and the ground surface altitude of this site given by Durno (1956) are incorrect.

REFERENCES

BRINKMANN, P. (1934) 'Zur Geschichte der Moore, Marschen und Wälder Nordwestdeutschlands', *Bot. Jb.* 66, 369–445

CHAPMAN, V. J. (1964) *Coastal vegetation*

DONNER, J. J. (1957) 'The geology and vegetation of Late-glacial retreat stages in Scotland', *Trans. R. Soc. Edinb.* 63, 221–64

DONNER, J. J. (1962) 'On the post-glacial history of the Grampian Highlands of Scotland', *Commentat. biol., Soc. scient. fennica* 24, 5–29

DURNO, S. E. (1956) 'Pollen analysis of peat deposits in Scotland', *Scott. geogr. Mag.* 72, 177–87

FAEGRI, K., and J. IVERSEN (1964) *Textbook of pollen analysis* (Copenhagen)

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

GODWIN, H. (1956) *The history of the British flora*

MOAR, N. T. (1969) 'Late Weichselian and Flandrian pollen diagrams from south-west Scotland', *New Phytol.* 68, 433–67

NEWEY, W. W. (1966) 'Pollen analysis of sub-carse peats of the Forth valley', *Trans. Inst. Br. Geogr.* 39, 53–9

SISSONS, J. B. (1966) 'Relative sea-level changes between 10,300 and 8,300 B.P. in part of the Carse of Stirling', *Trans. Inst. Br. Geogr.* 39, 19–29

SISSONS, J. B. and D. E. SMITH (1965) 'Peat bogs in a post-glacial sea and a buried raised beach in the western part of the Carse of Stirling', *Scott. J. Geol.* 1, 247–55

RÉSUMÉ. *Analyse de pollen et le principal rivage enfoui à la partie occidentale de la vallée de la Forth.* On discute les diagrammes de pollen du principal rivage enfoui et les dépôts associés à deux emplacements à la partie occidentale de la vallée de la Forth et on les compare avec le témoignage de pollen des dépôts pareils à deux autres emplacements dans la même région. À trois de ces emplacements les dépôts enfouis de la plage ont cessé d'accumuler à la fin de Zone IV, tandis qu'au quatrième emplacement il est très probable qu'à cette époque la plage a cessé de former. L'analyse de pollen ainsi soutient le témoignage géomorphique en indiquant le caractère essentiellement synchrone de la dislocation et soulèvement varié du principal rivage enfoui.

FIG. 1. Diagramme de pollen non-arboricole de l'emplacement « The Homesteads »
FIG. 2. Diagramme de pollen arboricole de l'emplacement « The Homesteads »
FIG. 3. Diagramme de pollen non-arboricole de l'emplacement « Bield »
FIG. 4. Diagramme de pollen arboricole de l'emplacement « Bield »
FIG. 5. Situation des emplacements de pollen relativement au principal rivage enfoui

Zusammenfassung. *Pollenanalyse und der verdeckte Hauptstrand im westlichen Teil des Forthtals.* Pollendiagramme des verdeckten Hauptstrandes und damit verbundene Ablagerungen in zwei Bereichen im westlichen Teil des Forthtals werden diskutiert und verglichen mit Pollenbeweismaterial aus ähnlichen Ablagerungen in zwei anderen Bereichen in derselben Gegend. Auf drei dieser Stellen hörten die begrabenen Strandablagerungen am Ende der Zone IV auf sich anzuhäufen, während es sehr wahrscheinlich ist, dass in dem vierten Bereich der Strand sich zu dieser Zeit nicht mehr formte. Pollenanalyse unterstützt also das geomorphische Beweismaterial, dass anzeigt, dass die verstellte und unterschiedlich erhobene verdeckte Hauptstrandlinie ein wesentlich synchrones Charakteristikum ist.

Abb. 1. Nicht baumartiges Pollendiagramm für den Bereich der ‚Homesteads'
Abb. 2. Baumartiges Pollendiagramm für den Bereich der ‚Homesteads'
Abb. 3. Nicht baumartiges Pollendiagramm auf dem ‚Bield' platz
Abb. 4. Baumartiges Pollendiagramm auf dem ‚Bield' platz
Abb. 5. Stellen von Pollenlagen in Bezug auf die verdeckte Hauptstrandlinie

Dating of Early Postglacial Land and Sea Level Changes in the Western Forth Valley

J. B. SISSONS & C. L. BROOKS

Department of Geography, University of Edinburgh, High School Yards, Edinburgh EH1 1NR

Radiocarbon dates, pollen analysis and morphological and stratigraphic evidence relating principally to a small area in the western part of the Forth valley (central Scotland) enable a graph of relative sea level changes and hence land uplift to be drawn for that area.

Most of the radiocarbon dates, pollen analysis and morphological and stratigraphic evidence used in this communication relate to an area 16 to 23 km west of Stirling. The chief morphological feature is the large expanse of almost flat ground representing raised mud flats, known in Scotland as "carse". The termination of the carse against surrounding higher ground is the Main Postglacial Shoreline, which marks the limit of the principal postglacial marine transgression. Over considerable areas the carse is covered by thick peat.

The Menteith moraine, a complex arcuate feature 20 km long, encloses the western part of the carse (Fig. 1). Pollen analysis[1] and radiocarbon dating[2] show that the moraine was formed in pollen zone III.

Beneath the carse clay are three buried raised beaches, each of which is partly or almost entirely covered by a buried peat layer. These features, referred to as the High, Main and Low buried beaches, are distinguished from each other particularly on the basis of altitude and composition. Their distribution in the Forth valley is known in considerable detail from about 2,000 bores put down to investigate them[3–6]. The borehole information is especially detailed for the ground on either side of the Menteith moraine.

The altitude of point 1 (Fig. 2, 12.2 m OD) is the average of twenty-three measurements on the horizontal shoreline of the High Buried Beach immediately east of the Menteith moraine[5]. The beach does not occur inside the moraine, but its deposits partly rest on buried outwash gravel laid down by glacial meltwaters that cut a deep channel through the moraine. Thus the beach ceased to be formed after the moraine had been built up but before significant glacier decay had occurred. This implies that the beach ceased to accumulate at or shortly after the end of pollen zone III, that is, probably between 10300 and 10100 BP.

No radiocarbon date was obtained for the thin patchy peat layer that intervenes between the carse clay and the buried beach. This peat probably developed in response to the rising watertable associated with the later transgression of the carse sea, an interpretation supported by pollen analysis[6].

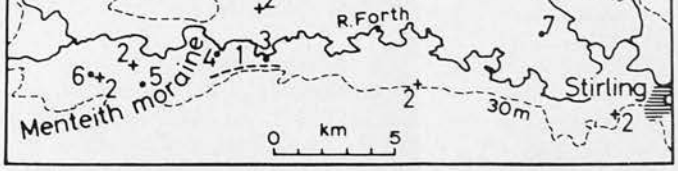


Fig. 1 Location of sites. +, Pollen sites; ●, pollen and radiocarbon sites; heavy broken line, buried raised shoreline forming site 1.

The altitude of point 2 (9.9 m) is the average of sixteen measurements of the Main Buried Shoreline where it is horizontal immediately east of the Menteith moraine. The uppermost deposits of the Main Buried Beach and the overlying peat have been analysed for pollen at two sites in the vicinity of the moraine and at two sites nearer Stirling[7,8]. At a fifth site near the moraine only the peat was analysed for pollen[9]. At all these sites regression of the sea from the beach at the end of pollen zone IV (standard system of zones) or at the IV/V junction is indicated.

No section showing buried peat resting on the Main Buried Beach has been found in the Forth valley. Radiocarbon dating of the peat has therefore not been attempted owing to the danger of sample contamination under pressure of the carse clay with the small borer available. If the zone IV/V boundary in the western Forth valley is approximately synchronous with the IV/V boundary dated at Scaleby Moss in northern England[10] it may be inferred that regression of the sea from the Main Buried Beach occurred about 9600 BP. This inference is supported by evidence from a section south of Perth, where peat shown by pollen analysis to have accumulated in the later part of pollen zone IV has a radiocarbon age of 9640 ± 140 BP (ref. 11).

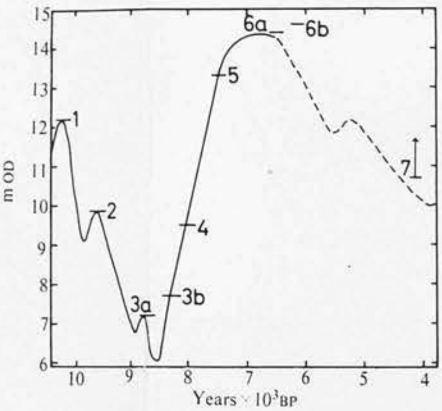


Fig. 2 Relative sea level changes at the Menteith moraine. For sites 3*a* to 7 horizontal lines extend one standard error either side of radiocarbon dates. Sites 1 and 2 based on other evidence and length of horizontal lines arbitrary.

Points 3*a* and 3*b* refer to a section (NS 630960) showing the upper part of the Low Buried Beach deposits, overlain by peat 50 cm thick which is, in turn, covered by 5 to 6 m of carse clay. Pollen analysis and macroscopic plant remains indicate that salt-marsh conditions characterized the final stages of accumulation of the buried beach deposits, that the marine regression that followed was accompanied by the development of freshwater swamp which was subsequently replaced by birch woodland, and that later transgression associated with the deposition of the carse clay resulted in the re-establishment of salt-marsh vegetation[7]. The basal 2 cm of the peat (7.2 m OD) gave a radiocarbon age of 8690 ± 140 BP (ref. 3). Regression of the sea from the now buried beach very shortly before that date is implied (3*a*, Fig. 2). The top 1 cm of the peat has a radiocarbon age of 8270 ± 160 BP (ref. 3) and dates the subsequent marine transgression across the peat at this point (3*b*, Fig. 2).

At point 4 (NS 631961) a section shows several metres of carse clay merging rapidly downwards at its base into a thin peat layer. That the peat formed in response to the rising water table associated with the transgression of the carse sea is suggested by its composition, for it consists chiefly of remains of *Phragmites* and *Carex*. Pollen analysis revealed high frequencies of pollen of Gramineae and some very high values for Cyperaceae (897% of the arboreal pollen count in one sample) along with limited quantities of Chenopodiaceae. The top 2 cm of the peat (9.5 m OD) has a radiocarbon age of 8010 ± 130 BP and this dates the transgression of the carse sea over the peat at this point.

Point 5 is located near the edge of the carse where the carse clay is thin. An excavation (NS 582952) exposed 64 cm of carse clay merging downwards into a 12 cm clay/peat transition; this, in turn, merged into 25 cm of peat, the whole resting on fluvioglacial gravel of the moraine system. A marked peak in pollen of Cyperaceae occurred at the top of the peat and in the lower part of the peat/clay transition, which corresponded to a very pronounced maximum of pollen of Gramineae (641% of the arboreal pollen count in one sample). Pollen of Chenopodiaceae appeared near the top of the peat and increased constantly in amount upwards to attain 24% of the tree pollen count at the base of the carse clay. This evidence points to a rising sea level associated initially with freshwater marsh and subsequently with salt-marsh conditions. A sample from the peat/clay transition (13.3 m OD) gave a radiocarbon date of 7480 ± 125 BP, which records the time of marine transgression at this point.

Points 6*a* and 6*b* relate to one of a series of boreholes put down in West Flanders Moss. At the site investigated in detail (NS 560955) the top 15 to 20 cm of the carse clay contained remains of *Carex* and *Phragmites*, which became abundant upwards as the carse clay faded out and finally disappeared. These deposits were covered by 4.25 m of peat. Pollen of Gramineae was plentiful in the carse clay, but this pollen dropped abruptly to very low values in the overlying peat. On the other hand, pollen of Chenopodiaceae, counts of which amounted to 25% of the arboreal pollen count in the carse clay where it contained few plant remains, diminished in quantity upwards as the macroscopic remains of *Carex* and *Phragmites* became abundant, and disappeared completely just before the carse clay faded out. Since the carse surface in this area accords with the maximum of the main postglacial marine transgression, this evidence apparently records the culmination of the rise in sea level and the beginning of the regression with salt-marsh being replaced by freshwater marsh and this in turn by the accumulation of *Sphagnum* peat.

Samples for pollen and radiocarbon dating at site 6 were obtained with a Hiller borer with 50 cm chamber. A sample from the basal peat (14.4 m OD) gave a date of 6490 ± 125 BP. The sample was obtained by putting down more than thirty closely spaced bores and taking from the bore chamber in each case only a narrow (~ 1 cm) central band of peat from the lowest 10 cm of the peat layer. Despite these precautions we were concerned about the possibility of contamination from higher levels in the peat and an additional sample 20 cm higher in the bores was therefore dated. This sample consisted of wood from a branch or trunk of birch (10 cm thick) and contamination during boring is very unlikely. The radiocarbon date obtained was 6135 ± 105 BP in accord with the lower date.

The arboreal pollen at site 6 suggests that the zone VI/VIIa transition occurs at or very close to the clay/peat junction. Within a vertical interval of 10 cm, *Pinus* pollen drops from 63% to less than 1% of the total tree pollen while *Alnus* pollen rises from 4 to 95%. The VI/VIIa transition was dated at Scaleby Moss as ~ 7400 BP (ref. 10). This date does not accord with the two radiocarbon dates for site 6. The correspondence of the VI/VIIa boundary with an important stratigraphic change suggests possible over-representation of *Pinus* in the carse clay because of marine transport. A second possibility is that peat growth did not begin immediately the carse clay ceased to accumulate. A third possibility, in our opinion the most likely, is that the zone VI/VIIa boundary is much later at site 6 than at Scaleby Moss. (At a site in north-west Scotland the *Alnus* expansion occurred about 1,000 yr later than at Scaleby Moss[12].) The radiocarbon dates for site 6 are therefore considered acceptable and it is inferred that by 6490 ± 125 BP sea level had begun to fall from its postglacial maximum.

The final point (No. 7) in Fig. 2 relates to an excavation (NS 749965) made through 2.5 m of surface peat down to the underlying carse clay. Samples for radiocarbon dating and pollen analysis were taken from the bottom 2 cm of the peat. The former gave an age of 4120 ± 105 BP whereas the latter showed no evidence of salt-marsh vegetation (W. W. Newey, personal communication). The pollen evidence suggests that peat accumulation did not immediately follow deposition of the carse clay at this locality, an interpretation supported by evidence published 175 years ago when peat clearance was in progress[13]. Very large trees were described as lying at the base of the peat, their roots usually standing in the underlying carse clay. Felling of some trees by human agency is indicated by axe marks and wooden trackways were also seen. This clear evidence of man's activities is particularly interesting when the radiocarbon date for the site is compared with a date of 4020 ± 100 BP for the change from forest to blanket bog at a site in north-west Scotland, where the forest destruction is believed to have been anthropogenic[12].

It thus seems that at site 7 the date obtained for the basal peat does not date marine regression. The sea fell below 10.7 m OD (the altitude of the carse surface here) at least sufficiently long before 4120 ± 105 BP for large trees to grow.

The transgression peak shown in Fig. 2 at point 1, which marks the culmination of a major rise of sea level, is based partly on evidence from elsewhere in the Forth valley[4]. Local evidence that the High Buried Beach marks a transgression maximum is the complete absence above its shoreline of the distinctive pink/brown highly micaceous deposits of which it is composed. Similar reasoning in relation to the distinctive light grey highly micaceous deposits comprising the Main Buried Beach accounts for the minor transgression (amplitude unknown) marked at point 2. Evidence of transgression is not available for point 3*a* but a transgression is shown because it is more probable than a relative still-stand of land and sea.

The trough between points 3*a* and 3*b* relates to the time when the sea was restricted to the well-marked buried channel of the Forth[3]. The amount of regression is unknown but it was at least sufficient to eliminate marine influence from site 3 and permit birch forest to grow.

The culmination of the principal postglacial transgression is marked as having occurred slightly before the date given by the lower of the two radiocarbon dates for site 6 because the dated basal peat lacks pollen evidence of marine influence. The later oscillations in the curve tentatively relate to visible raised shorelines below the Main Postglacial Shoreline[14].

The accuracy of the curve, of course, depends on the reliability of the dates used, but it will be noted that the dated points appear consistent with each other. Among other factors that might affect the validity of the curve, two will be considered. One of these is compaction, which is due almost entirely to peat compression by overlying sediments, especially the carse clay. The only point in Fig. 2 seriously affected by compaction is 3*b*, which relates to the top of a peat layer clearly compressed by the overlying carse clay. Marine transgression at point 3*b* occurred at a level higher than that shown on the graph.

The other factor is isostatic tilting of the land consequent on deglaciation. The principal sites on which Fig. 2 is based were intentionally selected from a small area to minimize isostatic complications. The only principal point located well away from the main group is point 7. As isostatic tilting in the Forth area is generally towards a direction south of east, the altitude of point 7 is too low in relation to the other points and an arrow in Fig. 2 indicates the probable amount of correction.

While the present investigation has been in progress, it has been found that the Main Buried Shoreline is dislocated at the Menteith moraine; it is 1 m lower just outside the moraine than immediately within it[5]. Because the altitudes of points 1 to 4 in Fig. 2 are based on evidence outside the moraine and points 5 and 6 are based on evidence within it, these two parts of the curve are not exactly comparable. The Main Postglacial Shoreline is essentially horizontal over a distance of 7.5 km that includes the moraine (seventy-three shoreline measurements giving a gradient of 0.008 m km^{-1} down valley). Thus the 1 m dislocation of the Main Buried Shoreline was produced before the culmination of the main postglacial transgression. It seems reasonable to infer that, because the dislocation was associated with isostatic recovery from glacial loading, it was formed chiefly (or entirely) in the earlier part of the 3,000 yr period available.

The Main Postglacial Raised Shoreline in the Forth valley has usually been considered to be about 5,500 yr old on the basis of a radiocarbon date in West Flanders Moss (situated east of the Menteith moraine), where wood peat from 10 to 12 cm above the surface of the carse clay gave a date of 5492 ± 130 BP (ref. 15). The evidence given above indicates that the shoreline is about 1,000 yr older than this. The revised age of the feature accords with evidence from near Leuchars in north-east Fife, where it has been shown that the transgression culminated between 7605 ± 130 BP and 5830 ± 110 BP (ref. 16).

The curve shown in Fig. 2 reflects essentially the interaction of isostatic uplift and eustatic sea level changes. The descent of the curve before about 8500 BP means that land uplift exceeded world sea level rise. The small reversals of this trend may relate to glacial readvances in North America and/or Scandinavia, but speculation about possible correlations seems unwarranted at present. But the pronounced reversal at about 8500 BP that initiated a transgression of 7 m in 1,000 yr implies rapid melting of the two great ice-sheets, causing eustatic sea level rise to overtake the isostatically rising land. In this context it is significant that Bryson *et al.*[17] believe that in Canada "catastrophic ice disintegration" followed the Cockburn Readvance. This readvance is considered to have reached its maximum between 8500 and 8000 BP. On the basis of Fig. 2 a date of 8500 BP seems probable.

The rapid reduction in the rate of sea level rise as the maximum of the postglacial transgression was approached, subsequently followed by regression, indicates that by this time decaying ice sheet remnants were contributing much less water to the oceans and the isostatic factor became dominant again.

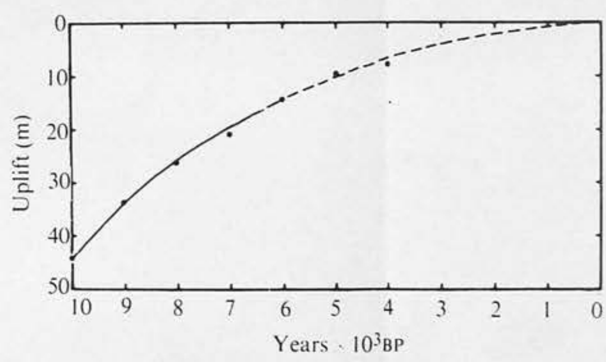


Fig. 3 Land uplift at the Menteith moraine during the past 10,000 yr.

In Fig. 3 the isostatic component has been plotted separately, land uplift at 1,000 yr intervals being determined from Fig. 2 in conjunction with published evidence on eustatic sea level changes. Initially a series of separate curves was drawn, each curve combining the evidence in Fig. 2 with the published eustatic data given by a particular author. Certain curves were rejected because (*a*) they were markedly divergent from the majority, or (*b*) they indicated reversals of isostatic uplift, or (*c*) they were based on evidence from areas of significant subsidence. The curves not rejected, using data from five sources[18–22], were then averaged and the result is reproduced in Fig. 3, the curve being extended to the present day. (In making the calculations 2 m was subtracted from the total for isostatic uplift at each point to take into account the fact that the data in Fig. 2 relate to high water mark.)

Although the uplift curve shown in Fig. 3 owes its smoothness partly to the elimination of aberrant eustatic data, the fact that such a curve can be drawn at all encourages the belief that the original data on which this communication is based have some validity.

We thank Dr W. W. Newey and Mr J. M. Gray for commenting on the draft of this article.

Received November 8, 1971.

[1] Donner, J. J., *Trans. Roy. Soc. Edinburgh*, **63**, 221 (1957).
[2] Sissons, J. B., *Scot. J. Geol.*, **3**, 375 (1967).
[3] Sissons, J. B., *Trans. Inst. Brit. Geog.*, **39**, 19 (1966).
[4] Sissons, J. B., *Trans. Inst. Brit. Geog.*, **48**, 19 (1969).
[5] Sissons, J. B., *Trans. Inst. Brit. Geog.* (in the press).
[6] Kemp, D. D., thesis, Univ. Edinburgh (1971).
[7] Newey, W. W., *Trans. Inst. Brit. Geog.*, **39**, 53 (1966).
[8] Brooks, C. L., *Trans. Inst. Brit. Geog.* (in the press).
[9] Durno, S. E., *Scot. Geog. Mag.*, **72**, 177 (1956).
[10] Godwin, H., Walker, D., and Willis, E. H., *Proc. Roy. Soc.*, B, **147**, 352 (1957).
[11] Callow, W. J., and Hassall, G. I., *Radiocarbon*, **12**, 181 (1970).
[12] Stuiver, M., *Radiocarbon*, **11**, 545 (1969).
[13] Sinclair, J., *Old Statistical Account of Scotland* (Edinburgh), **17**, 51 (1796); **18**, 102 and 320 (1796).
[14] Smith, D. E., *Z. Geomorph.*, **12**, 388 (1968).
[15] Godwin, H., and Willis, E. H., *Radiocarbon*, **4**, 57 (1962).
[16] Chisholm, J. I., *Bull. Geol. Surv. Great Brit.* (in the press).
[17] Bryson, R. A., Wendland, W. M., Ives, J. D., and Andrews, J. T., *Arct. Alp. Res.*, **1**, 1 (1969).
[18] Godwin, H., Suggate, R. P., and Willis, E. H., *Nature*, **181**, 1518 (1958).
[19] Shepard, F. P., in *Essays in Marine Geology*, 1–10 (University of Southern California Press, 1963).
[20] Schofield, J. C., *NZ J. Geol. Geophys.*, **7**, 359 (1964).
[21] Moran, J. M., and Bryson, R. A., *Arct. Alp. Res.*, **1**, 97 (1969).
[22] Morner, N.-A., *The Late Quaternary History of the Kattegatt Sea and the Swedish West Coast* (Stockholm, 1969).

Printed in Great Britain by Flarepath Printers Limited, Watling Street, Colney Street, St. Albans, Herts.