THE STRATIGRAPHY AND CHRONOLOGY OF LATE QUATERNARY RAISED COASTAL DEPOSITS IN RENFREWSHIRE AND AYRSHIRE, WESTERN SCOTLAND

VOLUME ONE

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SUMMARY

Despite the breadth of research in sea-level change and coastal evolution during Quaternary times in Scotland, certain parts of the coast have been largely neglected in recent years. One such area comprises the Renfrewshire and Ayrshire coasts of the Clyde Estuary and the Firth of Clyde. The work presented here partially rectifies this omission. Late Quaternary coastal history in two areas, one around Linwood (Renfrewshire) and the other between Irvine and Kilmarnock (Ayrshire), has been studied, using a multi-disciplinary approach.

At Linwood Moss -- a fragment of formerly more extensive peat overlying inorganic raised coastal deposits -- peat and pollen stratigraphy is studied in three cores. A late Flandrian history of local vegetation is established and the results of the stratigraphical analysis, together with data derived from a field survey of sedimentary exposures and a theoretical model to aid discussion, are used to construct a model which relates local patterns of peat stratigraphy to patterns of sea-level change, coastline movement and marine deposition during the Flandrian Age. An approximate position of the shoreline of the so-called "Linwood-Paisley Embayment" is suggested, indicating the extent of the middle Flandrian marine transgression in this area. Earlier suggestions regarding the stratigraphy in this area are reviewed and certain palaeotidal consequences are discussed.

In the Irvine-Kilmarnock area, a wider-ranging approach is used to establish a stratigraphical and chronological model for change of sea level and coastal environment since Late Devensian deglaciation in the area. A sedimentological study indicates that during the Flandrian Age the shoreline remained in approximately the same location, that is c. 1 to 2 km inland from the present shoreline. This suggestion is reinforced by stratigraphical and palynological investigations at Shewalton Moss -- a major peat body on raised coastal deposits -- which indicate that earlier views regarding the extent of the Flandrian marine transgression require to be revised. Sedimentological, micropalaeontological and geomorphological analyses provide input for a coastal-change model for the Late Devensian sub-age and the results of further stratigraphical, sedimentological, palaeontological and palynological research refines the model provided for coastal change during the last 15,000 years. The model is presented as a series of maps representing the coastal palaeogeography at certain periods, especially in relation to contemporaneous sea level. A generalized sea-level curve is also presented, and the entire model is discussed within the context of previous models for the same area and existing models for other areas in Scotland. The model suggests palaeoenvironmental conditions which contribute significantly to Mesolithic archaeological interpretation in the area. The feedback from archaeology and radiocarbon analysis provides independent support for certain parts of the model.

In synthesis, suggestions for further work are made, and discussion is concentrated on concepts used and developed within the research.

CHAPTER 1

INTRODUCTION

1. Aims of the work and general background

"There is, in fact, more than one coastline of Scotland" (Steers, 1973, p.xii). This statement refers, amongst other things, to the widespread presence of remnants of older, presently-raised, shorelines which lie along the margin of the present coastline. Around Scotland, the present and former coastal forms vary greatly, and it is perhaps appropriate, therefore, that the study of coastal development and the history of former coastlines, is also varied. Researchers have taken distinctive, individual approaches and, perhaps as a consequence, the geographical setting of investigation is not spread evenly around the long Scottish coastline. One stretch of coastline not studied in detail during recent years, lies in those parts of Renfrewshire and Ayrshire which border the Clyde Estuary and the Firth of Clyde. Although work was undertaken there during the last century (see references in Chapters 2.1 and 9.1) a detailed study, based on modern methods of research and expressed within the framework of modern terms and concepts, has not yet been provided for this readily-accessible area. It is the aim of this work to provide such a study.

The Ayrshire and Renfrewshire coastline contains many elements of the total that comprises the spectrum of coastal forms around the entire Scottish coastline: sheer rock cliffs at the Heads of Ayr; raised marine-cut solid-rock platforms at Lendalfoot and around Great Cumbrae; wide, flat expanses of raised coastal sediments around Irvine, Ayr and Paisley. The greatest changes in the past configuration of the coastline have occurred in the latter situation. In these places, during Quaternary times, the shoreline may have lain several kilometres inland from its present position, and in character the shore may have been very different from that at present. Not only have such areas already undergone the greatest palaeogeographical changes, but, given an unrealised potential global rise of sea level of at least 50 m (Tooley, 1978b, p.1), these areas may undergo considerable future change. Since the coastal zone tends to be an important location and focus for urban, industrial and agricultural development, the importance of past and future geographical change cannot be under-estimated. Two such areas, around Linwood (Renfrewshire) and between Irvine and Kilmarnock (Ayrshire) (Fig. 1.1), have been chosen for detailed study. Emphasis is placed on the past, and former shorelines and coastal environments have been reconstructed.

2. Physical setting

Linwood area. The area studied at Linwood lies approximately at the centre of a sub-circular basin-like area of low-lying terrain. The basin is c. 8 km in diameter and the land surface lies at c. 6-9 m A.O.D. and to 12-13 m A.O.D. where peat occurs. Surrounding this low-lying area on three sides is higher ground with subdued local relief, rising to around 150 m A.O.D. At present, the drainage pattern is radial, the dominant drainage direction being north-easterly towards the River Clyde. Without modern, artificially-produced drainage and peat clearance, the Linwood area would probably be a moderately extensive, poorly-drained and inhospitable region of raised bog. Remnants of peat lie on raised marine deposits consisting mostly of slightly fossiliferous, clay-rich sediments. On the surrounding hills, and probably beneath the raised marine sediments, glacial till is extensive, frequently forming drumlins, which are aligned approximately west to east. In places their upper parts project above the marine sediments and presumably were islands during former periods of high sea-level. The underlying bedrock, part of the Glasgow syncline, consists of faulted Carboniferous Coal Measures.

Irvine to Kilmarnock area. The area studied around Irvine is part of a crescent-shaped expanse of raised, mostly sandy beach deposits, about 10 km long (north-south) and to 5 km wide. To the west lies the Firth of Clyde and to the east higher ground (to c. 100 m A.O.D.) with subdued local relief. The surface of the raised beach deposits, generally lying at 8-12 m A.O.D. but rising inland to c. 30 m A.O.D., is overlain in places by sand dunes and peat, the most notable area of peat being Shewalton Moss. The main rivers are the Garnock Water (flows from the north) and the River Irvine. The latter flows westwards in a valley whose floor lies below 30 m A.O.D. for about 10 km between Kilmarnock and the coast, and in which raised beach deposits are commonly present. The raised beach deposits in this entire area generally lie on or against glacial deposits, consisting mostly of till. Drumlin-like forms, aligned approximately N.E. to S.W. are common. The underlying solid rocks are Carboniferous Coal Measures, forming part of the Kilmarnock synclinal basin, and generally overlain by superficial Quaternary deposits. Also present are various igneous rocks, which are more frequently exposed than the sedimentary rocks. The important igneous rock body in the study area is a teschenite sill forming high ground (to 105 m A.O.D.) and a cliff at Hillhouse. The cliff marks the south-eastern boundary of the study area. The northern boundary is defined approximately by a line extending eastwards from Irvine, the western boundary by the sea, and the eastern boundary by the landward limit of Quaternary raised coastal deposits.

3. Organisation of the thesis

The results of research presented in this thesis are contained in two volumes. Volume 1 (this volume) consists of the text, and Volume 2 of appendices, in particular those containing long tables and all the figures.

The text is divided into three main parts. In Parts A and B the research undertaken in the Linwood and Irvine-

Kilmarnock areas respectively is described and discussed. Part C is a synthesis of the research. In Parts A and B, a review of previous work in the respective areas is presented, followed by discussion of the problems to be discussed. Different approaches were taken in the two areas, and therefore the structures of Parts A and B differ.

Research at Linwood, initiated by the study of a core provided by the Institute of Geological Sciences (I.G.S.), concentrates on the use of data from terrestrial sediment (peat) in the elucidation of the position of a former shoreline. Part A consists, therefore, although not exclusively, of discussion of palynological data. The final chapter (Chapter 8), in which a tentative model for changes in sea level and shoreline position is proposed for the region, concentrates on discussion and theoretical considerations.

Since the work in the Irvine-Kilmarnock area is more extensive than that at Linwood, covering a larger geographical area, a longer time-span and a wider approach, Part B is correspondingly longer. The results of research are presented in thematic units which generally correspond to the order of investigation. Following this presentation and discussion of the wide range of evidence, the final chapter (Chapter 19) contains a proposed model for post-glaciation history of changing sea level and coastal environment in the Irvine-Kilmarnock area.

Late additions to the text are the results of radiocarbon analyses. Radiocarbon dates were not available by the time the final draft of the thesis had been written (early August 1982) and therefore are discussed at the end of the relevant chapters (Chapters 8 and 19). It should be noted that the dates have not been used in the construction of the models presented in the thesis, but are used as independent sources of support for the models.

4. Stratigraphical nomenclature

Post-glaciation stratigraphy. The thesis is concerned with the study and interpretation of sediments deposited during the last part of the Quaternary sub-Era. The problems of Quaternary stratigraphy are complex and controversial, and are discussed in numerous papers elsewhere (cf. Jardine, 1972, 1981a; Terasmae, 1972; Mitchell et al., 1973; Mangerud et al., 1974; Gray & Lowe, 1977; Holland et al., 1978; Hyvärinen, 1978; Lowe & Gray, 1980). No attempt is made here to discuss the problems or to resolve them, but it is necessary to explain the terms that are used (informally) throughout the thesis.

The beginning of the time interval involved in this study is the time at which the ice of the Late Devensian ice sheet began to melt in western central Scotland, i.e. c. 15,000 B.P. (cf. Price, 1975). The scheme of nomenclature used in the thesis is shown in Table 1.1. The Windermere Interstadial (spanning the interval c. 15,000 B.P. to 11,000 B.P. and with stratotype at Lake Windermere) is taken as defined by Coope & Pennington (1977). The term "Loch Lomond Stadial" is used in the broadest sense, as equivalent to the Younger Dryas Chronozone of N.W. Europe (Mangerud et al., 1974), and correlative with stratigraphical units described elsewhere by several authors (e.g. Jardine & Peacock, 1973; Jardine, 1981a; Lowe & Gray, 1980). The term "Loch Lomond" is preferred to "Younger Dryas", being a commonly-used British term. The end of the Loch Lomond Stadial is taken as 10,000 B.P., the date selected by the INQUA Holocene Commission as the beginning of the Holocene Epoch (and therefore the beginning of the Flandrian Age or Interstadial; cf. Bowen, 1978, p.106). In Britain the boundary between the Loch Lomond Stadial and the Flandrian Interstadial appears to represent a moderately synchronous major environmental change (Coope & Pennington, 1977).

The Late Devensian Glacial spans the interval between c. 26,000 B.P. and 10,000 B.P. (Shotton, 1973), and the term "late Late Devensian" is used informally to denote the combined units of the Windermere Interstadial and the Loch Lomond Stadial.

Table 1.1 Stratigraphical nomenclature used in this thesis

<table>
<tr><th>Radiocarbon years BP</th><th colspan="3">Climatostratigraphical units</th><th colspan="3">Equivalent Geological time units</th></tr>
<tr><td>0</td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>10,000</td><td colspan="3">Flandrian Interglacial</td><td colspan="3">Flandrian Age</td></tr>
<tr><td rowspan="2">11,000</td><td>Loch Lomond Stadial</td><td rowspan="2">late Late Devensian Glacial</td><td rowspan="3">Late Devensian Glacial</td><td>Loch Lomond sub-age</td><td rowspan="2">late Late Devensian sub-age</td><td rowspan="3">Late Devensian sub-age</td></tr>
<tr><td>Windermere Interstadial</td><td>Windermere sub-age</td></tr>
<tr><td>c.15,000</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

The conversion from climatostratigraphical units to equivalent geological time units follows the practice suggested by Holland et al., (1978), although the use of the informal term "sub-age" (cf. Harland et al., 1972) is preferred to that of "chron". The terms "early", "middle" and "late" are also used informally where necessary. Following Jardine (1981a) the "correct" phrase "sub-age of the Windermere Interglacial" is abbreviated, for convenience, to "the Windermere sub-age", and similar terms are abbreviated likewise.

Zonation of the pollen diagrams. The zonation of pollen diagrams has been discussed by Birks (1973, pp.273 ff). For purposes of discussion, the pollen diagrams presented in this thesis are divided into smaller biostratigraphical units, which are mostly assemblage biozones and, in some cases, acme biozones, as defined by Holland et al., (1978). These units are called "local pollen zones" (abbreviated in this thesis to L.P.Z.). The term "zone" is used, following standard Quaternary palynological practice (e.g. Pennington, 1970; Birks, 1973; Stewart, 1979; Dickson, 1981), in place of the more correct term "biozone" (Holland et al., 1978; cf. West, 1980, p.10). Also following standard practice, the zones are defined according to entire palynomorph assemblages, rather than strictly on the pollen assemblages. Local zones are defined for each diagram, and no attempt has been made to define regional pollen assemblage zones. The zones have been defined according to observed palynomorph stratigraphy, and they carry no ecological implications.

5. Methods

The methods used in the course of this research, both in the field and in the laboratory, are governed largely by the form of evidence found during initial fieldwork.

Pollen analysis is used partly for palaeoenvironmental reconstruction but largely as a dating tool. Sampling and preparation follow standard techniques (Faegri & Iversen, 1975, pp. 85 ff; Birks & Birks, 1980, ch. 8; Moore & Webb, 1980, ch. 3). Detailed description of the analysed cores follows Troels-Smith (1955) and Birks & Birks (1980, ch. 3). Most of the sediment properties are estimated by eye, except for the following: elasticity (sample squeezed between fingers); humicity (sample dissolved in cold sodium hydroxide and colour observed; reference is also made to the supernatent colour from the pollen analysis preparation); calcareous content (reaction of hydrochloric acid on sample); contents (sample dissolved in water and examined under a low power - x 8 and x 32 - microscope). Details of abbreviations used in the Troels-Smith descriptions are given in Chapter 1.6 and in Appendix 2.

Other methods, such as the description of sediment exposures and geomorphological features, are discussed when they first occur in the text.

6. Fossil identification and nomenclature

Identification of pollen and spores follows the keys of Faegri & Iversen (1975) and Moore & Webb (1980), the descriptions of Andrew (1980) and the slide collection of recent pollen held in the Department of Botany at Glasgow University. The following reference literature was also used: Iversen & Troels-Smith (1950), Jessen *et al*., (1959), Oldfield (1959), Beug (1961), Erdtmann *et al*., (1961, 1963), Fredskild (1967), Moe (1974) and Punt (1976).

The nomenclature of most of the pollen and spore taxa follow Moore & Webb (1980), except for the Caryophyllaceae species (following Faegri & Iversen, 1975) and the Ericales, Compositae, *Rumex* and *Plantago* species (following Andrew, 1970, 1980, pers. comm.), and the nomenclature of several other miscellaneous taxa also follow these authors: *Juniperus*, *Drosera* and *Hypericum* (Faegri & Iversen, 1975); *Caltha palustris*, *Hydrocotyle vulgaris*, *Jasione montana*, *Sorbus aucuparia* and Filicales (Andrew, 1970, 1980). Identification and nomenclature of *Anthoceras punctatus*, *Sphagnum tenellum* and *Tilletia sphagni* (Walker, 1948) follow Dickson (1973, pp.60 ff). Several taxa have been re-named in this work, being mainly agglomerated units: *Armeria* type (from *Armeria* type, A and B lines), Umbelliferae (from types 1, 2 and 3) and Rosaceae (undifferentiated) (cf. Moore & Webb, 1980); *Populus* (from *Populus tremula* and *P. balsamifera*) and Rubiaceae (from *Rubiaceae*)(cf. Faegri & Iversen, 1975). One taxon has been named following reference to the Glasgow University Botany Department slide collection: *Rumex cf. crispus*. The amalgamated *Corylus-Myrica* taxon has been named Coryloid (cf. coryloid, Godwin, 1975, p.269; Edwards, 1981). Identification and nomenclature of selected palynomorphs follow Van Geel (1978), Pals *et al.*, (1980) and Andrew (1970).

Plant macrofossils were identified under the direction of Mrs. C. A. Dickson, and by reference to a collection of fossil and recent plant remains held in the Department of Botany, Glasgow University. The following texts and keys were also used: Godwin (1956), Watts (1959), Körber-Grohne (1964), Nilsson & Helmqvist (1967), Ross-Craig (1967-1970), Clapham *et al.*, (1968), Dickson (1970), Jane (1970), Grosse-Braukmann (1972, 1974), Dickson (1973) and Kats *et al.*, (1977).

Nomenclature for plant names follows Clapham *et al.*, (1968), except for *Phragmites australis*. Following Haslam (1972), the more familiar name, *P. communis*, is used. This is in accord with current Quaternary botanical usage (cf. Birks, 1973; Godwin, 1975, p.400).

Other fossils discussed in the text were identified using the following texts: Graham (1971), Campbell & Nichols (1976), Tebble (1976) (Molluscs); Whatley *et al.*, (1971), Abou-Ouf (1974) (foraminifers and ostracods); Neeves (1961), Playford (1962), Sullivan (1964), Sullivan & Marshall (1966), Felix & Burbridge (1967), Smith & Butterworth

(1967), Hibbert & Lacey (1969) (Carboniferous microspores). The nomenclature used follows these texts.

7. Introductory notes

Several terms and abbreviations used in the thesis are explained or defined below:-

Altitudes and elevations -- These are described as being above Ordnance Datum (A.O.D.) or below Ordnance Datum (B.O.D.), where Ordnance Datum is mean sea level at Newlyn, Cornwall. Several positions of the surface of the sea are abbreviated: high and low water marks of spring tide (H.W.M.S.T. and L.W.M.S.T., respectively) and mean tide level (M.T.L.).

Units of measurement -- S.I. units of length used are metres (m), kilometres (km, equivalent to 10^3 m), millimetres (mm, equivalent to 10^{-3} m), microns (µm, equivalent to 10^{-6} m). Where original measurements are presented in feet (ft), the values are converted to metres using 1 m = 3.281 ft. The unit of mass used is the kilogramme (kg, equivalent to 10^3 grammes).

"Radiocarbon dates" -- Several dates from other literature sources are quoted. These are labelled according to the laboratory in which the age determinations were made. Following standard practice, all radiocarbon ages quoted in the text are given in radiometric years before present (years B.P.; where present is AD 1950) calculated on the basis of the Libby half-life of radiocarbon (5,568 $\pm$ 30 years; Godwin, 1962). Exact ages are quoted plus or minus ($\pm$) one standard deviation, i.e. there is a 66% chance that the age lies within the range stated.

Institutions -- The following institutions are referred to by abbreviation: The Institute of Geological Sciences (I.G.S.); International Union for Quaternary Research (INQUA); Ordnance Survey (O.S.).

Locations and directions -- Reference to specific locations include the use of National Grid References (Nat. Grid Ref.). In several cases, directions are abbreviated (N., E., S.W., etc.).

Cores, local pollen zones and pollen and macrofossil data presentation -- cores collected and analysed in the course of this work are named after the site name, year of collection, and, if necessary, core number (e.g. SM-81-I = Shewalton Moss, 1981, core I). Local pollen zones (L.P.Z., plural L.P.Z.s) also follow this scheme (e.g. SM-81-I.1, etc.). Troels-Smith units are labelled simply (e.g. T.S. 1) for each core. Pollen values are expressed as percentages of total pollen or pollen plus pteridophyte spores (stated in text) or as percentages of total arboreal pollen (A.P.). The frequency of macrofossil remains is described on a nominal five-point scale, from absent to abundant or very abundant. For plant names the following abbreviations are used: sp., species (singular); spp., species (plural); subg., subgenus.

<u>Lithothamnium</u> -- The convention and abbreviations used are discussed and explained in Chapter 12.4, and follow Bosence (1976) and Sneed & Folk (1958).

Electrical resistivity survey -- The convention and abbreviations used are standard (cf. Parasnis, 1979), and are discussed and explained in Chapter 13.3.

Chemical formulae -- The following chemical formulae are used: NaCl, sodium chloride; $Na_4P_2O_7$, sodium hypophosphate; HF, hydrofluoric acid. pH denotes degree of acidity.

Reference abbreviations -- In references in the text to items of literature, several abbreviations are commonly used: cf., confer, compare (with); <u>et al.</u>, <u>et alia</u>, and others (authors); p, page; pp, pages; ff, following; ch., chapter; fig., figure; pers. comm., personal communication.

Standard abbreviations -- The use of i.e., e.g. and etc. follows common practice, and <u>c.</u>, <u>circa</u>, indicates approximation.

Changes of sea level -- All references to changes of sea level are to relative changes of sea and land level, rather than to absolute (eustatic) sea-level changes.

Sediments -- All the sediments discussed are unconsolidated and uncemented unless otherwise stated. The terms used to describe the principal size grades of the sediments - gravel, sand, silt and clay - are used informally, but following standard practice (cf. Jardine, 1980, p.5). Descriptions of sediments of the form "silty sand with clay" denote a sediment composed, in this example, predominantly of sand with a lesser amount of silt (say 20-40%) and a minor amount of clay (say less than 20%). Again such terms are used informally.

Terminology of the Troels-Smith sediment descriptions -- The use of this terminology is discussed in Troels-Smith (1955), Tooley (1978, pp.10 ff.) and Birks & Birks (1980, pp.39 ff.). To standardize the stratigraphical descriptions, the scheme for the description of sediments proposed by Troels-Smith (1955) has been used for most of the cores or sections of cores for which pollen analysis has been undertaken. For the terminology used in this thesis, see Appendix 2.

Tables and figures -- Short tables are included within the text, numbered, for example, "Table 16.1", i.e. table 1 for chapter 16, and long tables are included in Appendix 3 (Volume 2) and are numbered, for example,"A.16.1". All the figures are contained in Appendix 4 (Volume 2) and are numbered, for example, "Figure 16.1".

PART A:

LINWOOD AREA

CHAPTER 2

LITERATURE REVIEW AND INTRODUCTION

1. Early work

During the 19th century there were frequent reports of exposures of fossiliferous clay and sand from the Glasgow and Paisley areas (Smith, 1836, 1838a; Bennie, 1867a, b; Crosskey, 1867a; Crosskey & Robertson, 1867, 1871b, 1874; Brady et al., 1874; Fraser, 1874; Robertson & Crosskey, 1874; Scott, 1888; Blair, 1893). The fossils were often recognised as marine or brackish water in nature and were used to deduce former changes in climate (Smith, 1839b; cf. Robertson, 1877a) from "arctic" conditions, represented by the so-called "Clyde Beds" (Smith, 1839a, c, d) containing ice-rafted boulders (Jamieson, 1865) and what was considered as an "arctic" fauna (Brady et al., 1874; cf. Benson, 1969), to warmer conditions similar to those of today (Robertson, 1877b; Scott, 1888). Environments of deposition were considered to have changed from marine to brackish water and in some cases to freshwater conditions (Crosskey, 1867b; Robertson, 1877c; Neilson, 1906). These changes, which in places appeared to be relatively rapid (Smith, 1838a), and the range of altitude at which the sediments were found, were used to deduce former fluctuations of sea level, although the actual mode of sea-level change was under some debate. Sudden, rapid and irregular changes in sea or land levels (Smith, 1838a; Crosskey, 1867b) were regarded as probable by Bell (1874) who proposed a model of gradually falling or rising sea level, similar to models established in the last two decades (Jardine, 1982). Little work was undertaken to establish a physical picture of the coastline during the periods of high sea level (or land submersion) although a series of successively lower terraces in the Glasgow city area was interpreted as a series of successively younger "sea benches" (Dougal, 1867) and the undulating former sea floor was described from commercial borelog data (Bennie, 1871).

Although marine sediments were recorded up to a maximum elevation of 102 ft (c. 31 m) A.O.D. in central Glasgow (Robertson, 1879) and to 73½ ft (c. 22.5 m) A.O.D. near Paisley (Blair, 1893), the clays were most frequently found up to c. 60 ft (c. 18 m) A.O.D. They were interpreted as having been deposited by what was termed the "100 ft" (c. 30.5 m) sea (Clough et al., 1911, p.190, 1925, p.231; Anderson, 1947).

2. The Late Devensian marine transgression

Recently two main problems have been investigated. The first concerns the Late Devensian marine inundation of the Glasgow-Paisley area. Although a few new Clyde Bed sites have been discussed (Jardine & Moisley, 1967; Aspen & Jardine, 1968; Brett & Norton, 1969; Jardine, 1973a), the highest level at which recently-described marine sediments occur is c. 25 m A.O.D. (Mitchell, 1952; Jardine, 1969). This altitudinal marine limit, in combination with a proposed area of stagnant ice in the Glasgow area during deglaciation, has been interpreted as representing marine inundation of the area at a time after sea level had begun to fall from the Late Devensian marine maximum (Sissons, 1974a, b, 1976a). However, consideration of the pattern of deglaciation (Price, 1975) and radiocarbon ages of the fauna of the marine clay (Peacock, 1971; Browne et al., 1977) suggests that the early Late Devensian marine inundation of an ice-free Glasgow and Paisley area may have been from the south-west, through the "Lochwinnoch Gap" (Ward, 1977, 1980). This suggestion is supported by evidence of high-level (c. 34 m A.O.D.) beach gravel at Old Kilpatrick lying east of an ice front (Rose, 1975, 1980), an alternative to Mitchell's (1952) interpretation of sediments at Garscadden which suggests a marine limit at

c. 33.5 m A.O.D. (Anderson & Simpson, 1952; Rose, 1975), and possible evidence from sites elsewhere (Browne, 1980).

3. The Flandrian marine transgression

The second problem regards the limits of the Flandrian marine transgression. This is the problem investigated in this thesis.

Despite a limited distribution of Flandrian raised coastal sediments mapped by the Geological Survey (cf. Jardine, 1971, fig. 3), a series of radiocarbon age determinations (Table 2.1) for material from sites at or near Linwood Moss, about 5 km inland from the limit of the mapped raised coastal sediments, suggests that an extensive area may have been inundated by the sea during the Flandrian marine transgression.

The sediments in the Linwood area have been interpreted (Jardine, 1971, p.112; Bishop & Coope, 1977, pp. 72 ff.) as representing the following events:

(1) Deposition, prior to c. 12,650 B.P., of a great thickness (to 21 m) of dark blue-grey clay containing cold-water marine fauna.

(2) Marine regression, leading to the emergence of the clay surface and, after c. 9,231 B.P., the growth of peat on that surface at an altitude near c. 12 m A.O.D.

(3) Continuation of marine regression and fall of sea level to a level lower than 3.55 m A.O.D., at which level wood, dated at c. 8,039 B.P., was deposited in fluvial sediments.

(4) Marine transgression, sea-level rise and deposition of up to 6 m of unfossiliferous silt, to a maximum altitude of at least 8 m A.O.D., during middle Flandrian times.

(5) Marine regression and fall of sea level, followed, at c. 3,550 B.P., by peat growth at c. 8.2 m

Table 2.1 Radiocarbon dates from the Linwood Moss area

Location	Sample No.	Description of sample, height AOD and author	Radiocarbon age
Linwood Moss NS 439 664	Birm-2	Wood from base of peat overlying grey silt. 26.9 ft (8.2 m) A.O.D. Shotton *et al.*, 1967.	3,572 ± 64 B.P.
Clippens Farm NS 433 654	Birm-3	Wood in basal level of peat. 40 ft or 12.22 - 12.60 m A.O.D. Shotton *et al.*, 1967, Bishop & Coope, 1977.	9,231 ± 96 B.P.
Wester Fulwood NS 432 669	Birm-4	Wood from bed of black, unsorted sand with gravel and abundant organic material. *c.* 11 ft (3.35 m) A.O.D. Shotton *et al.*, 1967.	8,039 ± 128 B.P.
Linwood Moss NS 439 664	Birm-13	Peat from base of peat overlying grey silt. 26.9 ft (8.2 m) A.O.D. Shotton *et al.*, 1968.	3,513 ± 56 B.P.
Wester Fulwood NS 432 669	Birm-122a	Inner portions of large valves of *Arctica islandica*, in marine clay. 3 m A.O.D. Shotton *et al.*, 1970.	12,650 ± 200 B.P.
Wester Fulwood NS 432 669	Birm-122b	Outer portions of large valves of *Arctica islandica*, in marine clay. 3 m A.O.D. Shotton *et al.*, 1970.	13,020 ± 220 B.P.

A.O.D. on the exposed silt surface.

Recently (1980) an I.G.S. core at Linwood Moss yielded the bore log shown in Table 2.2. The two thin inorganic layers present within the peat were thought to represent (M.A.E. Browne, pers. comm.) a middle Flandrian double marine transgressive event, similar to that recorded in Loch Lomond (Dickson et al., 1978). The core is described in greater detail below (Chapter 3).

Evidence of complex interactions between conditions of deposition of marine inorganic sediments and of terrestrial peat in the Linwood area prompted Browne (1980, p.13) to suggest the following possible circumstances: (a) the extensive flat areas lying between c. 6 and 9 m A.O.D. are remnants of a surface, in older, Late Devensian estuarine deposits, that was eroded, perhaps during the time of the formation of the "Main Late-glacial shoreline" (Sissons, 1974a, b); (b) during the Flandrian marine transgression, the presence of Linwood, Barochan and Paisley peat mosses prevented access of the sea to most of the area that they now occupy.

Clearly the extent and significance of the middle Flandrian marine transgression in this area has not yet been fully established.

4. Problems in the interpretation of Flandrian stratigraphy and chronology in the Linwood area

Assessment of previous work done in this area is hampered by four main problems:

(1) The nature of the sediments. The thin cover of grey silt in this area which is thought to represent the Flandrian marine transgression (Jardine, 1971) is, by Bishop & Coope's (1977) interpretation, unfossiliferous; it has been described by the latter authors as "probably of fresh or brackish water origin" (p.72). Sea level in middle Flandrian times is thought to have risen above the

Table 2.2 Summary bore log from the I.G.S. core at Linwood Moss (NS 4459 6588)

Depth below surface (m)	Sediment type	Height A.O.D. (m)
0.00 - 1.76	peat	10.18 - 8.42
1.76 - 1.80	silty clay	8.42 - 8.38
1.80 - 2.66	peat	8.38 - 7.52
2.66 - 2.70	silty clay	7.52 - 7.48
2.70 - 3.50	peat	7.48 - 6.68
3.50 - unmeasured	unfossiliferous sand and silt	6.68 - ?

level at which the silt lies, and the surface of the silt has been interpreted as an erosion surface cut into Late Devensian sediments in middle Flandrian times (Bishop & Coope, 1977) or possibly earlier (Browne, 1980), or is a surface produced during the middle Flandrian transgression (Jardine, 1971).

(2) Radiocarbon dates. Some of the radiocarbon dates (Table 2.1) are of little relevance here. The Late Devensian dates (Birm-122a and b) are similar to others from fossiliferous clay at Gallowhill and Ralston, Paisley (Peacock, 1971), and indicate that the fossiliferous clay found throughout the Linwood-Paisley area is Late Devensian in age. This helps little in the elucidation of the Flandrian history. The other Wester Fulwood date (Birm-4) relates to allochthonous material within fluvial sediments. All that this date indicates is that at some time after c. 8,000 B.P., the base level (probably contemporaneous sea level) of the River Gryfe lay lower than c. 3.55 m A.O.D., as it does at present. The two dates from Linwood Moss (Birm-2 and 13), from wood and peat respectively, are statistically indistinguishable. Therefore, from the six dates available from the area, only two are of real use. They indicate that at two adjacent sites, Linwood Moss and Clippens Farm, initiation of peat growth occurred respectively at c. 3,550 B.P. and c. 9,230 B.P. It follows that, because of the uncertainties regarding the underlying inorganic sediment and its surface, these dates are related only to peat growth initiation, and not directly to sea-level changes. However, in this area of thick peat cover, it may be significant that there are at least two episodes of peat-growth initiation separated by nearly 6,000 years.

(3) Sites and records. The sites described by Bishop & Coope (1977) were all temporary in nature and it is no longer possible to examine them or samples from them. Also, commercial trial-pit records made around 1960 at these sites no longer exist, and newer records for nearby

sites suggest that the earlier records would have been of minimal use.

(4) Landforms. There appears to be no geomorphological expression of the middle Flandrian shoreline in the area. This may be for three main reasons: (i) Large areas have a cover of peat of irregular thickness which may mask any older surface features; (ii) features commonly caused by coastal erosion may not have been formed, erosion being minimal in a sheltered area such as this; (iii) there is uncertainty as to whether or not Flandrian marine and/or estuarine sediments are present. In the quiet-water environment probably occurring here, coarse-grained depositional coastal features, i.e. beaches, are expected to be absent.

5. Problems to be investigated and approaches taken

The four main questions to be answered here are:

(1) Is there evidence of Flandrian marine conditions as far inland as Linwood? If there is, then:

(2) What effects, erosive and/or depositional, did the marine transgression have? How does the marine transgression relate to sediment stratigraphy in the area?

(3) Can the chronology of the marine transgression be improved?

(4) Can the position of a middle Flandrian shoreline be defined?

The approach used is two-fold:

(1) Stratigraphical examination of cores from Linwood Moss. The peat and the underlying sediments were sampled. These cores provide dating and palaeoenvironmental information. The locations of sites investigated are shown on Figure 2.1.

(2) Description and mapping of exposures, especially where the peat base can be seen.

CHAPTER 3

LINWOOD MOSS, I.G.S. CORE (IGS-LMP-80)

1. Introduction

This core (Chapter 2.3; Table 2.2) was the first core from Linwood Moss to be analysed. It was collected from Nat. Grid Ref. NS 4459 6588. Although initially there is no evidence regarding the marine or non-marine nature of the two inorganic layers within the peat, closer examination of the core might yield such evidence and, if that evidence implied a marine origin of the clayey silt layers, pollen analysis would provide a general indication of the date(s) of the marine transgression(s).

This core is not very satisfactory. It was not collected by the writer, and it has not been analysed extensively. Above 1.35 m below the top of the core, a section of peat is missing, and below the basal clayey silt layer only a bulk sample of peat was retrieved. The peat had shrunk slightly by the time the writer received the core. The analysis of the core was designed as a preliminary examination only. Further cores were to be collected, depending on the results of the analysis of this core.

2. The results

Troels-Smith and macrofossil analyses. The results of a detailed Troels-Smith analysis are shown in Table A.3.1, and the results of the macrofossil analysis are shown in Figure 3.1. On the basis of the conclusions from the pollen analysis (Chapter 3.3) the basal clayey silt is regarded as the base of the core, and the basal bulk sample of peat, not being *in situ*, therefore was not examined for macrofossils.

Clayey silt layers. 10 mm thick samples were taken from these layers, cleaned and separated in hot water and hydrogen peroxide, wet-sieved through a 75 μm sieve, and examined for micro- and macro-fossils under a low power (x 8 and x 32) *Leitz* binocular microscope. The samples appear to be almost unfossiliferous, yielding a few unidentified plant macrofossils and one faunal specimen. The faunal specimen is a gastropod shell, identified as Cingula semicostata (Montagu), a member of the marine, but non-estuarine, Rissoidae family (Graham, 1971).

Although it is unwise to draw conclusions from such scanty evidence, a tentative marine origin for the upper clayey silt is suggested. Although the fossil may have been washed in with the inorganic sediment, alternatively such a small object may have been blown in; this latter interpretation implies a nearby source. Another possibility is that the gastropod may have been eroded from higher level Late Devensian fossiliferous clay and been redeposited in a freshwater or marine sediment. The evidence is inconclusive.

Pollen analysis. Due to uncertainty regarding the validity of the basal sample, the pollen frequency curves (Fig. 3.2) commence above the basal clayey silt. As the examination was only a reconnaissance survey, relatively few, widely-spaced samples were analysed. This is unsatisfactory, but the results of the pollen analysis confirmed the doubts regarding the reliability of the core, and further analysis was not undertaken. Due to the low number of samples and the wide spacing, division of the diagram into pollen assemblage zones perhaps is not justified. However, it provides a convenient structure for discussion, and since there are several major changes in the pollen spectra within the diagram, local pollen zones are defined. Unless otherwise stated, all values are percentages of total pollen. All recorded depths are depths below the top of the core (ground surface). The low degree of resolution of the diagram must be emphasised. The following pollen zones are recognised in Figure 3.2.

IGS-LMP-80.1 "Coryloid Local Pollen Zone"

Sample 3 (1 sample); below 2.76 m; basal bulk sample.

The main characteristic of this zone is the high Coryloid value (46%). Betula is common (16%) and Salix, Pinus, Alnus, Ulmus and Quercus are all present. Ericaceous pollen, including Calluna, is common (22%) and Gramineae (6%) and Cyperaceae (2%) are present. Sphagnum is very common (85%).

IGS-LMP-80.2 "Cyperaceae - Herb Pollen Local Pollen Zone"

Sample 2 (1 sample); 2.76 to 2.55 m; above top of basal silt.

The main characteristic of this zone is the abundant presence of Cyperaceae pollen (63%) and other herbs. Gramineae has a value of 26%, and Taraxacum and Cerastium types, Filipendula and Chenopodiaceae are present. Tree taxa, Betula, Quercus, Alnus, Pinus and Salix, are poorly represented (6% in total).

IGS-LMP-80.3 "Salix Local Pollen Zone"

Sample 8 (1 sample); 2.55 to 2.33 m.

The predominant feature of this zone is the high Salix value (54%). Betula (14%), Quercus, Pinus and Alnus are present. Gramineae, Filipendula and, especially, Cyperaceae make up 27% of the total pollen spectrum.

IGS-LMP-80.4 "Coryloid - Betula Local Pollen Zone"

Samples 7 to 5 (5 samples); 2.33 to 1.55 m; to top of the diagram.

This zone is characterised by high values of Coryloid pollen, which rise from 32% to 44%, having been virtually at zero in the previous zone. Betula has moderate values (44%) falling to c. 20%. Alnus and Pinus are present, rising to 8% and 6% respectively at the top, and Ulmus and Quercus have constant but minor presence. Salix maintains constant, low values (4%). Herb pollen values are low, with Calluna and Ericales having peaks (16% and 18% respectively) in the middle of the zone, on either side of the silt layer. Sphagnum is rising throughout this zone from 3% to 40%.

3. Discussion

Introduction. Useful discussion relating to the local pollen zones and the Troels-Smith analysis cannot be made due to large differences in the sampling intervals used in the two analyses. Some comments, however, regarding the macrofossil analysis are relevant. The main concentration of Betula macrofossils (fruits and fruit scales) occurs during the peak of Betula pollen. The other, unidentifiable tree remains (wood, bark, leaves and bud scales) have a similar but wider distribution, perhaps also originating from locally-growing Betula or perhaps Corylus. Ericaceous remains and burnt Calluna leaf and twig fragments are only present at the peaks in Calluna and Ericales pollen. Charcoal dust and burnt herb material are present throughout the diagram, except during the Salix peak. Menyanthes and Juncus conglomeratus/effusus seeds are present during the Salix L.P.Z. Although the Cyperaceae pollen values are low throughout the Coryloid - Betula L.P.Z., there is a peak of Eriophorum vaginatum macrofossils in this zone.

Coryloid Local Pollen Zone. This zone is based on one sample from the bulk sample. As such, it is unsatisfactory, and is discussed only briefly. The pollen is local in origin, with moderate to high values of such taxa as Coryloid, Erica, Gramineae, Sphagnum and Pteridium. The spectrum is very similar to that of two samples in the middle of the Coryloid - Betula L.P.Z.

Cyperaceae - Herb Pollen Local Pollen Zone. This zone is also based on one sample, taken from immediately above the silt-peat boundary. The pollen spectrum reflects local open vegetation, with high values of Cyperaceae, Gramineae and herb pollen and Juncus seeds, all of which are absent or less common later. Filipendula is the exception. A regionally open landscape is reflected by the minimal presence of tree taxa, with approximately equal amounts of Betula, Pinus, Alnus and Quercus (c. 1% each) probably representing minor regional presence of these trees. The charcoal macrofossils, where identifiable, consist of burnt twigs and especially burnt herb material. The latter is very similar to material found in peat immediately overlying inorganic sediments at Moss Cottage (Chapter 4.2).

Salix Local Pollen Zone. The pollen spectrum, again defined on the basis of one sample, is local in origin, with a moderate value of Cyperaceae and the important presence of Salix (54%). This is an entomophilous plant whose pollen must be regarded as local. The wood macrofossils, being more common here, probably are derived from the locally-growing Salix. The damp conditions suitable for Salix are reflected by the 2% value for Filipendula pollen and the presence of Menyanthes macrofossils. Betula values are beginning to rise but other tree taxa are still only sparsely represented. Values for these regional components are probably depressed by the high Salix values, and the filtering effects of locally-growing Salix will also reduce the input of non-local pollen at the site.

Coryloid - Betula Local Pollen Zone. The high values of Coryloid pollen and slightly lower Betula values, together with abundant macrofossils, suggest that the spectra of this zone represent local Betula-Corylus woodland. The increasing values for the tree taxa, Alnus, Pinus, Quercus and Ulmus, towards the top of the diagram suggest that these species are becoming more common locally and regionally. The local woodland was probably moderately damp, there being evidence of, first, Eriophorum vaginatum and, later, Sphagnum and Filipendula growing at or near the site. Immediately above and below the silt layer are peaks in Calluna and Ericales pollen curves. These may reflect the slightly more open vegetation prior to and after deposition of the silt. In this silt layer the single specimen of Cingula semicostata was found, indicating, albeit very tentatively, marine conditions. Reliable indicators of salt marsh vegetation are absent. However, coastal heath, forming for a short period during the marine transgression, may be represented by the peaks in the ericaceous pollen taxa.

The age of the peat. Certain features in the pollen curves suggest an early Flandrian age. Very low values of Quercus, Pinus and Ulmus, the last occurring from only midway through the Coryloid - Betula L.P.Z., are typical of early Flandrian patterns. Also, whereas the succession suggested from the Cyperaceae - Herb Pollen L.P.Z. upwards, can be explained purely in terms of local vegetational development from locally open to closed conditions, the initial regional openness implies early Flandrian conditions, and the local development follows early Flandrian patterns established elsewhere (e.g. Donner, 1957; Vasari & Vasari, 1968; Lowe & Walker, 1977; Walker & Lowe, 1977; Robinson, 1981, pp. 77 ff) in which, following open herb-dominated vegetation, temporary expansions of shrubby plants such as Juniperus, Empetrum and Salix occur. Although these expansions are widely recognised, they may have been of moderately local significance only. These were followed initially, by local expansion, and later, by regional expansion of Betula. At this site, the bare outlines of such a vegetational development are present. The succession of local pollen zones from the Cyperaceae - Herb Pollen L.P.Z. through the Salix L.P.Z. to the Coryloid - Betula L.P.Z. is based on such coarse sampling that a feature such as an Empetrum peak could easily be missed. The coarse sampling is also responsible for the gradual rise in Coryloid values. This rise represents the Corylus rise which is normally more abrupt, and which may have occurred shortly after the Salix peak. At the top of the diagram, a less certain trend is discernible. The Alnus rise at some sites is associated with a semi-synchronous temporary rise in Pinus values (Donner, 1957; Walker, 1975; Stewart, 1979; Robinson, 1980, pp. 84 ff). At the top of this diagram, both Alnus and Pinus curves are starting to rise, indicating a possible uppermost age immediately prior to the Alnus rise.

The vegetational developments outlined above strongly suggest an early Flandrian or even a late Late Devensian age for the peat above the lower silt layer. If this is so, it is highly improbable that the bulk sample, supposedly from below the basal silt (M.A.E. Browne, pers. comm.) is *in situ*. The pollen spectrum from the bulk sample bears little resemblance to any early Flandrian or Late Devensian spectrum from elsewhere, as its supposed stratigraphical position demands that it should. Furthermore, this spectrum bears such close similarity to two spectra in the middle of the Coryloid - *Betula* L.P.Z. that these two zones must be contemporaneous. The basal (bulk) sample is therefore regarded by the writer as not being *in situ*, and it is not used further in this stratigraphical study. The revised succession is shown in Figure 3.3. Since the lowest, *in situ* peat appears to be early Flandrian, the basal silt must, at least, be very early Flandrian or possibly Late Devensian in age.

The coarse sampling makes the exact location of significant fluctuations in the pollen curves difficult to establish. However estimated locations for the *Corylus* and *Alnus* rises, together with interpolations from Birks' isochrone maps (1980, fig. 53), allow very crude estimation of the age of the peat: the base is around 10,000 to 10,500 years old, a point about one third of the way up the diagram (*Corylus* rise) is *c*. 8,800 years old, and the top of the pollen diagram is older than *c*. 7,000 years old. These "ages" indicate an approximately constant rate of peat accumulation of *c*. 0.4 mm/year, which is consistent with peat-accumulation rates elsewhere (Hibbert *et al*., 1971; Aaby & Tauber, 1974; Godwin, 1975, p.35). The upper silt layer, by extrapolation, may be dated at *c*. 8,000 B.P.

4. Conclusion

The peat core, unsuitable as it is, represents early Flandrian peat accumulation at the site, with a possible marine transgression at around 8,000 B.P. In view of the poor core sampling, future work must be continued on freshly-collected cores.

CHAPTER 4

MOSS COTTAGE CORE (MC-80)

1. Introduction

The first of two cores collected to replace the IGS-LMP-80 core was obtained using a "Russian" corer (Jowsey, 1966), from Nat. Grid Ref. NS 4440 6610, and analysed for pollen and spores up to 0.20 m from the top. There is no indication of a thin inorganic layer within the peat as in the IGS-LMP-80 core. After initial analysis, it became apparent that the peat base is considerably younger than that in the IGS-LMP-80 core. Ground surface at the site was instrumentally levelled, and lies at 10.265 m A.O.D.

2. Results

Pollen analysis. The results of the pollen analysis are shown in Figure 4.1. All depths are below ground surface, and percentages are of total pollen unless otherwise stated.

For the purposes of discussion, the following pollen assemblage zones are identified.

MC-80.1 "Carboniferous Spore Local Pollen Zone"

Samples 15 and 16 (2 samples); below 2.98 m; within the silt underlying the peat.

This zone is unusual, in that it is based entirely on allochthonous secondary microfossils. Quaternary pollen and spores are very scarce (Table 4.1). There are present, however, many pre-Quaternary spores which are often indistinct. It is not the purpose of this work to systematically describe pre-Quaternary spores so only a brief discussion of them is given here. It is assumed that the spores are Carboniferous in age, since the surrounding solid rocks at the site consists mainly of Carboniferous strata, and the glacial till in the area is derived largely from these rocks and from highland metamorphic and igneous rocks.

From a survey of the literature on Carboniferous

Table 4.1 Moss Cottage, Linwood Moss; MC-80: Quaternary pollen and spores recorded in Samples 15 and 16

p = present, - = absent

	Sample 15	Sample 16
Pinus	p	-
Quercus	p	p
Alnus	-	p
Coryloid	p	-
Betula	p	-
Gramineae (24 μm diam.)	p	-
Sphagnum	p	p
Filicales	-	p
Polypodium	-	p
Total grains per slide	7	8

spores, tentative identification is provided for four spores present (Table A.4.1). Spore A is common in both samples 15 and 16, B is common in sample 15, and C and D are present, but scarce, in both samples.

MC-80.2 "Gramineae - *Quercus* Local Pollen Zone"

Samples 21 to 18 (5 samples); 2.98 to 2.56 m; most of T.S. units 2, 3 and 4 (Chapter 4.3), the silt and clay with organic detritus.

This zone is characterised by high Gramineae (35-50%) and *Quercus* (9-16%) values. The latter values are the highest for *Quercus* throughout the diagram. *Alnus* (14-24%) and Coryloid (10-15%) are common, whereas *Betula* (2-6%) and *Ulmus* (*c.* 1%) are less so. Although Cyperaceae has values of 6 to 12%, other herbs are generally scarce; *Sphagnum* values are less than 4% and total pteridophytes provide less than 10%. The basal boundary for this zone is where pollen begins to become plentiful, and Carboniferous spores decline in their dominance. Despite this, there is still constant presence of Carboniferous spores, with values of mostly 10 to 12%.

MC-80.3 "*Alnus* Local Pollen Zone"

Samples 17 and 12 (2 samples); 2.56 to 2.36 m.

The base of this zone is where most curves show sharp sudden declines, but where *Alnus* increases sharply to 70%. Gramineae values are low, lying at *c.* 13%, and all trees are poorly represented (e.g. *Betula* at *c.* 5%). Other herbs, *Sphagnum* and pteridophytes are also poorly represented, and Carboniferous spores are no longer present.

MC-80.4 "*Betula* - *Alnus* - Coryloid Local Pollen Zone"

Samples 23 to 24 (5 samples); 2.36 to 2.03 m.

This zone is characterised by less dominance by a single taxon than occurs in the previous zone. There is some fluctuation in the general proportions, but the main taxa are *Betula* (*c.* 40%, rising from 26% at the beginning, and falling to 30% at the end), *Alnus* (*c.* 23%, falling from 38% and rising to 29%) and Coryloid (around 17%). *Quercus* is constantly present, and *Pinus* and *Ulmus* are sporadically present. Gramineae (*c.* 6%, rising to 12% at the end), Cyperaceae(*c.* 4%) and pteridophytes are present, and other herbs become progressively more common (1 to 4%) throughout this zone.

MC-80.5 "*Betula* - Coryloid - Herb Local Pollen Zone"

Samples 31 to 27 (7 samples); 2.03 to 1.68 m.

Betula values are generally high (24-46%) during this zone, although in one sample a value of 13% is recorded. Coryloid shows a slight average increase, with values ranging up to *c.* 38%, and *Alnus* shows a decline to c. 12%. Other trees have low values, either being constantly present (Quercus, Pinus and Salix) or sporadically present (Ulmus and Fraxinus). Gramineae (3-10%) and Cyperaceae (2-10%) have low values, although, in one sample, Cyperaceae peaks to 22%. The distinctive curves in this zone are those for other herbs. These curves fluctuate, with three main peaks of high values. From the base upwards, they are (1) (Sample 10) Rumex acetosa (11%) with Plantago lanceolata, Filipendula, Rumex acetosella (1% each) and other herbs, (2) (Sample 11) R. acetosa (6%) with P. lanceolata, Urtica (3% each) and Filipendula (1%), and (3) (Sample 27) Menyanthes (15%). Following the first two peaks are massive increases in Sphagnum (1 to 72% and 15 to 192% respectively), the latter occurring during the Menyanthes peak. Following the first peak, there is also a Cyperaceae peak (22%) and two peaks (to 10% each) in the Gramineae curve. Throughout this zone, pteridophyte values are moderately low (1-6%) and there is a constant presence of Amphitrema flavum (to 5%) and Assulina seminulum and Copepoda spermatophores (to 1% each).

MC-80.6 "Calluna Local Pollen Zone"

Samples 26 to 5 (6 samples); 1.68 to 0.90 m.

The base of this zone is where the Calluna curve rises rapidly from 5 to 22%. At the same place, the herbs, except Gramineae and Cyperaceae, fall from 17 to 1%, and Quercus and Alnus have small peaks (7% and 19% respectively). The zone is characterised by high Calluna values (to 30%) and the lowest A.P. values in the entire diagram. Betula declines from 22% to a steady value around 6%, Quercus remains low (4%), Alnus has moderate values (12-14%) changing little from the previous zone, and Coryloid is falling to 11% from a maximum of c. 25% at the end of the previous zone. The other trees (Pinus, Ulmus, Fraxinus and Salix) all have minor, sporadic presence. Cyperaceae has fluctuating values (6-38%), but the few other herbs are generally scarce.

MC-80.7 "Sphagnum - Betula Local Pollen Zone"

Samples 4 to 1 (4 samples); 0.90 m to the top of the core (ground surface).

At the base of this zone, Calluna values fall sharply from 30% to 13%, and then average 9% throughout the zone. Together with this change is an increase in A.P., mostly reflecting the rise in Betula values from 5% to 15%, thereafter having an average value of c. 18%. The high Sphagnum values (40-293%) are also typical of the zone, having risen sharply (to 125%) at the end of the previous zone. Quercus and Coryloid values are variable, whereas Alnus shows a steady decline (15% to 7%), and Pinus, Ulmus, Fraxinus and Acer are only sporadically present. Gramineae has steady values around 10% and Cyperaceae values are c. 15% in the lower half of the zone and c. 42% in the upper half. Other herbs are few and scarce, and pteridophytes are uncommon (c. 3%) except at the top, where there is a peak of 36%.

Macrofossil and Troels-Smith analyses. The results of the T.S. analysis of the core are shown in Table A.4.2. The major peat compositional changes closely correlate with the L.P.Z. boundaries, suggesting that the pollen zones defined above represent local vegetational conditions. One exception occurs near the base of the peat, where the *Alnus* L.P.Z. occurs mainly within herb peat (T.S. 5) which contains only occasional woody detritus; despite the very high *Alnus* values, *Alnus* was not growing directly at the site.

The general features of the macrofossil analysis results (Fig. 4.2) correspond with the main T.S. unit boundaries. Of particular note are the *Juncus* macrofossils in the lowermost T.S. units (1 to 5), the tree macrofossils in the woody herb peat layers (T.S. 6 to 9), *Calluna* remains in T.S. 11 to 13, and *Sphagnum* remains in the uppermost units (11 to 16).

In the lower part of the diagram, most of the charcoal consists of very fine, unidentified fragments although, especially in the lowest part (T.S. 2 to 4), larger fibrous fragments appear to be burnt, non-wood, non-grass organic material. In one sample at the base of T.S. 4, many fragments appear to be coal. Prompted by the probable presence of coal, the fibrous charcoal was compared with fusain, a type of coal formed from mineralised charcoal (Pettijohn, 1957, p.491). Throughout Renfrewshire and the Glasgow area are many exposures of coal seams, and it is possible that these supplied eroded material which resembles recent charcoal. Examination of fusain fragments ruled out such a source for the fibrous charcoal. The same conclusion was reached in relation to similar material found in a similar stratigraphical position at Flanders Moss (Table A.5.1; Fig. 5.1) and in the IGS-LMP-80 core (Chapter 3.3). Despite the predominance of non-wood charcoal in the lower part of the Moss Cottage core, there are two records of wood charcoal and one of a burnt *Calluna* leaf. This contrasts with the upper half of the core, in which, despite the presence of much fine, unidentified charcoal dust, there are almost continuous records of burnt *Calluna* twigs and leaves. Given the lack of tree macrofossils here, it is assumed that other, unidentified twig charcoal is also burnt *Calluna*. There is a notable lack of charcoal in the middle of the diagram.

The tree macrofossils are concentrated in the central section of the core, coinciding with the *Betula* - *Alnus* - Coryloid and *Betula* - Coryloid - Herb L.P.Z.s. The most common identified remains are those of *Betula* species. Both for *Betula* and other tree species in the lower zone, there tends to be fruit, wood, twigs and bark remains, whereas in the upper zone there are tree leaves, bud scales and *Betula* fruits, fruit scales, catkins and catkin scales. This distribution may indicate that in the *Betula* - Coryloid-Herb L.P.Z. trees were present at the site rather than at a short distance from it as earlier, and their roots and fallen branches contributed to the lower wood macrofossils. The general scarcity of tree remains in the *Alnus* L.P.Z. confirms the previously suggested non-local nature of *Alnus*.

The ericaceous macrofossils, mostly from *Calluna*, occur during the peaks in the *Calluna* pollen curves.

All the *Juncus* remains are seeds, many identified as *J. maritimus* and, more frequently, *J. conglomeratus*/*effusus*. They occur almost entirely at the base of the core in the basal herb peat and inorganic layers. Of note is the maximum presence of *Juncus* during the *Alnus* L.P.Z.

There are small amounts of *Eriophorum* macrofossils, mostly spindles from *E. vaginatum* and larger fragments of the plant with spindles in position. These occur throughout the middle parts of the core, being especially common where other indicators of damp conditions (e.g. *Menyanthes* pollen and *Sphagnum* spores and macrofossils) are common.

Sphagnum remains, leaves, stems and opercula, are present in the upper part of the core where *Sphagnum* is the major peat-forming component. *Sphagnum* remains also occur sporadically elsewhere in the core. In the *Betula* - Coryloid - Herb L.P.Z. *S.* subg. *Litophloea* reaches maximum values where the other *Sphagnum* taxa are absent or only poorly represented.

3. Discussion

Carboniferous Spore Local Pollen Zone. The spectrum of this slightly anomalous zone clearly reflects the allochthonous nature of the basal silt, the Carboniferous spores representing inwash material from the surrounding area.

Gramineae - Quercus Local Pollen Zone. The main feature of this zone is the abundant presence of Gramineae pollen. The Gramineae pollen grain size frequency distribution for four of the five samples in this zone (Fig. 4.3) indicate normal distributions around means of 24 to 26 µm, suggesting that much of the pollen may be included in Faegri & Iversen's *Phragmites* type (1975, p.245). The significance of Gramineae grain size is discussed in greater detail elsewhere (Chapter 11.3). Although several grasses provide pollen of a similar size, much of the Gramineae pollen probably represents *Phragmites communis*. The Gramineae grains are in much better condition than those of any other taxon, and bundles of grains are also present. The lack of Gramineae macrofossils suggests an adjacent source rather than one directly at the site. The *Juncus* seeds, pteridophyte spores, Cyperaceae pollen and much of the other herb pollen probably originated from a similar site. A few herb taxa, such as *Glaux* and *Lychnis* type, indicate possible coastal conditions, whereas others, such as *Filipendula* and *Potamogeton* provide evidence of a nearby damp environment.

Quercus and *Ulmus* pollen is probably regional, the larger than usual regional values, especially for *Quercus*, resulting from the extremely open nature of the site. Betula and possibly Corylus and Alnus must have occurred close to the site, although probably further away than the grasses, sedges and rushes discussed above. The pollen from the tree taxa are either very poorly preserved, presumably due to being washed to the site or, as in the case of Coryloid and Alnus, very fresh, presumably having been blown to the site. Betula is sufficiently close to provide inwashed macrofossils which, in the process of transportation, have been damaged sufficiently to allow identification only to the "Betula sp." level.

The predominant allochthonous nature of the sediment is reflected in the continued, if lesser, presence of Carboniferous spores and the poorly-preserved and, in some cases, severely eroded grains.

This pollen zone represents allochthonous deposition, probably under marine conditions, at or near to coastal reedswamp, slightly further from damp woodland, at a time when the regional vegetation was dominated by Quercus woodland.

Alnus Local Pollen Zone. This pollen zone probably represents a site very close to dense Alnus woodland. The Gramineae grain sizes (Fig. 4.3) again tentatively suggest the presence of Phragmites. The macrofossil remains of Juncus spp., Sphagnum and Menyanthes also indicate that within this zone herb peat was deposited at a moderately open marshy site. The presence of J. maritimus seeds suggests that the site lay at or immediately above the contemporaneous H.W.M.S.T. Although the high Alnus values suggest nearby presence of Alnus (cf. Andersen, 1967; Tinsley & Smith, 1974; Caseldine & Gordon, 1978; Caseldine, 1981), Betula, represented in low numbers by poorly preserved grains, was probably growing in the area further away from the site than Alnus. The more regional components, Quercus, Pinus and Ulmus, have declined in values, perhaps suggesting that the Alnus woodland is close enough to effectively filter the regional pollen rain. Alternatively, in a relative diagram such as this one, the high values of Alnus cause a depression of values of other components. The autochthonous nature of the peat is reflected in the absence of Carboniferous spores.

Betula - Alnus - Coryloid Local Pollen Zone. This zone represents the development of damp woodland, perhaps dominated by Betula, but with Alnus and Corylus common. Although conditions remain damp -- Filipendula, Menyanthes, Potamogeton, Chrysosplenium, Assulina seminulum, Copepoda spermatophores and Sphagnum are present -- there are also indications of increasing dryness. These are rises in the curves of Gelasinospora spp. and Cenococcum geophilum and the increasing degree of humification. The vegetation is becoming slightly more open towards the top of the zone.

Betula - Coryloid - Herb Local Pollen Zone. The characteristic feature of this zone is the high degree of fluctuation in the pollen curves, suggesting at least local changes in the degree of openness at the site. The most noticeable changes are the peaks in herb taxa curves. Of these, the earliest, in which Rumex acetosa rises to 11%, reflects the largest-scale vegetational change, occurring as Betula values, in particular, and tree values, in general, show a sharp temporary decline. The other two peaks in herbs (R. acetosa again, and Menyanthes) possibly represent changes of a more local nature, although there is a general decline in the abundance of the local tree components (Betula, Coryloid and Salix) and an increase in the more regional components (Quercus and Ulmus). Throughout this zone the site appears to have been surrounded by Betula woodland, with Corylus and Alnus being less important than earlier, and small amounts of Salix being present. Fraxinus is locally present, representing the colonization of cleared vegetation by this shade-intolerant plant (cf. Robinson, 1980, pp.84 ff.). There are also signs of increasing dampness at the site, reflected by the large increases in Sphagnum, Menyanthes, Cyperaceae and Amphitrema flavum, and the presence of Drosera, Potamogeton, Ranunculus, Salix, Eriophorum vaginatum, Assulina seminulum and Copepoda spermatophores.

An important problem is that of the cause of these changes. Although the changes may have been relatively local in character, their stratigraphical position, immediately preceding the major shift to a more open heath vegetation, suggests that the changes may have been of considerable importance. The abundant presence of Rumex spp., Plantago and Urtica may be indicative of human agricultural activity. Immediately following the earlier R. acetosa peak is a large increase in Gramineae, with a value of 52% of A.P. (Fig. 4.5). A peak of this size fits into Turner's "extensive clearance" phase, as recorded some distance from the edges of Bloak Moss and Flanders Moss (Turner, 1965, 1970); it is notable that the Moss Cottage site lies at the centre of the moss area (cf. Turner, 1970). The later herb peaks, while associated with smaller pteridophyte peaks, in general also found during clearance phases, do not coincide with a Gramineae peak. At most sites at which there is evidence of human clearance activity, there are abundant charcoal remains. This local pollen zone, however, occurs in the only part of the Moss Cottage core where there are virtually no charcoal remains, and Gelasinospora spp., possible indicators of burning (Van Geel, 1978, p.48), are not present here although they are found elsewhere in the core. This argues strongly against human clearance of the local vegetation at the time represented by this pollen zone. It is possible, however, that nearby clearance provided conditions for the expansion of the agricultural indicator species, and so the vegetation, not altered deliberately at this marginal site, was changed by chance.

About 10 km to the west of the Moss Cottage site, Gryfesdale was an important centre of Neolithic activity (Newall, 1972), and sites and finds with evidence of both Neolithic and Bronze Age activity are also moderately common on the higher ground surrounding the Linwood area (Newall, 1974, 1976). In addition, there is an abundant presence of Iron Age and Roman sites (crannogs, "hillforts" and farms; roads and forts, respectively) and Roman small finds, notably coins (Paisley Museum Records). There was probably Roman military activity during both the first and second centuries A.D. (Newall, 1975), and Viking activity in this region is recorded in silver and gold hoards on Bute and near Port Glasgow (Graham-Campbell, 1976) and finds at Dumbarton Castle (Alcock, 1976). Briefly, although there is little evidence of prehistoric activity in the low-lying area around Linwood Moss, there has been such activity for a long time in the surrounding higher areas (Fig. 4.4). It is plausible that prehistoric vegetation clearance was important in the surrounding areas although not actually at Linwood Moss.

There is also evidence in the results of the pollen analysis for environmental changes not induced by human interference. The increasing dampness, already discussed, may have been a critical factor in the opening of the woodland. There is a peculiar, initially-unidentified pollen grain, which occurs at several horizons within this pollen zone. The grain appears to be triporate, but severe crumpling is sufficient to obscure the pores. It was named variously "?Betula", "?Coryloid" or "?Alnus". Betula catkins found in this part of the core contained this unidentified pollen grain, and it is thus identified as either a diseased grain or a grain from diseased Betula trees. Alternatively, the grain is an immature Betula pollen grain. Although this grain only occurs during the herb peaks, its main presence is during the second peak, in which there is no associated Gramineae peak.

The cause of the vegetation changes discussed above remains unresolved. Natural environmental factors at the site, such as increasing dampness or tree disease may have been supplemented, at an early stage, by the effects of nearby clearance by humans. A more probable alternative is that the removal of woodland vegetation in the surrounding area, with the consequent increase in runoff into this low-lying area and raising of the water table (cf. Bormann et al., 1968; Bormann & Likens, 1970; Chadwick, 1975; Culleton & Mitchell, 1976; Davis, 1976; Edwards & Rowntree, 1980) was responsible for the increasingly damp conditions and onset of soligenous mire or ombrogenous bog conditions (cf. Merryfield & Moore, 1974; Moore, 1975, 1979; Moore & Wilmott, 1976).

Calluna Local Pollen Zone. This zone represents open Calluna heath, with Calluna and other ericaceous species growing at the site. Throughout the zone are Calluna macrofossils, all of which are burnt. The unidentified wood, twig and bark remains are probably also Calluna remains. The spectra here indicate Calluna wet heath vegetation (Gimingham, 1964b, pp. 284 ff.), the evidence of Calluna being supplemented by Cyperaceae, Gramineae and Coryloid pollen (the latter perhaps from Myrica gale), Sphagnum spores and macrofossils, and Eriophorum vaginatum macrofossils. Following the vegetational changes in the previous zone, there is a steady decrease in arboreal pollen to the lowest values in the entire diagram. Within this zone, regional components, Quercus, Pinus and Ulmus, are better represented than previously, reflecting the contemporaneous open nature of the site. Betula fruits and fruit scales, while indicating the nearby presence of Betula, have been transported sufficiently far to be damaged and become recognisable only to genus level.

Conditions represented by this pollen zone appear to become initially drier, although by no means dry, and then wetter, with the increased presence of Amphitrema flavum, Assulina seminulum and, especially, Sphagnum, notably S. imbricatum, and a decline in Gelasinospora spp.

Sphagnum - Betula Local Pollen Zone. Most of the pollen zone appears to represent wet raised Sphagnum bog conditions, with Sphagnum spores dominating the pollen spectra, and the peat being composed almost entirely of Sphagnum remains. The increasingly wet conditions at the site prior to this zone are, in this L.P.Z., reflected in the reduction of Calluna pollen and the absence of macrofossils, which indicates that Calluna is no longer growing at the site. Other indicators of wet conditions are sparse, although Amphitrema flavum and Assulina seminulum have their maximum values in this zone. Towards the top of this part of the diagram, the local vegetation becomes more varied, with Cyperaceae and Calluna present, perhaps as a response to decreasingly wet conditions, indicated by the scarcity of A. flavum and virtual absence of A. seminulum. This may be due to nearby peat clearance; there are two records of Hyalosphenia subflava, a supposed indicator of disturbed peat conditions (Van Geel, 1978, p.79). Betula is common nearby, although not present at the site, and despite local open conditions, values of Quercus and Ulmus are declining, suggesting that regionally the landscape was becoming more open. A slight rise in the Pinus curve at the top may represent the beginning of the modern Pinus rise. The interpretation of this pollen zone is regarded as tentative since the sampling in this part of the core is coarse (the samples are 0.20 m apart), and so the interpretation of the pollen analysis must have a correspondingly low degree of resolution.

Age of the peat. Throughout the Flandrian Age certain regionally-recognisable vegetation changes, while being diachronous (Smith & Pilcher, 1973), have been dated widely enough to be used as approximate chronological indicators. Most of these changes occur during the first part of the Flandrian Age and since c. 5,000 B.P. many changes have been influenced locally by human activity rather than by regional environmental factors such as climatic change, soil development and plant migration. The most recent of these major vegetational changes is the Ulmus decline, occurring throughout Britain at c. 5,000 B.P. None of the earlier changes, such as the Corylus rise, is apparent in the Moss Cottage core. A magnified curve for *Ulmus* as percentage of total A.P. (Fig. 4.5) shows that high values (5-7%) of *Ulmus* occur during the Gramineae - *Quercus*, *Calluna* and early *Sphagnum* - *Betula* L.P.Z.s, all zones representing locally-open conditions, during which there was a high regional tree pollen input. The *Ulmus* decline at many Scottish sites (e.g. Donner, 1957; Turner, 1965; Walker, 1975; Robinson, 1980, p.76) tends to precede conditions of more open vegetation. At the Moss Cottage site, the reverse is true; the declines in the *Ulmus* curve correspond to declines in the Gramineae curve and increases in the curves of pollen from local tree and tall shrubs. Although the declines in *Ulmus* values are of a similar order to those at the *Ulmus* decline (proper) at other sites, it appears that the regional *Ulmus* decline is not present here. It is possible that the regional *Ulmus* decline coincides with local vegetational changes, especially at the peat base. In such a case, it would not be recognisable. All of the peat is probably younger than *c.* 5,000 years. Some of the recorded taxa (e.g. *Acer*, *Fraxinum*, *Trifolium*, *Crataegus* and *Drosera*) are present predominantly after the *Ulmus* decline elsewhere in Britain (Godwin, 1975).

In the *Betula* - Coryloid - Herb L.P.Z., some of the vegetational changes may have been influenced by human activity. The fluctuations resemble those typical of Turner's (1965) "extensive clearance" which occur, very broadly, during the Iron Age and are radiocarbon dated at between 1,900 and 1,300 years B.P. The vegetational changes at Moss Cottage, however, have not been convincingly shown to be caused by human activity, and given the nature and location of the site, such a cause may not be possible to prove (cf. Edwards, 1979, 1982).

There is no evidence within the peat of any break in deposition, although there is slight evidence of disturbance near the top. In the area around what remains of Linwood Moss, large areas of peat appear to have been removed and in places the sub-peat silt is exposed. Although in adjacent areas peat-cutting appears to have been important, the peat at this site has been allowed to grow continuously. If a maximum average rate of peat accumulation is taken as 1 mm/year (see Chapter 13.1), the Betula - Coryloid - Herb L.P.Z. is c. 1,600 to 2,000 years old, and the base of the peat is c. 2,500 years old. Peat accumulation rates are likely to have been lower than 1 mm/year (cf. Berglund, 1979, p.47), and the peat base may be twice as old as suggested although, on the basis of the discussion above, it is unlikely to be older than the Ulmus decline.

Nature of the sub-peat sediment. There is no fossil evidence within the silt underlying the peat to suggest a marine origin for it, although the basal silt lies lower (below c. 7.75 m A.O.D.) than the clayey silt in the IGS-LMP-80 core which contains a marine gastropod. A few vegetational features suggest that the silt may be marine in origin, or at least that sea level (or H.W.M.S.T.) lay at or above 7.75 m A.O.D. Few reliable indicators of coastal conditions are present here. Glaux is an important one, being present throughout the Gramineae - Quercus L.P.Z. and into the Alnus L.P.Z. Glaux maritima is, at present, an almost exclusively coastal plant in Britain and Europe (Perring & Walters, 1976 p.205; cf. Bell, 1969; Adam, 1977) found on grassy salt marshes (Clapham et al., 1968, p.294). At Moss Cottage, Juncus maritimus is also represented below the peat base; this is another plant found exclusively at the coast, on salt marshes above high tide mark (Clapham et al., 1968, p.463; Perring & Walters, 1976, p.320). The basal pollen zone, which contains abundant pollen, is dominated by Gramineae pollen, tentatively identified as Phragmites. Phragmites communis is the commonest dominant in vegetation communities in the transitional belt between salt marsh and non-saline swamp, often extending a considerable distance into the salt marsh (Gimingham, 1964a, p.118).

It appears that the basal organic sediment was deposited under saltmarsh conditions, and therefore, by implication, the underlying silt was either deposited under marine conditions or was at least flooded by salt water.

4. Conclusion

The pollen diagram for the Moss Cottage site represents a hydoseral succession from salt marsh and tidal *Phragmites* reed swamp through non-tidal swamp with encroaching *Alnus* woodland to damp, mixed *Betula* woodland (cf. Moore, 1968; Walker, 1970). Following some local disturbance of the woodland vegetation, *Calluna*-dominated wet heath was established, later to become *Sphagnum* raised bog, which has become drier recently.

The core represents continuous sedimentation from saline to non-saline conditions within the last 5,000 years. The maximum altitude for which there is evidence of saline conditions is *c.* 7.8 m A.O.D.

CHAPTER 5

THE POLLEN RECORD IN MARINE SEDIMENTS AND ESPECIALLY AT THE JUNCTION BETWEEN SALTWATER AND FRESHWATER SEDIMENTS

1. Introduction

The recognition in pollen spectra of salt marsh and other coastal vegetation may be difficult, as illustrated in the discussion of the MC-80 core (Chapter 4.3). In order to aid interpretation, a literature review and a practical example are presented below.

2. Literature review

There are two main aspects of pollen spectra at the boundary between saltwater and freshwater sediments. Firstly, at the boundary there is usually an over-representation of *Pinus* pollen, frequently documented in the analysis of coastal marine clays and associated non-marine sediments (Morrison, 1961; Zagwijn, 1965; Newey, 1966; Dickinson, 1973; Murray, 1975; Devoy, 1979; Jennings & Smyth, 1982).* Although high *Pinus* values are generally considered characteristic of marine and estuarine sediments, they are most frequently found in salt and river marsh sediments, at the top of an allochthonous sedimentary cycle (Zagwijn, 1965); occasional flooding at the highest tide levels may be responsible for the hydraulic selection and concentration of *Pinus* pollen grains (Zagwijn, 1965; Hartman, 1968). In low-energy environments, similar processes may operate for the preferential selection of Ericales tetrads (West, 1980, p.7), and pollen representation may become a function of grain morphology and bouyancy (cf. Hopkins, 1950; Muller, 1959).

Secondly, and more widely recognised, is the influence of local vegetation on the pollen spectra. In 1943, a sequence through salt marsh, freshwater fen and fen scrub

* Addendum: see also Traverse & Ginsberg (1966), Morrison *et al*. (1981) and Smith *et al*. (1982); references on p.285.

sediments was illustrated using, as indicators of salt marsh, pollen of Chenopodiaceae-Alsineae and Compositae types, followed rapidly by a peak in Gramineae pollen (Godwin, 1943). Earlier work by Brinkman (1934) and by Godwin & Newton (1938), illustrating a similar succession, is quoted by Godwin (1943, p.201), and other similar successions were later described (Godwin, 1956b), including one in which the inland limit of the marine transgression lay seawards of the site, but where a Chenopodiaceae pollen peak was coincident with minima in other herb and Ericoid pollen curves. Since then, salt marsh vegetation frequently has been recognised from pollen spectra (Morrison, 1961; Von der Brelie, 1963; Morrison & Stephens, 1965; Zagwijn, 1965; Boerboom & Zagwijn, 1966; Newey, 1966; Singh & Smith, 1966; Nichols, 1967; Brooks, 1972; Tooley, 1974, 1978a, b, 1980; Murray, 1975; Devoy, 1979; Jennings & Smyth, 1982). Details are highly variable. Pollen of Chenopodiaceae and, to a lesser extent, Compositae are the most frequent herb taxa, varying from traces to over 20% of total pollen. Other taxa are Plantago maritima, Glaux maritima, Armeria maritima, Ruppia, Mentha type, Cruciferae and Caryophyllaceae. The Compositae taxa are Bellis and Aster types and Artemisia. Frequently, high Gramineae and aquatic taxa frequencies and occasionally lower Cyperaceae frequencies are present, although in certain cases the other herb pollen outnumber these taxa. Gramineae pollen is often associated with Phragmites macrofossils.

The pollen catchment area for a coastal site changes during a marine transgression and regression (West, 1980, p.5), this being reflected in the alternation between a regional, arboreal pollen spectrum and a local, often Alnus-dominated spectrum (Zagwijn, 1965; Zagwijn & Veenstra, 1966; Nichols, 1967; Murray, 1975; Devoy, 1979).

Coastal vegetation indicators are frequently recorded. Nevertheless, on many occasions no such pollen spectra can be recognised, despite reliable geomorphological, stratigraphical or palaeontological evidence for the presence of former marine conditions (Morrison & Stephens, 1960; Nichols, 1967; Moar, 1969; Alhonen, 1971; Berglund, 1971; Saarnisto, 1971; Dickinson, 1973). High frequencies of indicators are restricted to a narrow zone represented by salt marsh deposits and brackish water clays, and other tidal and near-tidal deposits tend to contain low proportions of these taxa (Zagwijn, 1965). At some sites, local vegetational taxa are outnumbered by more regional arboreal taxa (Alhonen, 1971) or by Gramineae (Newey, 1966), and at others it is difficult to interpret small quantities of a taxon as representing salt marsh conditions, when that taxon may equally well represent open-ground conditions, as in the case of Chenopodiaceae and Plantago (Nichols, 1967).

The best representation of salt marsh conditions appears in a restricted areal and stratigraphical zone, which may be missed easily during the sampling of a core. Sediments representing salt marsh may be further reduced or entirely removed from the sedimentary record by erosion during a marine regression or, especially, a transgression. Although such conditions can be recognised, even inland beyond the transgression limits (Godwin, 1956b; Tooley, 1974), it may not be possible to recognise the presence of marine conditions from the pollen alone. Ironically, it seems that salt marsh, and to a lesser extent, sand dune vegetations may be better represented in deep marine cores, distant from the coast (Zagwijn & Veenstra, 1966).

3. A practical example: Flanders Moss

Introduction and results. In the western part of the valley of the River Forth, in an area south and south-east of the Lake of Menteith, are large remnants of Flanders Moss, lying at c. 15 to 30 m A.O.D. The peat, where it is undisturbed, is generally more than 4 m thick, and in places up to 8 m thick (J. H. Dickson, pers. comm.). It overlies estuarine carse clay (Sissons, 1966). About 3 km north-west of Kippen, at NS 622 972, a core containing the conformable boundary between the carse clay and the overlying peat was collected. Although the primary objective of the pollen analysis of the sediment was to assess the probabilities of recognising salt-marsh conditions in a core from a site where the peat overlies sediment deposited in saline water, the Flanders Moss core was also used to test the practicality of a recently-proposed preparation method (see Appendix 1).

As the core was required for experimental purposes only, the ground level of site was not measured. The results of the Troels-Smith analysis of a 0.75 m section of the core which includes the boundary between the clay and the peat, are shown in Table A.5.1. Figure 5.1 shows the results of the macrofossil analysis and the sample positions. Figure 5.2 shows the results of the pollen analysis, presented as percentage values of total pollen and total A.P.

Salt marsh and coastal vegetation indicators. Most of the characteristic spectral changes discussed above (Chapter 5.2) can be recognised in the diagram. In the topmost part of the clay, tree taxa are poorly represented. The regional components, *Quercus* and *Ulmus*, are more common than *Betula*, which probably grew at the site later. Also of note are the unusually high *Pinus* values (to 50% of A.P., 6% of total pollen). Immediately above the top of the clay, *Pinus* values drop markedly, behaving in a manner unlike those for *Quercus* and *Ulmus*. This suggests that either real vegetational changes are operating or that the mode of transport has altered. The coincidence between the *Pinus* decline and the sedimentary change from allochthonous to autochthonous deposition (i.e., from clay to peat sedimentation) suggests that the mode of transport has changed.

Indicators of local vegetation provide good evidence of the presence of salt marsh. Within the clay there is an abundant range of herb taxa, many of which have been used previously to indicate salt marsh conditions. Their sudden decline and absence from the clay indicates major local environmental changes. Associated with these herbs are very high Gramineae values. The grain size frequency curves (Fig. 5.3) show mean sizes around 24 μm. Phragmites macrofossil remains in the sediment here indicate the presence of P. communis, a grass with pollen grains of c. 24 μm diameter (Andrew, 1980), so the high values of Gramineae pollen are interpretated as representing P. communis.

Contrast with MC-80. In the MC-80 core there is not an abundant range of herb indicators of salt marsh. The Gramineae values and grain sizes show similar patterns to those at Flanders Moss, reinforcing, but not proving, the interpretation that P. communis was present at Moss Cottage. In the MC-80 core, Pinus values are not noticeably greater at the base of the diagram, although the tree spectra are more regional in character.

Spectral differences between sites may be due to many factors - extent and form of the vegetational development at the time, subsequent erosion and deposition, post-depositional chemical and biological activity, etc. - which are expected to vary considerably in a dynamic coastal situation. In this case it must be noted that (1) microfloral remains are present in a greater thickness of sub-peat silt at Moss Cottage (to 0.50 m below the peat base) than at Flanders Moss (to 0.20 m below the peat base), and (2) sampling at Flanders Moss is much denser than at Moss Cottage, and clear indicators of salt marsh may easily have been missed at the latter site.

CHAPTER 6

LINWOOD MOSS WOOD CORE (LMW-80)

1. Introduction

This is the second core collected to replace the IGS-LMP-80 core. The peat was sampled, at Nat. Grid Ref. NS 4395 6005, using a "Russian" corer (Jowsey, 1966), but the basal core used for pollen analysis was collected using a "Livingstone" corer (Livingstone, 1955; Wright, 1967). There is no indication of a thin inorganic band within the peat as in the IGS-LMP-80 core.

Ground surface at the site has been instrumentally levelled, and lies at 12.785 m A.O.D. The peat base lies c. 3.66 m below the ground level (9.125 m A.O.D.).

2. The results

Pollen analysis. Although the pollen diagram (Fig. 6.1) produced is moderately short, there are several rapid spectral changes. For the purposes of discussion, local pollen zones are identified. All heights are measured from the top of the basal silty clay. Percentages are of total pollen unless otherwise stated. The sample and local pollen zone positions are shown in Figure 6.2. The following local pollen zones are recognised.

LMW-80.1 "Herb - Gramineae - Filicales Local Pollen Zone"

Sample 1 (1 sample); 0 to 15 mm.

The main characteristic of this zone is the high herb pollen value. Whereas Gramineae has a moderate value (19%) and Cyperaceae a low one (4%), other herbs constitute 48% of the total pollen, with *Filipendula* providing 40%. The range of herbs is wide, *Chrysosplenium*, *Lychnis* and *Senecio* types, *Menyanthes*, *Potamogeton*, *Rumex* spp., Umbelliferae and *Valeriana* being present. Filicales is also common (26%). Trees and tall shrubs are poorly represented. *Betula* and Coryloid having similar values (12% and 10% respectively), *Salix* a low but significant value (6%), and the other trees, Pinus and Alnus, 1% each.

LMW-80.2 "Betula - Salix Local Pollen Zone"

Sample 2 (1 sample); 15 to 65 mm.

This zone, again based on one sample, is characterised by a spectrum very different from that of the previous pollen zone. Betula has risen considerably (to 49%) and Salix less so (to 15%). These increases correspond to a decrease in herb values; Gramineae to 6%, and other herbs to 15%, with Filipendula dropping to 3%. There is still a wide range of herbs, and Sphagnum has increased dramatically.

LMW-80.3 "Empetrum Local Pollen Zone"

Sample 4 to 5 (3 samples); 65 to 245 mm.

Again there are substantial spectral changes following the previous pollen zone. Betula values are lower (14-20%) and Coryloid values rise steeply from 12% to 42%. The other trees are poorly represented. The characteristic feature of this zone is the series of high Empetrum values (34-47%). This coincides with the beginning of a gradual rise in Calluna values (2 to 4%) and low values of Gramineae, Cyperaceae and other herbs.

LMW-80.4 "Coryloid Local Pollen Zone"

Samples 6 to 8 (3 samples); 245 mm to the top of the pollen diagram.

This pollen zone is characterised, in contrast to the previous zone, by the rapid reduction (to 1%) and maintenance of low Empetrum values. Throughout this zone, Coryloid pollen dominates the spectra with high values of 49-66%, and Betula has moderate values (13-21%). Calluna still rises (5 to 8%) and Empetrum and Ericaceae peak at the top (to 11% and 6% respectively). Gramineae and Cyperaceae values are low (3% and 5%) and other herbs are virtually absent. Sphagnum is rising (25 to 98%).

Troels-Smith and macrofossil analyses. The results of the Troels-Smith analysis are shown in Table A.6.1, and those of the macrofossil analysis in Figure 6.2. There is a moderately close correlation between the macrofossil distributions, the T.S. units and the local pollen zones, suggesting that the pollen spectra throughout this diagram largely reflect local vegetational changes. The range of macrofossils is limited, probably reflecting the high degree of humification throughout most of the section. Of particular note is the sharp, apparently unconformable boundary between the peat and the underlying silty clay.

3. Discussion

Herb - Gramineae - Filicales Local Pollen Zone. The pollen spectrum for this zone reflects local, very open vegetation, in which a moderately rich herb flora is growing on damp soil. The abundant presence of *Filipendula* pollen and *Juncus* seeds, and the lesser presence of *Menyanthes* and *Potamogeton* pollen and Copepoda spermatophores indicate the presence of local standing water. The Gramineae grain-size frequency distribution (Fig. 6.2) indicates a mixed population, grains of the *Phragmites* and *Dactylis* types (Faegri & Iversen, 1975) being represented.

The regional tree pollen component is noticeably sparse for such an open site with *Betula* and, to a lesser extent, *Pinus* represented. *Salix* and probably *Myrica gale* are present locally. Non-local pollen may have been effectively filtered out of the pollen rain by the nearby, densely growing *Filipendula* (cf. Tauber, 1965).

Betula - *Salix* Local Pollen Zone. Locally, woodland has rapidly expanded, with both *Salix* and *Betula* present. The herb flora has been reduced by this change. *Filipendula*, *Menyanthes*, *Nuphar* and Cyperaceae pollen, abundant *Sphagnum* spores and macrofossils, *Eriophorum vaginatum* macrofossils and the presence of *Assulina seminulum* and Copepoda spermatophores all reflect increasingly damp conditions.

Empetrum Local Pollen Zone. Locally, major vegetational changes occur yet again. The ground vegetation becomes dominated by *Empetrum*, perhaps reflecting an increase in the soil dryness at the site. Although no *Empetrum* macrofossils are present, the high pollen values indicate that *Empetrum* is growing a very short distance from, if not at, the site. This is also reflected in the corresponding decrease in Gramineae, Cyperaceae and other herb pollen and the drop in abundance of Eriophorum vaginatum macrofossils.

Towards the top of this pollen zone, the rapid expansion of Coryloid pollen reflects a rise in the abundance of Corylus, since conditions appear to be too dry for this Coryloid rise to represent a major increase in Myrica. Corylus appears partially to replace Betula.

Coryloid Local Pollen Zone. The macrofossils present throughout this pollen zone suggest that the pollen spectra here represent a moderately open, damp site within Betula-Corylus woodland. Calluna, Ericaceae and Empetrum pollen, Eriophorum vaginatum macrofossils, Sphagnum spores and the general scarcity of Gramineae and Cyperaceae and other herbs suggest that the vegetation cover at this site is very similar to that described by Ratcliffe (1964, pp. 476 ff.) for lowland Calluna-Eriophorum bog.

In the area surrounding the site, Betula and Corylus are still important woodland components but, regionally, Ulmus and Quercus are becoming more important.

Age of the peat. Although many of the pollen spectra discussed here represent local vegetation conditions, various vegetational features can be recognised regionally. At the base of the peat, the vegetation is both locally open and regionally moderately open. A rich, tall herb flora, especially with abundant Filipendula, supplements this picture, suggesting that the basal local pollen zone represents very early Flandrian or possibly very late Late Devensian conditions. The Betula and Pinus values are very similar to Late Devensian values at, for example, Muir Park Reservoir (Donner, 1957; Vasari & Vasari, 1968). Filipendula, while being abundant during Late Devensian times throughout Britain (Godwin, 1975, pp. 182 ff.), probably reflects the local wet conditions and cannot be used as an accurate chronological indicator.

The tree curves also suggest an early Flandrian age for the peat. At many sites, after an initial rapid rise and peak in values, the Betula curve drops to steady, moderate values (e.g. Nichols, 1967; Vasari & Vasari, 1968; Robinson, 1980, pp. 81 ff.). Likewise, the Coryloid curve always shows a very rapid rise in values shortly after this Betula peak, and this has been interpreted as a regional Corylus expansion. Regionally, these changes are followed by the less spectacular arrivals of Quercus and Ulmus. The next major regional change is the Alnus rise, which is the only major change not recorded in the LMW-80 core pollen analysis. Alnus is either absent or very poorly represented throughout the pollen diagram, a feature common in the early Flandrian parts of other pollen diagrams from nearby sites (e.g. Walker, 1975).

Vegetational developments occurring more locally, notably the temporary dominance of Salix and Empetrum, are also short-term vegetational developments that often occur in the early phases of the Flandrian Age. Commonly, these early shrub colonizations occur prior to the establishment of Betula woodland (e.g. Lowe & Walker, 1977). At Linwood Moss, however, they appear to be coincident with and following the main Betula expansion. This may be due to certain aspects of the local environment. Either, the newly available site, with only a very thin soil cover on the silty clay, was a suitable place for a very early Betula expansion, occurring at the same time as the Betula expansion elsewhere was still limited by the presence of such shrubs as Empetrum and Juniperus, or the locally wet conditions allowed local expansion of Salix and, as the site became drier, it became a temporary refuge for Empetrum. A different explanation for the occurrence of the Salix and Empetrum shrub colonizations during and after the main Betula expansion at this site, rather than before it, as at several other sites, is that the early expansion of Betula represents the local presence of Betula nana, tree birch being present only slightly later (cf. Walker, 1975, p.20; Walker & Lowe, 1979, p.354; D. E. Robinson, pers. comm.).

A peak in Salix values is not a feature found exclusively during the early Flandrian Age; at Dubh Lochan, for example, a Salix peak follows the Ulmus decline (Walker, 1975). In some places, as well as Empetrum and Salix, Juniperus also has a temporary expansion during early Flandrian times (Vasari & Vasari, 1968; Walker, 1975; Lowe & Walker, 1977; Robinson, 1980, p.80). A complete check was run to look for Juniperus pollen, but none was found. Although Juniperus is difficult to identify, it is unlikely that there has been a Juniperus expansion at this site.

On the basis of the above discussion, the peat can be dated approximately. The top of the pollen diagram pre-dates the Alnus rise, and the peat was therefore deposited before c. 7,000 B.P. (Birks, 1980). The peat base perhaps dates from slightly before 10,000 B.P. and the peat at c. 0.20 m above the base (the Corylus rise) may be dated at c. 8,800 B.P. These dates suggest an acceptable, approximate peat accumulation rate of 0.2 mm/year.

CHAPTER 7

LINWOOD MOSS, FIELD SURVEY

1. Introduction and data

In Figure 7.1 an approximate outline of the extent of Linwood Moss is presented. This is drawn to enclose the area in which a substantial thickness of peat is present; this thickness is generally taken as 1 m or more, although in places it is less. In the surrounding areas, especially to the south and west, much of the soil is peaty, but the peat is only a thin superficial layer overlying silt or clay, and both the peat and the underlying inorganic sediment have been disturbed by ploughing. Elsewhere, notably to the north of the Moss Cottage woodland area, the soil is developed on clay or stony clay, and to the west, south of Auchens, the soil is developed on till. The edge of Linwood Moss is often clearly defined by a break in slope, with peat lying at a higher level than the surrounding countryside. Although not always the case, the breaks in slope coincide with field boundaries, and therefore the breaks are considered in many places to have been caused by peat clearance. Approximately one quarter of the area of Linwood Moss is used as a municipal refuse dump, and the peat is now inaccessible.

The information obtained from the field survey is documented below, and the locations of the sites shown in Figure 7.1. Each site is given a number, a grid reference (all within square NS), and in some cases, an instrumentally-levelled ground surface altitude A.O.D. Where the altitude is an estimate, this is signified by "(e)".

<u>LM.1</u>

4420 6607
Temporary exposure in drainage man-hole.
<u>c</u>. 0.50 m of peat conformably over silt.

LM.2

4420 6621; 9.425 m.
Temporary exposure in drainage ditch.
Peat, grading into silty clay; silty clay at c. 0.70 m below ground surface.

LM.3

4420 6633, 8.305 m.
Temporary exposure in drainage ditch.
Peat grading down through 0.10 m of yellow sand to blue sandy clay; clay top c. 0.30 m below the ground surface.

LM.4

4421 6634 to 4438 6637, 8.105 to 7.805 m.
Partial exposure along stream bank.
Peat grading down into silty and, in places, stony clay; level of clay is variable, from 0.30 m to c. 2 m below ground surface.

LM.5

4441 6636 to 4441 6652 and 4445 6637 to 4445 6631.
Partial exposures along two ditches in the wood.
General succession: peat grading down into brown organic silt, then in places into sandier silt, and everywhere into blue clay. Inorganic sediment surface is variable in level over a range of c. 2 m at c. 8 m A.O.D. (e); in some places, steep- to vertical-sided channels within the inorganic sediments are infilled with peat.

LM.6

4445 6560, 8.145 m; 4448 6561, 8.645 m.
Hand-dug holes at field edges.
In both holes c. 0.40 m of peat overlies yellow-brown silty clay (at least 0.15 m thick), separated by a sharp boundary. Samples from the clay show it to be unfossiliferous.

LM.7

4401 6631, 7.695 m.
Hand-dug hole.
c. 0.15 m of peat grading down into clay.

LM.8

4375 6628, 9.385 m.
Auger hole.
c. 1 m peat overlying c. 0.50 m of peat becoming increasingly inorganic downwards, until the sediment is an entirely non-organic blue silty clay.

LM.9

4360 6620, 11.435 m.
Auger hole.
2.74 m of peat, becoming silty at base and grading into blue inorganic silty clay at 2.95 m below the surface.

LM.10

4367 6609, 12.715 m.
Auger hole.
4.60 m of peat overlying blue silty clay with sand partings and occasional pebbles. The peat-clay boundary is sharp.

LM.11

4395 6605, 12.785 m.
Livingstone and Russian core holes; site of LMW-80 core.
3.66 m of peat, lying unconformably over silty clay.

LM.12

4440 6610, 10.265 m.
Russian core holes; site of MC-80 core.
2.5 m of peat overlying 0.45 m of organic-rich silt, becoming less so downwards, overlying inorganic silty clay to at least 4.30 m below the surface.

LM.13

4430 6560, 10.075 m.
Russian core hole.
c. 1.13 m of peat lying unconformably over clayey silt; silt and clay to at least 1.30 m below the surface.

LM.14

4440 6580, 12.075 m.
Russian core hole.
Peat, 2.99 m thick, overlying clayey and sandy silt; gradational boundary.

LM.15

4450 6585, 12.630 m.
Russian core hole.
Peat, c. 3.20 m thick, overlying silty clay; gradational boundary.

LM.16

Area around 4330 6545, 12-15 m (e).
Surface exposures.
Peaty soil.

<u>LM.17</u>

4320 6535 to 4390 6570, 12-17 m (e).
Partial exposures in ditch, and auger holes along edge of ditch.
Peat is at least 0.80 m thick and in places more than 2 m thick.

<u>LM.18</u>

Small area around 4365 6560, 16-17 m (e).
Temporary exposures in holes and ditches for drainage pipes.
Peat at least 1.20 m thick.

<u>LM.19</u>

4365 6585, 13-14 m (e).
Hand-dug hole.
Peat at least 0.80 m thick in the lowest part of hollow in field.

<u>LM.20</u>

4375 6630 to 4365 6645 to <u>c</u>. 4395 6665, below 9 m (e).
Drainage ditches.
Peat at least 1 m thick.

<u>LM.21</u>

4400 6600 to 4400 6640, 12 to 10 m (e).
Drainage ditch.
Peat at least 2.5 m thick.

<u>LM.22</u>

4400 6620, 8-9 m (e).
Hand-dug hole.
Peat at least 0.80 m thick.

<u>LM.23</u>

4430 6565, 10 m (e).
Hand-dug hole.
Peat at least 1 m thick.

<u>LM.24</u>

4450 6565, 8 m (e).
Surface exposure.
Small area of clayey soil in hollow within area of peaty soil.

<u>LM.25</u>

4460 6590, 10.18 m.
IGS-LMP-80 core.
Peat base at <u>c</u>. 7.4 m A.O.D.

2. Sites 13 and 14, pollen analysis

Introduction. Following the pollen analysis of cores IGS-LMP-80, MC-80 and LMW-80, and given the radiocarbon ages for the peat at Clippens Farm and Linwood Moss (Bishop & Coope, 1977; see also Chapter 2 above and Table 2.1), it is suggested that at Linwood Moss, there are areas of "young" and "old" peat. These terms refer to peat whose formation commenced during the later part of the Flandrian Age (after 5,000 B.P.) and at the beginning of the Flandrian Age (c. 10,000 B.P.) respectively. Since detailed pollen analysis of both "old" and "young" peat has been undertaken (LMW-80 and MC-80, respectively) pollen analysis results for single sample analysis from the peat base in other cores can be compared with results given above (Chapters 4 and 6), and it should be possible to establish whether the peat is "old" or "young" at any site.

The results. Samples were taken for analysis from cores at sites 13 and 14. The results are shown in Table 7.1, and the results of the Troels-Smith analyses are shown in Tables A.7.1 and 2.

Although the spectra are all strongly local, reflecting damp conditions at the sites - Caltha palustris, Filipendula, Potamogeton and Gramineae (possibly Phragmites type; Table 7.2) are present - there is sufficient evidence to suggest that the peat at both sites is "old". The spectra are obviously pre-Corylus-rise, Coryloid pollen being virtually absent. The Betula values are also sufficiently low to suggest a pre-Flandrian age. The high Salix and Filipendula values are reminiscent of features in the LMW-80 diagram (Fig. 6.1).

3. Discussion

Sites LM.16 to 23 indicate minimum depths of peat on Linwood Moss, and sites LM.6, 7 and 24 indicate the thinness

<u>Table 7.1</u> Linwood Moss: results of pollen analyses of samples from Sites 13 and 14. The base of the peat at site 13 lies 1.13 m below the ground surface, and at Site 14 lies 2.99 m below the ground surface. All values are presented as percentages of total pollen.

+ = less than 0.5%

Site number	13	14	14
Sample number	1	1	2
Depth below ground surface (m)	1.11-1.20	2.97-2.96	2.92-2.91
Betula	5	2	3
Coryloid	1	-	+
Salix	32	5	14
Gramineae	14	76	19
Cyperaceae	12	7	37
Caltha palustris	1	-	1
Cerastium type	-	-	+
Chenopodiaceae	-	3	-
Empetrum	+	1	-
Filipendula	34	5	11
Geum type	-	-	+
Lychnis type	+	-	-
Matricaria type	+	-	+
Menyanthes type	-	-	8
Prunus type	-	-	1
Ranunculus type	+	1	2
Rumex acetosa	-	-	+
R. acetosella	-	-	+
Senecio type	+	-	-
Taraxacum type	-	1	-
Umbelliferae	-	-	1
Valeriana	+	-	-
Potamogeton	+	-	1
Typha latifolia	+	-	-

(continued)

Table 7.1 (Continued)

Site number	13	14	14
Sample number	1	1	2
Depth below ground surface (m)	1.11-1.10	2.97-2.96	2.92-2.91
Sphagnum	1	2	-
Tilletia sphagni	+	-	+
Filicales	2	-	2
Athyrium	-	-	1
Dryopteris filix-mas type	1	-	+
Selaginella	-	-	1
Pre-Quaternary spore	+	-	-
Summaries :			
Betula	5	2	3
Coryloid & *Salix*	33	5	14
Gramineae & Cyperaceae	26	83	56
Other herbs	36	10	27
Total pollen	519	105	507
Total pollen + spores	531	105	526

Table 7.2

Linwood Moss, site LM.14, sample 1: Gramineae pollen grain sizes. The measurements (μm) are converted from microscope eyepiece graticule divisions and are rounded to the nearest μm.

Size (μm)	Total	Frequency (%)
21	1	4
23	3	13
24	8	33
26	6	25
27	4	17
29	1	4
30	1	4
	24	100

of peat in the surrounding area. At site LM.6 the peat and the top of the clay is disturbed by ploughing.

At most of the sites at which the peat is undisturbed, the peat lies conformably on the underlying inorganic sediment. Along the length of the exposures at site LM.5 the peat appears to infill channels within the clay, lying conformably on the upper surface. At no place is a channel base visible. The channels have the appearance of tidal-flat channels (cf. Jardine, 1980, p.31). In a few cases, i.e. at sites LM.10, 11, 13 and probably 25, the boundary between the peat and the clay is sharp, and peat growth does not appear to have followed immediately after cessation of deposition of the underlying sediment. In contrast, at the other sites sedimentation across the clay to peat boundary appears to have been continuous.

The significance of the sediment succession patterns described in this chapter is discussed below (Chapters 8.2 & 8.3).

CHAPTER 8

GENERAL DISCUSSION

1. Introduction

In this chapter the foregoing data from the Linwood area are considered within several contexts. In particular, the significance of the "old" and "young" peat at Linwood Moss is discussed and subsequently assessed, with the aid of a theoretical model for transgressive shoreline development in areas of peat, in relation to the regional situation in the (so-called) Linwood-Paisley Embayment. Proposed limits for the marine inundation of this area and certain consequences are discussed.

2. "Old" and "Young" peat

Introduction. The terms "old" and "young" peat have been introduced above (Chapter 7.2). On the basis of the evidence given in the preceding chapters, these terms are defined as below.

"Old" peat. This is peat whose growth commenced at, or slightly before, the beginning of the Flandrian Age. This includes the peat sampled in the LMW-80 and IGS-LMP-80 cores and at sites LM.13 and 14, in addition to the peat sampled at Clippens Farm (Shotton *et al*. 1967; Bishop & Coope, 1977). This peat typically lies unconformably on silt or clay, or grades very rapidly (within 10 mm) into the underlying sediment. The peat at sites LM.10 and 15 probably also is "old" peat.

"Young" peat. This is peat whose growth commenced in the later part of the Flandrian Age, i.e. after *c*. 5,000 B.P. This includes peat sampled in the MC-80 core and at Linwood Moss (Shotton *et al*. 1967; Bishop & Coope, 1977). The peat typically is conformable on the underlying silt, there being a moderately thick intervening layer (to 0.50 m) of peaty silt or silty peat, representing the transition from inorganic allochthonous sedimentation, probably under marine or saline conditions, to autochthonous deposition, under freshwater conditions. The peat at sites LM.1 to 5 and 7 to 9 probably is "young" peat.

3. Sea-level changes; the significance of the "old" and "young" peat

Introduction. Although there is some debate regarding the maximum altitude reached by the Late Devensian sea in this area (Sissons, 1974b, 1976a; Rose, 1975; Browne, 1980), there is little doubt that the entire area now covered by Linwood Moss was inundated during this period of high relative sea level; the surface in this area, located below 15-20 m A.O.D., lies below the lowest accepted maximum marine limit (c. 25 m A.O.D.; Sissons, 1974b, 1976a). The clays of marine origin, containing cold-water fauna, are well documented (see references in Chapter 2), and at Wester Fulwood, less than 1 km from Linwood Moss, specimens of *Arctica islandica* have been dated, providing radiocarbon ages around 13,000 B.P. (Shotton *et al.*, 1970). Therefore, although no field evidence for the Late Devensian marine inundation in the Linwood Moss area is presented here, it is assumed that, underlying the peat at Linwood Moss, either directly or indirectly, are marine sediments of Late Devensian age.

In places, unfossiliferous silt, deposited up to at least 8 m A.O.D. is regarded as marine in origin, and dating from the period of the middle Flandrian transgression (Jardine, 1971; Bishop & Coope, 1977). Evidence from Loch Lomond suggests that the Flandrian marine altitudinal limit in that region is 12-14 m A.O.D. (Dickson *et al.*, 1978; Rose, 1981). In the IGS-LMP-80 core, tentative evidence for marine conditions suggests that during the early part of the Flandrian Age sea level rose to higher than c. 8.4 m A.O.D., and at

Moss Cottage, there is evidence of hydroseral succession from saltwater to freshwater vegetation, with a suggested altitudinal limit for H.W.M.S.T. of at least 7.8 m A.O.D.

There appear to have been at least two periods since deglaciation in which relative sea level in this area reached maximum altitudes, and on the grounds of this hypothesis, the "old" and "young" peat are interpreted as follows. The interpretation given below corresponds closely with those of Jardine (1971) and Bishop & Coope (1977).

The "old" peat. This is peat deposited in areas previously flooded by the sea during the period of (late) Late Devensian high sea level. Since initiation of peat growth probably dates from c. 10,000 B.P. (Chapter 6.3), sea level (H.W.M.S.T.) at this time lay below 7.4 m A.O.D., this being the lowest elevation at which "old" peat is recorded (site LM.25). There does not appear to have been continuous deposition from the inorganic to organic sedimentation. This may be for one of three main reasons:

(1) The nature of the late Late Devensian marine regression. The marine regression prior to peat growth was either (i) erosive, destroying existing salt marsh, (ii) non-erosive, non-depositional, or (iii) very rapid, with insufficient time for salt marsh to develop.

(2) Post-regression periglacial erosion. The regression was followed by erosion that was unrelated to marine activity. Since peat growth commenced at the end of, or immediately following, the Loch Lomond Stadial, periglacial soil movement was probably an important process operating at this time, soil being destroyed, or its development being hindered, by cryoturbation, solifluction and allied periglacial processes. If the inorganic sediments emerged from the receding sea during the (Windermere) interstadial preceding the Loch Lomond Stadial, any interstadial soils that may have formed have been entirely destroyed during the long period of periglacial activity. Alternatively, sea level may have dropped below the level of the peat base

immediately prior to the initiation of peat growth, but during a period in which the growth of coastal vegetation and deposition of inorganic sediments was hindered by a short spell of periglacial activity.

(3) Periglacial soil development. Due to low rates of biological activity and the presence of chemically "inactive" frozen or very cold water, soil development is minimal under periglacial conditions. In general a periglacial soil consists of a very acid humus surface layer, occasionally underlain by a zone of leaching, and in most cases with no zone of concretion. Commonly such a soil is characterised by a sharp junction between the overlying organic layer and the mineral soil (Tricart, 1970, pp.83-85). The base of the peat in the LMW-80 core, with its sharp basal boundary and its possibly Late Devensian pollen spectrum, may represent the upper part of a periglacial soil.

Following peat initiation and beyond the limits of the middle Flandrian transgression, peat growth probably was continuous throughout the Flandrian Age. Assuming that this was so, rates of peat accumulation are of the expected order of magnitude; 0.25 mm/year (IGS-LMP-80), 0.37 mm/year (LMW-80), and 0.31 mm/year (Clippens Farm, Bishop & Coope, 1977) (see also Chapter 13.1). Peat growth is unlikely to have been interrupted for any considerable length of time.

The "young" peat. Following a period during which sea level (H.W.M.S.T.) lay at or above c. 8.7 m A.O.D. (Sites LM.2 and 9), and as sea level fell, peat growth commenced on the emerging salt marshes, tidal flats and infilling tidal channels. By c. 3,500 B.P., H.W.M.S.T. lay lower than 8.2 m A.O.D. (Shotton et al., 1967, 1968; Bishop & Coope, 1977), and probably considerably earlier than c. 2,500 B.P., H.W.M.S.T. lay lower than c. 7.8 m A.O.D. at Moss Cottage.

The area occupied by the "young" peat therefore is regarded as the area occupied by the sea during the middle Flandrian transgression.

4. The middle Flandrian coastline at Linwood Moss

Areal extent. Since the "young" peat occupies approximately the area flooded during the middle Flandrian marine transgression, the inland limit of the distribution of "young" peat sites is approximately equivalent to the inland limit of the shoreline position of the middle Flandrian marine transgression. The position of this shoreline is shown in Figure 8.1, and the line is drawn in a deliberately over-simplified form. The only site that may lie on or very close to the line is Site LM.25 (IGS-LMP-80). At this site there is evidence of no more than an early, short period of marine inundation (shoreline (a) in Figure 8.1) and it is probable that for most of the period of high relative sea level the shoreline lay to the north of Site LM.25 (shoreline (b)).

The surface and uppermost sub-peat sediments to the north and west of this area have been interpreted (Bishop & Coope, 1977) in a manner similar to that given above, i.e. there is an area of middle Flandrian marine sediments overlying the Late Devensian marine sediments that outcrop further to the south and west. The boundary between these two sedimentary units and, by implication, the middle Flandrian marine shoreline, lies very close to the western end of the shoreline proposed here, lending strong support to the model. The boundary proposed by Bishop & Coope (1977) is included in Figure 8.1.

Shoreline form; theoretical model. As an aid to the understanding of the changing shoreline positions in the Linwood area during the Flandrian Age, probable sedimentary successions are suggested for a theoretical coastal situation in which an area of peat is inundated by the sea during a marine transgression, and in which peat growth continues after regression succeeds the transgression. The model is a simplified version in which only major sedimentary units are considered. It is based on the following assumptions:

(1) Initial peat growth occurs in all places at a uniform rate on a surface that dips gently seawards.

(2) Transgression is moderately rapid, reducing to a minimum the effects of erosion and deposition during the transgression. Erosion and deposition are assumed to be active only during the period of high sea level.

(3) The entire sequence, from commencement of peat growth, through transgression and regression, to final peat growth, takes ten time units of equal length. Transgression occurs immediately after the fourth unit and regional regression occurs after the seventh unit. "Regional" regression is defined here as general regression caused by a relative lowering of sea level with respect to the land.

(4) The main sedimentary units are: (i) the sub-peat substratum, assumed to be homogeneous over a large area, and greater in thickness than the vertical extent of any erosion that occurs; (ii) freshwater peat, regardless of the type of peat; (iii) marine sediments, which are assumed to be quiet-water, fine-grained sediments and which may include, at the upper limit, salt-marsh sediments.

(5) The transgression is defined as erosive and/or depositional in character. Where it is erosive, two limits are considered in the model: one where the entire pre-transgression peat is removed, and the other where a minimal amount of peat is removed. Similarly, where the transgression is depositional, two limits are considered in the model: where there are minimum and maximum amounts of sedimentation. In the latter case, it is assumed that sedimentation is sufficient to influence, in its later stages, progradational regression prior to the onset of regional regression. In one situation, where there is no erosion, deposition is assumed to cause only early progradational regression. The possible combinations are shown in Figure 8.2 (Cases 1a, 1b, 2a to 3bii).

Sections for each outcome are drawn at right angles to the transgressive shoreline (Fig. 8.2). These show that, in most cases, there is an erosive and constructional buried peat-cliff at the position of the shoreline. In cases 1a and 1b, there is only a constructional cliff, and in 1b it is minimal in height.

In most practical situations, sections such as those shown in Figure 8.2 are not available for examination; more probably, as at Linwood Moss, small exposures or core sections are available. For this reason, the expected successions at three core positions are presented (Fig. 8.3). The three positions considered are (a) landward of the shoreline, (b) immediately seaward of the shoreline and, (c) a considerable distance seaward of the shoreline. In these successions, emphasis is placed on the ages of the peat bases and tops, since peat is the most easily datable material. It is assumed that the marine origin of the inorganic sediment (other than the substratum) can be proved.

<u>Shoreline form; discussion</u>. From consideration of the model, a few comments can be made regarding the peat successions at Linwood Moss, and by implication, the form of the shoreline during the period of high sea level.

The areas of "old" peat are clearly represented by succession (a), regardless of the transgressive processes involved. As shown earlier, and as expected, the "old" peat represents areas not inundated during the middle Flandrian marine transgression.

The areas of "young" peat are best represented by succession (b) for models 3ai and 3bi, or succession (c) for models 1b 3ai, 3aii, 3bi and 3bii. More probably models 3bi and 3bii represent the "young" peat, since there is no record of peat lying below the marine sediments. Lack of evidence is always poor evidence, but in the absence of any indication of deep-lying peat, it is assumed that models 3bi and 3bii are represented here.

In the IGS-LMP-80 core, succession (b) for model 1b appears to be present.

On the basis of the foregoing, it is suggested that the middle Flandrian transgression represented at Linwood Moss was generally both erosive and depositional in nature, but whether or not deposition was sufficient in certain cases to cause progradational regression is not known. Locally, the transgression was non-erosive and depositional, and local progradational regression rapidly followed the transgression. If this interpretation is correct, then, although in some places the buried shoreline may be difficult to recognise, in general the shoreline should be recognisable.

There are certain complicating factors which may introduce uncertainty into the model presented above. Many parameters are kept constant, or at least fluctuations have been kept to a minimum. As discussed later (Chapter 16.3), the balance between coastal erosion and deposition may fluctuate in response to relatively small environmental changes in sediment supply, weather, climate, etc. Consequently, certain of the outcomes of the models presented above may be superimposed. However, the models are sufficiently generalised to absorb much of the fluctuation. Sedimentation and erosion are considered in the model as net effects over, in most cases, a long time. Fluctuations in factors and superimposition of effects will be of greatest importance at, and slightly seaward of, the shoreline, i.e. at section (b) (Fig. 8.3), and will be restricted to a limited zone along the coast. The extent of this zone will be dependent on the scale of fluctuation.

A major complicating factor is that transgression and regression may not be rapid and even, and the processes which are modelled in such a way as to occur only during the period of high sea level, are likely to have been operative also during transgression and regression. This may result in the superimposition of effects, in this case distributed more horizontally than vertically.

Maximum elevation of sea level. An important consequence follows from certain outcomes of the model. Where the regression cannot be proved to be progradational it cannot be assumed that the maximum elevation of marine sediments represents the maximum elevation of sea level. Consequently, only a minimum altitudinal limit for the middle Flandrian marine transgression can be given. At Linwood Moss, this minimum limit is 8.7 m A.O.D.

5. The Linwood-Paisley Embayment

Introduction. From the information obtained at Linwood Moss, it is possible to draw an approximate outline of the area inundated by the sea during the middle Flandrian transgression. The position of the coastline (Fig. 8.4) is determined as follows:

(1) Since the minimum elevation of the sea-level limit has been identified as 8.7 m A.O.D., where there is no superficial peat, the shoreline is drawn along the estimated position of the 8.7 m A.O.D. contour. Where the shoreline crosses a river valley, it is drawn slightly seaward of the 8.7 m contour, to account for post-transgressional fluvial erosion.

(2) Where peat is present, it is assumed that the situation was similar to that at Linwood Moss. In such cases the shoreline is drawn where the ground surface lies at c. 11 m A.O.D.

It must be stressed that the method provides only a very approximate position for the shoreline. There are several potential sources of error: (i) because only a minimum altitudinal limit is used, the shoreline is placed too far seawards; (ii) the buried shoreline under other areas of peat may not have the same characteristics as at Linwood Moss, and the shoreline therefore may be placed too far seawards or landwards, more probably the latter; (iii) substantial areas of peat may have been removed, resulting in the shoreline being placed too far inland; (iv) the position of the shoreline is estimated between given contours.

<u>Discussion</u>. An important feature of the model is that, contrary to Browne's (1980) suggestion (Chapter 2.3), the main peat mosses of the Linwood-Paisley area probably did <u>not</u> prevent access of the sea to most of the area during the main Flandrian marine transgression. Although certain parts of Linwood and Fulwood Mosses remained unflooded and peat was able to grow uninterrupted by the sea, the larger parts of the areas now covered by these were flooded by the sea. In contrast, Barochan Moss, both as it exists now and as it existed in the past when it probably covered a larger area than at present, lies high enough to have remained substantially unflooded by the sea. This interpretation is based on the provisional altitudinal marine limit of 8.7 m A.O.D.; it may be ammended should a higher estimate of the limit be obtained. Paisley Moss, most of which is now removed, may or may not have been inundated by the sea.

Again contrary to Browne's (1980) view, there is no evidence to support the concept that the extensive flat areas lying between <u>c</u>. 6 and 9 m A.O.D. to the east of Linwood Moss are remnants of a possible "Main Late-glacial shoreline" surface. At Linwood Moss, the surface below the "young" peat is highly likely to be middle Flandrian in age. This point is less clearly resolved than that of the marine inundation of the peat bodies in this area.

The interpretation of sediments in the Linwood Moss area provided by Jardine (1971) and Bishop & Coope (1977) is altered only in detail. No fresh evidence has been provided concerning Late Devensian marine sedimentation, other than that, by <u>c</u>. 10,000 B.P., H.W.M.S.T. lay lower than 7.4 m A.O.D., and that by this time freshwater peat sedimentation was in progress. There is doubt concerning the suggested low sea level (lower than 3.35 m A.O.D.) at <u>c</u>. 8,000 B.P. Doubt concerning the relevance of the radiocarbon date (Birm-4, 8,039 $\pm$ 128 B.P.; Shotton <u>et al</u>., 1967) has already been expressed (Chapter 2.4), and there is evidence in the IGS-LMP-80 core suggesting the culmination of local transgression at <u>c</u>. 8.4 m A.O.D. at a similar time (i.e.

c. 8,000 B.P.). The minimum estimated marine altitudinal limit is now raised to 8.7 m A.O.D., although this may lie below the real marine altitudinal limit.

Palaeotidal consequences of the Linwood-Paisley Embayment.
A tide is a long wave, with a period of approximately either 0.5 or 1 day, whose behaviour is governed by the natural laws of wave motion (Doodson & Warburg, 1941; Zenkovich, 1967, ch.13). The amplitude, wavelength and symmetry of a given wave are altered by the geometry of the coastal area through which that wave is travelling. For this reason, the amplitude increases as a tidal wave travels landwards within a funnel-shaped embayment (the "estuary effect") and all tidal levels rise as the wave travels up the lowermost reach of a river course (the "river-gradient effect") (Van de Plassche, 1982, pp.13-15). Of importance here is a third effect known as the "floodbasin effect". In a situation where a tidal wave enters a large embayment with a narrow inlet, the large storage capacity of the embayment accommodates the volume of water brought in by the tidal wave, and in certain cases dissipation of tidal energy due to the friction of the tidal wave travelling over a large area further decreases the tidal amplitude, in places to zero (Van de Plassche, 1982, p.13). In such situations, since water inflow at the mouth of the embayment is restricted, high tide occurs later inside the embayment than outside it (Zenkovich, 1967, p.620).

It is suggested that, during the period of the middle Flandrian transgression, the large area of the Linwood-Paisley Embayment was largely micro-tidal or perhaps non-tidal. The distinction between H.W.M.S.T. and M.T.L. in the area at that time therefore must have been minimal, and any limit established for the level of H.W.M.S.T. may be used as a substitute for M.T.L. or mean sea level.

The formation, and ultimate disappearance, of the large embayment probably had marked effects on the tidal regime in the estuary of the River Clyde west of the Erskine-

Old Kilpatrick mouth. As a tidal sink, such as this embayment was, becomes closed to the tidal wave, the tidal range in the remaining outer part of the estuary increases (cf. Harten & Vollmers, 1978). Thus along the coast west of Old Kilpatrick and Erskine there may be evidence for an apparent sea-level still-stand towards the end of the late Flandrian marine regression, as the effects of the dropping sea level were counteracted by the increase in the tidal range, in particular, the increase in elevation of H.W.M.O.T. At Ardmore Point, Flandrian raised beaches present at 5 and 4 m A.O.D. (Rose, 1980) may represent such evidence.

The middle Flandrian double marine transgressive event. In the introduction (Chapter 2.3), comment was made concerning a postulated middle Flandrian double marine event in Loch Lomond (Dickson *et al.*, 1978; Stewart, 1979). Following analysis of the IGS-LMP-80 core (Chapter 3), there is no evidence for such an event at Linwood. Two related questions, however, still remain:

(1) What does the evidence at Loch Lomond represent?

(2) If such an event occurred at all, would it be expected to be represented in the Linwood-Paisley Embayment?

These questions are approached together below. The evidence from Loch Lomond is discussed and comparison is drawn between Loch Lomond and the Linwood-Paisley Embayment.

In Loch Lomond there is evidence for a period during the Flandrian Age in which marine dinoflagellates were present, and microspores of *Isoetes*, a freshwater pteridophyte, were temporarily absent. The dinoflagellates identified suggest less than fully-marine salinity conditions, and the double-peaked nature of the dinoflagellate concentration curve is interpreted as indicating "a decrease in "marinity" within the incursion" (Stewart, 1979, p.83). The presence of the relevant dinoflagellates indicates only that salt water conditions were present, and the concentration changes represent fluctuations in the freshwater/saltwater balance at the site. There are several ways in which this balance may have been altered in Loch Lomond.

With the outflow threshold at c. 8 m A.O.D., Loch Lomond would be sensitive to changes in regional sea level as sea level rose to and above this altitude. Although changes in M.T.L. probably reflect changes in mean sea level, M.T.L. also may be affected as tidal ranges vary in response to changes of coastal geometry. As sea level rose and fell to and from its maximum elevation during the Flandrian Age, there were marked changes in the coastal geometry of the Clyde region. Due to the marine inundations of the Loch Lomond basin and the Linwood-Paisley Embayment (and probably also the Glasgow area), interaction between the changes in tidal range and M.T.L. in these areas probably was complex. In this context, again the sensitivity of Loch Lomond with its restricted exit threshold is important, and (for example) even a small lowering of low tide mark may have allowed the water in Loch Lomond to become fresher than previously. Furthermore, without changes of sea level or tidal regime, the saltwater/freshwater balance may have changed by an increase in the freshwater input, perhaps brought about by changes in the rates of precipitation and/or runoff within the Loch Lomond drainage basin. Because of the sensitive nature of Loch Lomond, such changes need not have been large.

The cause of the salinity fluctuations in Loch Lomond has not been established. Given the above possibilities, however, the probability that such changes are recognisable in the Linwood-Paisley Embayment can be discussed.

Small changes of sea level may be recognisable at Linwood, but probably would not be. By the middle of the period of high sea level, probably both erosional and constructional peat cliffs were formed, and therefore slight raising or lowering of sea level would not result in significant flooding or exposure of peat or other sediments. Although saltmarsh grows rapidly (Steers, 1959), it may be destroyed by subsequent marine transgression, especially if the preceding regressive phase is short-lived. Alternatively, if changes of sea level are relatively small, the "regressive" saltmarsh may form a barrier to subsequent transgression.

The scale of changes of sea level is important in this context. The relationship between the maximum elevation of sediment surfaces and sea level at Linwood Moss has been discussed above (Chapter 8.4). The magnitude of the change in mean sea level may be within the elevation difference between the sediment surface and mean sea level.

Similar arguments hold for changes of tidal range. Furthermore, changes of tidal range have less effect regionally than changes of mean sea level. The two basins of Loch Lomond and the Linwood-Paisley Embayment are not directly connected, and the tides within them need not necessarily react in similar ways to changing coastal geometry. The pattern of tidal changes in the Linwood-Paisley Embayment may well have differed from that in Loch Lomond.

The drainage basins of the two areas differ markedly in geographical characteristics, the Loch Lomond basin being much larger and more highland in character than the Linwood-Paisley Embayment basin. The freshwater input therefore probably was more important in Loch Lomond than in the Linwood-Paisley Embayment (cf. Jennings & Smyth, 1982).

More importantly, the effects of changes of salinity may not be recognisable in unfossiliferous inorganic sediments, and would therefore not be detectable in the Linwood-Paisley Embayment.

An important factor in the case of the Loch Lomond basin was the altitude of the outflow threshold, which makes Loch Lomond sensitive to all the processes discussed above. Such a threshold did not exist in the case of the Linwood-Paisley Embayment. The changes recorded at Loch Lomond may therefore only be recorded because of the presence of this threshold, and evidence for a double marine transgressive event recognised at Loch Lomond would not necessarily be present in the Linwood-Paisley area.

6. Radiocarbon dates

Moss Cottage. The following radiocarbon dates have been obtained for samples from core MC-80:

lab. no.	years B.P.	m below surface
SRR-2030	3,070 ± 60	1.70 - 1.80
SRR-2031	3,630 ± 50	2.20 - 2.30
SRR-2032	3,650 ± 60	2.40 - 2.50

All the dates confirm, in general terms, the conclusions reached in the discussion of the pollen analysis. In particular, there is no need to alter those aspects of the geological model (Chapter 8) based on the evidence from the Moss Cottage site. The radiocarbon dates (SRR-2031 and 2032) correspond closely with those from the base of the peat at Bishop's Linwood Moss site (Birm-2, 3,572 ± 64 B.P., Birm-13, 3,513 ± 56 B.P.; Shotton et al., 1967, 1968; Bishop & Coope, 1977), supporting the suggested association (Chapter 8.2) between that site and the Moss Cottage site.

Dates SRR-2031 and 2032 (3,630 ± 50 B.P. and 3,650 ± 60 B.P.), respectively from the top and base of the *Alnus* peak in the pollen diagram, are statistically inseparable, suggesting that the basal part of the peat may have accumulated very rapidly. The period in which *Alnus* was locally dominant must have been very short, and the hydroseral succession represented by the changes in pollen spectra probably also progressed rapidly. Rapid development of vegetation, such as indicated here, from open water to fen carr woodland and ultimately to bog is recorded at many sites (Walker, 1970).

The age of the base of the peat was estimated (Chapter 4) on the basis of the pollen results and by consideration of rates of peat accumulation, to lie between 2,500 and 5,000 years B.P., most probably in the middle of the range. The results of radiocarbon dating of the two basal samples indicate an age which is in agreement with the earlier estimate of age.

Date SRR-2030 (3,070 ± 60 B.P.), from the Betula-Coryloid-Herb L.P.Z., is older than expected. However, within the discussion of the pollen diagram (Chapter 4), there is considerable speculation regarding the age of events recorded at this level. Two points should be noted. Firstly, although the changes of vegetation recorded at Moss Cottage are similar to those of Turner's (1965) "extensive clearances" elsewhere, these changes have not been shown conclusively to be caused by human activity. Secondly, if these changes do indicate human activity around Linwood Moss, they may equally represent "Bronze Age" or "Iron Age" activity.

Assuming that the uppermost peat is very recent in age, the overall rate of peat accumulation (c. 0.65 mm/year) is acceptable. Deposition of the lower layers of peat was considerably more rapid than average, probably due to the high input of tree detritus, especially wood, which may remain less compressed than other peat components.

Linwood Moss Wood. The following radiocarbon dates have been obtained for samples from core LMW-80:

lab. no.	years B.P.	m below surface
SRR-2028	9,290 ± 90	3.44 - 3.46
SRR-2029	8,460 ± 80	3.64 - 3.66

The radiocarbon dates generally confirm the conclusions reached in the discussion of the pollen analysis (Chapter 8). Although there is slight uncertainty regarding the date obtained from the lower sample (see discussion below), the more acceptable date, SRR-2028 (9,290 ± 90 B.P.), is inseparable (statistically) from a date obtained from wood at the base of the peat at Clippens Farm (Birm-3, 9,231 ± 96 B.P., Shotton et al., 1967; Bishop & Coope, 1977) and, as in the case of Moss Cottage, the geological model for the Linwood area requires no modification.

The radiocarbon dates SRR-2028 and SRR-2029 show a very apparent age/depth inversion. Given that there has been no confusion of samples (and there is no reason to believe so), the most probable explanation is the presence of unrecognised contamination by younger carbon in sample SRR-2029 (D. D. Harkness, pers. comm.). There are several problems involved in the radiocarbon dating of peat. The majority appear to result from the downward movement of organic material in solution and the penetration of the deposit by living roots and rhizomes of plants growing on the peat surface. (Smith *et al.*, 1971a, p.124, 1971b, p.465; Aaby, quoted in Robinson, 1981, p.75; Robinson, 1981, p.75). *Phragmites* appears to be of particular importance in this context, since the penetration of peat by living *Phragmites* rhizomes is greater than that by the living root system of, e.g. *Carex* species. Although *Phragmites* macrofossils are not recorded at the base of the peat at Linwood Moss Wood, there is tentative identification of *Phragmites* pollen, which occurs in considerable quantities. This contrasts with the peat above the part of the core from which sample SRR-2028 was taken, in which pollen evidence suggests the presence of *Calluna*-*Eriophorum* bog vegetation.

Since the date for the lower sample is regarded as being too young, only the date from the upper sample (SRR-2028) is discussed. This date, 9,290 ± 90 B.P., was obtained from a sample representing the *Corylus* rise. Compared with a date of later than 9,000 B.P. (adapted from Birks, 1980, fig. 53), this date appears to be slightly older than expected. It must be noted, however, that Birks' figure is based on relatively few sites in central western Scotland. Furthermore, the Linwood Moss Wood date is of the correct magnitude and given the slightly non-typical order of development of the vegetation that occurred prior to the *Corylus* rise at this site (Chapter 6), a slightly early date poses no problems.

PART B

IRVINE-KILMARNOCK AREA

CHAPTER 9

INTRODUCTION

1. Previous work

The earliest reference to work on the raised coastal deposits of this area is made by James Smith in the late 1830s. In Smith's study of the fossiliferous deposits in west central Scotland, the Irvine area is at the margin. Quoting Landsborough, Smith (1938b) describes a water-worn cave near Largs which "was once the bounding barrier of the sea" (p.66) and is now separated from the sea by sand and gravel deposits commonly 18 to 25 ft (6 to 8 m) thick, overlying clay which contains a littoral fauna. The New Statistical Account for the parish of Ardrossan also contains reference to faunal evidence which indicates that "a considerable portion of the lower grounds of this parish was under the dominion of the sea" (Smith, 1938b, p.66). By 1841, the "subfossil sea shells" (Smith, 1838b, p.66) were divided into two distinct groups; at Stevenston, Landsborough (1841) collected only shells of recent species in the superficial raised coastal deposits, whereas in blue clay underlying such deposits, of 27 species collected, 8 were extinct or unknown. Smith (1839c, d) noted that fossils from newer and older beds were never mixed and, recognising that the latter fauna contained colder water species than are found at present, developed his ideas regarding climatic change.

Although little work in the Irvine area followed immediately after this, studies in the area of the Clyde progressed, and when Crosskey reported a section in the bank of the River Irvine in which whale bone remains had been discovered (Crosskey, 1864), the lack of laminated "Clyde Bed" deposits containing an arctic fauna was noted. Crosskey described a succession in which a thin "peat" overlying slightly weathered till was overlain in places by fossiliferous sand and gravel. The non-arctic fauna indicated conditions shallowing upwards. A short distance to the north, at Ardeer, sediments were described which, resembling those at Stevenston described by Landsborough, contained arctic and non-arctic faunas, the former in blue clay and the latter in overlying sand (Crosskey & Robertson, 1871a; Brady et al., 1874, p.67). The discovery of two valves of Leda arctica - Nucula Portlandica Hitchcock opened the debate regarding whether the beds in the east of Scotland, where L. arctica is common, are older and represent colder conditions than the beds in the west, where L. arctica had previously not been found. The problem, however, was left unresolved by the authors (Crosskey & Robertson, 1871a, p.129). Further discovery was made nearby (Robertson, 1877d) in the Garnock Water, of a shell bed containing Velutina undata (Smith), a species regarded as high arctic and very uncommon in the Clyde Beds. The shell bed, lying on till, was overlain by c. 12 ft (4 m) of sand and gravel. Near Kilwinning (Robertson, 1877e), a basal clay containing deep-water fauna also contained shallow water algae encrusted on stones with scrapings, which were in what were considered to be unusual locations. Robertson suggested that these were iceberg-transported drop stones.

While these investigations of exposed sections and faunas continued, the Geological Survey, as part of a general national survey, published several brief geomorphological descriptions of the raised beach phenomena in this area. Fragments of four terraces were recorded, lying at approximately 90, 60-70, 40 and 25 ft (27.4, 18.3-21.3, 12.2 and 7.6 m, respectively) (Geikie, 1869; Geikie et al., 1869; Geikie et al., 1872). The Survey officers were in little doubt regarding the origin of such features: "Reference has been made ..... to certain rather vaguely defined terraces of sand and gravel which occur at various heights along the Ayrshire coast. Probably some of these are remnants of raised beaches marking former sea-levels during the elevation of the country." (Geikie et al., 1872, p.30).

The 25 ft beach was described as "by much the most perfect example of a raised beach ...", forming "... a tolerably level platform ... varying from 20 to 30 feet (6.1 to 9.1 m) above mean tide-mark, and from 100 to 1200 yards (91 to 1097 m) in breadth" (Geikie, 1869, p.7). Although there were few exposures, those that did exist indicated that the terraces consisted of "layers of sand and gravel identical in character to those forming in the present beach" (Geikie et al., 1869, p.26).

Although Geikie et al., had been unable to find any suitable section to establish further details of the strata which constitute the raised beaches, during the next 30 years John Smith was able to construct a detailed picture (Smith, 1882, 1896a). From a series of sections exposed in sand quarries, railway cuttings and river banks, Smith suggested the existence of the following groups of "Surface Beds" (1896a, pp.48-50):

(1) Two boulder clays, separated in places by "interglacial beds", and formed during separate periods of glaciation.

(2) "Stratified iceberg-boulder clay", about 40 ft (12.2 m) thick and lying at c. 200 ft (61 m) above sea level.

(3) "High-level sands and gravels", up to 120 ft (36.5 m) over sea level and deposited when there was floating ice in the Firth of Clyde.

(4) "Beds of clay (Leda-clay), sand and gravel", from 33 ft (10.1 m) below sea level to 70 ft (21.0 m) above it, with arctic fauna, and resting on the lower layers of (3) at Kilwinning.

(5) "Forty-feet beach beds", containing in situ peat and recent fossils of non-arctic fauna. They represent depression of the land below sea level and subsequent elevation, during a period of climate similar to that at present.

(6) "Twenty-five-feet beach period", represented by terraces and possibly some of the shell beds.

(7) The present beach and deeper water deposits.

Finally Smith drew a composite section, parallel to the coast, of these deposits, and attempted to date some of them using pumice found on the 25 ft beach at Ardeer and the 40 ft beach at Shewalton (Reade, 1896; Smith, 1896b; cf. Binns, 1967a, b, 1972a, b).

On the basis of evidence provided by the drift deposits in Ayrshire, Smith later argued (1898) that not only were low-level beds ((3) to (6) above) due to submergence, but so also were the boulder clays: "From a study of the Ayrshire drift, I think we are warranted in abandoning all ideas of great "mountains of ice" conjured up for us by the imaginations of some geologists in trying to account for certain scratchings on hills and for the positions occupied at high levels by erratic stones and boulders." (p.121).

Since then there has been virtually no work on the raised beaches of the Irvine area. Anderson (1925) summarised most of the work to date, and gave information regarding the depth of the peat at Shewalton Moss, which surmounts the 25 and 40 ft beaches. He also described high raised coastal deposits in the Irvine valley, which include some of the workable brick clays containing marine, possibly arctic fauna, at Bankhead, Gargieston, Damdyke Bridge, Drumuir Farm and Caprington. Explanation is minimal, and later Geological Survey authors have nothing to add (Richey et al., 1925, 1930).

More recently, peat underlying the raised beach sand at Dundonald Burn was dated by radiocarbon analysis (Godwin & Willis, 1962; Ergin et al., 1972; Harkness & Wilson, 1979). The dates indicate that in early Flandrian times, sea level was only slightly higher than at present (Jardine, 1964). The beginning of the Flandrian transgression in this area was not dated. Other recent work consists of descriptions of fauna from the "Great Bend" section of the

River Irvine (Bertie, 1975; Akpan, 1981, ch. 7), and a brief description of three raised-beach terraces around the Shewalton-Barassie area (Holden, 1977, pp. 106 ff.).

The current state of knowledge in the area is presented by Jardine (1971). There is limited exposure of Late Devensian marine clay (to 12 m thick) with occasional shell layers and erratic rock fragments. These are overlain, up to c. 24 m A.O.D., by stratified sand and gravel. During the Flandrian Age, the Irvine area formed the largest of three marine embayments (Irvine, Ayr and Girvan areas) now filled with sediments. The sand is fossiliferous in places, and the surface has an irregular cover of dune sand and in places more than twenty ridges of gravelly sand. In figure 2 in Jardine, 1971, the inner edge of the Flandrian raised coastal sediments is drawn at the seaward edge of the Geological Survey's "higher raised beach" deposits.

2. Problems to be investigated

The Quaternary history of this large coastal area is incompletely understood. The main objective is therefore to establish a stratigraphy or stratigraphies for the sediments present and chronological index points. Following this, the aim is to establish time-development models for coastal evolution in the area, in which consideration is given to changes in coastline location, associated off-shore depositional and erosional environments, coastal on-shore environments, and sea-level changes. These models are compared with older models from the area, and with sea-level fluctuation curves from elsewhere in Scotland.

3. Introductory note

The locations mentioned in the text are shown in Figure 9.1.

More detailed discussion concerning problems to be examined is given at the beginning of each major chapter.

CHAPTER 10

SHEWALTON MOOR QUARRIES; FIELD SURVEY AND SEDIMENT ANALYSIS

1. Introduction

To the south of the River Irvine, approximately between north-south Nat. Grid Ref. lines 33 and 34, are several used and disused sand and gravel quarries. These lie in an area mapped as "Deposits of Raised beach with coast at 40 ft." (Sheet XVI S.W., Drift Version, Geological 6 Inch Map, 1911). Towards the coast, sand dunes and occasional peat occur in places.

The earliest extant extensive geological records for this area are bore logs from the Estate of Shewalton which are now kept by the Kenneth family in Dreghorn. Between 1861 and 1940, detailed records of both the superficial and solid geology were kept. The journals of about 60 bores covered an area bounded by lines joining the three points, c. 322 372 (immediately west of the Great Bend, River Irvine), c. 336 337 (near the A78 and A759 road junction, Hillhouse) and c. 358 365 (Drybridge) and including a strip of land north of the River Irvine. Within this area, the logs recorded variable thicknesses of sand and gravel, in places containing some clay. These sediments are occasionally overlain by, and contain, organic bodies. Commonly they overlie till directly, and occasionally they rest on solid rock.

Recently commercial and public developments, especially around Irvine New Town, have provided a vast amount of bore-log data. Although there is so much bore-log data, and despite enthusiastic use of commercial data by some researchers (Sissons, 1970, 1971; Menzies, 1981), the bore-log data within this area tends to be of limited use: borehole surface levels frequently were not recorded, sediment descriptions frequently were not detailed enough, and structural features rarely were recorded. Since core recovery on superficial deposits may not be complete (Lancaster-Jones, 1976) thin strata were not recorded, and frequently the cores were shallow, recording only the superficial dune and other differentiated sands. Such problems are not only recent (cf. Bennie, 1871).

About five hundred bore logs from the area between Barassie and Irvine were examined, but data from Irvine New Town were not studied due to the large amount of information present, the time required to study it and doubts regarding its usefulness. Certain material, however, did provide useful information; this is discussed later (Chapter 18).

Generally, the data provide a picture similar to that given by the older Shewalton Estate bore-log data. At a few sites terrestrial peat and shell-bearing sediments are recorded but, generally, unfossiliferous sand and gravel is present throughout the area. The sediments commonly are described as raised beach deposits, due to: (1) their association with fossiliferous sediments elsewhere (e.g. at Stevenston; Landsborough, 1841); (2) their geomorphological character (e.g. Geikie, 1869); (3) their sedimentary similarity to beach deposits (e.g. Geikie _et al._, 1869). The present day occurrences of large exposures in the sand and gravel quarries allows this explanation to be widely tested.

Introduction to sedimentological model. With virtually no fossil evidence for the marine nature of the sediments, attention must be paid to sedimentological characteristics. Sand and gravel is deposited in three main environments: fluvial, fluvio-glacial and coastal. The three main properties of sediments, texture, composition and structure (Pettijohn, 1957, p.7), are discussed briefly in relation to environments of deposition. In particular, characteristics are sought which may indicate, unambiguously, whether or not the sediments represent a fossil beach.

Texture. There are no characteristic size frequency distributions for beach sediments (Doeglas, 1946) since the size frequencies are dependent on those of the source material (Giles & Pilkey, 1965; Eisma, 1968). Sorting tends to be very good and typically unimodal and, due to the high energy environment and long distance of transport during alternate ebb and flood tides, rounding tends to be very well developed (Klein, 1977; Rust, 1979). Close to the sediment source, these characteristics can be used to distinguish beach gravel from fluvial gravel (Rust, 1979). Further, wave-worked coarse sediments tend to be better separated into discrete layers on the basis of grain size than river alluvium (Clifton, 1973) due to the variety of processes in action (Visher, 1969). Grain size increases inland (Reineck, 1967; Elliott, 1978), and as a beach progrades, under stable sea-level conditions, a coarsening-upwards sequence forms.

In fluvial sediments, sorting and roundness vary with distance from source (Rust, 1979). The distribution of grain size frequencies depends on the sediment location within the river; coarser material is found in the channels and finer sediments on the levees (Doeglas, 1946). River sediments tend, due to variable deposition and transport rates, to show a fining-upwards sequence (Allen, 1970, pp.132-134; Walker & Cant, 1979).

Fluvio-glacial sediments tend to be coarse-grained and poorly-sorted with a high degree of angularity, especially if derived from till (Sugden & John, 1976, p.329). They may be difficult to differentiate from upland fluvial or flood deposits but the angularity of the clasts is a distinctive feature. In some cases, rounding may be well-developed due to short-distance transport in a very high energy environment (Embleton & King, 1968, p.312).

Composition. Mineral composition is related to sediment source, transport processes and post-depositional environment (Pettijohn, 1957, ch.3; Giles & Pilkey, 1965). Quartz content generally increases with sediment maturity -

the degree to which a sediment has been differentiated or has evolved from the parent material. Since most beach material is redeposited fluvially-transported sediment (Bloom, 1969, p.113) non-shell-bearing beach sediments have a higher quartz content than fluvial and especially fluvio-glacial sediments.

Clay minerals - stable secondary minerals derived from the decomposition of chemically unstable primary minerals - tend to form (fine) clay-size clasts, so are absent in well-washed beach sand and gravel (Van Straaten, 1954a, 1960).

Heavy, stable minerals occur in sediments as minor components. In rivers they occur near the source, as intergranular "fines" within coarser material (Collinson, 1978a). On beaches, especially storm beaches and in the backshore beach section, efficient sorting produces heavy mineral concentrations (Lovinenko & Remizov, 1963; Reinson, 1979) which are increasingly more common inland (Depuydt, 1972).

Structure. The literature on sedimentary structures is extensive. The formation of primary structures in water-deposited sediments depends on flow velocity, particle size and flow depth (Harms et al., 1975). Details of structure are complex, but in general cross bedding dips in the current-flow direction. In river sediments, major structures, related to high-velocity flow, tend to dip downstream, and minor structures, related to low-velocity flow, tend to have more varied dip direction, with an overall downstream direction (Collinson, 1978a). In fluvio-glacial environments, variation in stream load is high, braided systems are common and, as in other coarse-grained, braided-stream alluvium, dip directions tend to be variable (Bluck, 1974, 1979).

Primary structures in beach deposits are also controlled by flow conditions. Tidal flow and wind- and wave-driven currents are important (Klein, 1967b), interacting to form a series of complex but predictable beach profile changes (Sonu & Van Beek, 1971). The resulting sedimentary structures vary, depending on location on the beach with respect to factors such as wave base, water table and tidal levels (Klein, 1970, 1971; Elliott, 1978). Generally, in intertidal sand bodies, uni- or bi-modal dip directions are diagnostic (Van Gelder, 1974; Klein, 1977). If the distribution is uni-modal, reactivation surfaces, smoothing the dominant tidal-flow ripples are present (Klein, 1977, p.25). In the back- and fore-shore parts of the beach, under all wave regimes, the dominant structures are gently seaward-dipping (2-3^{o}) laminations and steeper landward-dipping (to 30^{o}) laminations (cf. Lovinenko & Remizov, 1963). On the shore face, wave regime is more important, but in general small-scale, landward-dipping ripple laminations interbedded with seaward-dipping parallel laminations are present, the landward dips being higher angled (Elliott, 1978). Tidal and non-tidal coastal beach-ridge sediments are indistinguishable (Davis et al., 1972).

Destruction of primary structures by bioturbation increases seaward (Reineck, 1967) until, in the transition zone, bioturbation structures are dominant (Davidson-Arnott & Greenwood, 1976).

Summary of sedimentological model. Certain characteristics may be used to determine whether beach sediments are present at Shewalton Moor. Beach sediments will consist of well sorted, differentiated and rounded grains, largely of quartz, perhaps also with some heavy minerals. Structures will show a marked landward dip component, contrasting with fluvial sediments. The proto-River Irvine may have meandered sufficiently to have flowed inland in places, despite its general east to west seaward flow, but this will be recognisable by the limited distribution of landward-dipping structures.

Methods of investigation. The sites are named after adjacent place names, and these may not be the locally-used names (Fig. 10.1; Table 10.1). Site descriptions are based mainly on field observations, but in some cases the properties of the finer sediments have been investigated under a low power (x 8) Leitz binocular microscope. No mechanical analyses of grain size were made. Dip directions and angles given are mainly "apparent" rather than "true" values. The sections shown in illustration (Appendix 4) are diagrammatic representations of the exposed *in situ* sediments; slumped, overgrown or dumped material is not shown. Altitudes at the sites were levelled instrumentally using an "autoset" level.

2. Woodside Cottage Quarry, Site 1

Description. Site 1 lies beside the entrance to the quarry, *c.* 75 m E.S.E. of Woodside Cottage. The section (Fig. 10.2) is a south-facing face of a small pit, presently disused.

The main sedimentary units, from base to top, are:

(i) Medium to coarse sand, with well-sorted gravel layers and lenses, white and yellow, becoming browner eastwards; dip E, *c.* 20°. To west, light grey medium sand, no bedding structures. At base, very coarse gravel, horizontally bedded.

(ii) Medium sand, yellow and orange at top, white at base; dip E, *c.* 20°; overlying coarse gravel to east, but rests directly on the unbedded sand of unit (i) to the west. At east end, *c.* 0.11 m horizontally-bedded dark yellow sand, overlying an iron pan.

(ii)-(iii) Iron pan (80 mm thick), unconformity.

(iii) Variable yellow medium and coarse sand and gravel, little apparent bedding, but some easterly-dipping bedding at west end; at east end, 40-100 mm thick basal layer, well-sorted fine gravel.

(iii)-(iv) Soil "B".

(iv) Yellow medium sand, no apparent bedding, containing an irregular soil profile.

Table 10.1 National Grid References for the Shewalton Moor quarry sites

	Nat. Grid Ref.
Woodside Cottage Quarry Site 1	333 369
Site 2	334 369
Site 3	334 369
Site 4	333 364
Site 4a	334 366
Site 5	332 364 to 331 365
Shewalton Moor Small Quarry	334 364
Shewalton Moor Quarry Section 1	333 362
Section 2	332 362
Section 3	333 363 to 335 360
Section 4	335 361
Woodside Cottage North Quarry	333 371

Interpretation. The high degree of sorting and the easterly dip component suggest that the sediments are beach deposits. The following sequence of events is suggested.

(1) Formation of a storm beach, and deposition of at least 0.10 m of coarse to very coarse gravel.

(2) Landward migration over the storm beach of a foreshore ridge, forming the typically high-angled landward-dipping laminations (cf. Hoyt, 1962; Kraft et al., 1973) on the landward slope of the ridge. The coarse, well-sorted nature of these dipping beds represents the high preservation potential of material deposited here during and immediately following a high wave-energy storm period.

(3) Partial erosion of the foreshore ridge, possibly cutting a small cliff in the sand, and deposition, in places, of up to 0.10 m of coarse gravel.

(4) Landward migration of a foreshore ridge, again showing typically steeply-dipping laminations, but constructed of finer material than in (2). The horizontally-bedded sand may represent the gently seaward-dipping sediments deposited on the ridge crest and seaward slope (cf. Hoyt & Weimer, 1963).

(5) Extensive erosion of the sediments of both foreshore migration episodes, with minor deposition of fine gravel to the west.

(6) Landward migration of another foreshore ridge; steeply landward-dipping laminations are preserved only towards the west.

(7) Local marine regression, followed by the development of a soil (Soil "B"; probably a humus-iron podzol; Bown, in press) on the exposed surface. The position of the associated iron pan (the lower one) probably was controlled by the junction between sediments of the last ridge to form and the more compacted and perhaps slightly iron-cemented sand and gravel of the lower ridges. Biological activity in the soil may explain the lack of preserved sedimentary structures.

(8) Deposition of wind-transported sand, with at least one moderately long period of soil development, with which the formation of the upper iron pan was associated.

The section represents a common type of rhythmic form (Dolan & Frem, 1968; Dolan, 1971) known as "ridge and runnel topography" (Elliott, 1978). During fair weather conditions ridges form parallel to the coast and migrate landwards, infilling the runnel immediately up-beach. During storm conditions the beach is planed off, but later ridges re-form and the cycle is renewed (Davis & Fox, 1972). The development of this cyclical form appears to be favoured by moderately-high wave-energy conditions acting on flat, fine-grained meso-tidal beaches with abundant sediment supply (Elliott, 1978). The final progradation is represented by dune sand at the top of the section. At this site progradation was due to marine regression, followed by a period sufficiently long for soil to develop and, later, sand dunes were formed. Alternatively, the beach sediments were deposited in the outer nearshore zone where landward-dipping laminations are formed by the migration of lunate mega-ripples in non-barred high wave-energy conditions (cf. Clifton et al., 1971); the erosional unconformities and the upper proximity of dune sand, without the intermediate gently seaward-dipping bedding, suggest that, for this site at Woodside Cottage Quarry, this interpretation is not valid.

3. Woodside Cottage Quarry, Site 2

Description. Site 2 lies c. 50 m E.S.E. of Site 1. The section (Fig. 10.3) is a south-facing face and slope within a small disused part of the quarry.

The main sedimentary units, from base to top, are:

(i) Fine gravel, with some differentiation between well-sorted gravel and more poorly-sorted gravel with sand; dip E, c. 25°. Westwards the gravel rests unconformably on similar gravel, dip E,

c. 10°. In places further west, in occasional east-facing exposures, the sediment is horizontally-bedded.

(ii) Horizontally-bedded silty sand; in places, structures are unclear and sand appears massive. Basal 0.40 m is blue-grey and the upper 0.40 m is white-yellow. The basal sand contains horizontal layers and lenses (to 0.10 m thick) of organic detritus, including tree wood, bark and leaf remains and well-preserved Corylus nuts. 20 to 30 m eastwards, this organic layer is replaced by horizontally-bedded sand.

(iii) Sand with layers and lenses of very well-sorted fine gravel; dip E.

Interpretation. Using the easterly-dipping, well-sorted sediments as indicators of the beach environment in which these sediments probably accumulated, the following sequence of events is suggested.

(1) Landward migration of a foreshore ridge; the decrease in the angle of dip of the fine gravel towards the west may represent the ridge crest. The horizontally-bedded gravel further west may either be a strike section of these dipping beds, or represent the flatter-bedded sediments typical of the seaward slope of the foreshore ridge.

(2) The landward migration of the foreshore ridge was followed by erosion and deposition of the horizontally-bedded sand. Laminated sand predominates in the middle shoreface, with occasional ripple cross bedding (Reineck & Singh, 1973, p.316). Where sedimentary structures are poorly-preserved, lenses of organic detritus may infill ripple hollows (Van Straaten, 1954a). The organic detritus is derived from the land, but none is in growth position. If the sand is marine-deposited beach sand this implies marine reworking possibly of primary organic material, of fluvially-transported organic detritus, or of peat; the northerly long-shore drift in central Ayrshire and the proximity of Shewalton Moss to the south suggest that the latter is most probable. Drifted plant remains are common in sediments associated with tidal deposition (Van Straaten,

1954b; Klein, 1971). Alternatively, the sand may be fluvial alluvium deposited above or within the tidal range. Kumar & Sanders (1974), for example, use parallel-laminated sand, low-angle cross bedding and ripple laminations as indicators of the former presence of a shallow tidal channel.

In a diagram showing the internal structure of a migrating beach ridge (fig. 9, Davis <u>et al</u>., 1972) cross bedding in truncated by horizontal bedding which becomes cross-bedded inland. The sequence at Woodside Cottage Quarry Site 2 may therefore represent a landward-migrating beach ridge.

(3) Landward migration of a foreshore ridge, perhaps during lower wave-energy conditions than for the lowest ridge.

4. <u>Woodside Cottage Quarry, Site 3</u>

<u>Description</u>. The site (Fig. 10.4) lies <u>c</u>. 100 m S.E. of Site 2, and the section is part of a long west-facing quarry side. Most of the quarry side (<u>c</u>. 250 m in length) is obscured by slumped or dumped material; where visible, the sediments are typically horizontally-bedded gravel, sandy gravel and, less frequently, sand, and lie between <u>c</u>. 5.5 m (quarry floor), and possibly lower, and 12-13 m A.O.D. Three former ground surfaces are present at 12 to 13 m A.O.D., and there is a sequence similar to that at Site 1. One surface lies sub-horizontally on the horizontally-bedded sediments, whereas the other two occur within the overlying sand, and their surface levels are variable. The former ground surfaces are extensive, although one of the latter two is not continuous.

The main sedimentary units at Site 3, from base to top, are:

(i) Horizontally-bedded gravel and sand, well sorted and differentiated into distinct size-frequency layers; at the northern and southern ends cut by unconformity "A"; the horizontally-bedded sediments are the same as the dipping gravel as Site 2.

(ii) Cross-bedded white sand, infilling depressions in unit (i); cut by unconformity "A"; the basal layers also contain organic detritus.

(iii) Thin sandy gravel layer, wedging out northwards.

(iv) Fine white to grey horizontally-bedded sand, at least 0.5 m thick; equivalent to the horizontally-bedded silty sand at Site 2.

Interpretation. Similarity between sediments at this site and at Site 2 allows the following sequence of events to be suggested.

(1) Landward migration of a large foreshore ridge, under moderately high wave-energy conditions, involving landward storm beach migration and minimal erosion. Alternatively, the great thickness of sediments that is present may reflect rising sea level associated with continuous supply of sediment; the vertical growth of a foreshore ridge, or series of ridges, occurs with minimum erosion, remaining in approximately the same location. Although transgressive sequences are unlikely to be preserved (Klein, 1974, quoted in Reinson, 1979), they may be, given rapidly-rising sea level (Kraft, 1971, 1978).

(2) Erosion of the beach ridge by channels. No evidence indicates flow direction, but the presence of organic detritus at the base of at least two of the channels suggests an inland source for the water. Cross bedding, predominantly dipping northwards, shows lateral infilling of the channels from the south, perhaps due to high-tide longshore current influence. Alternatively, the cross-bedded sand layers may be point bar foresets, formed when the channel contained a meandering stream. Lack of a horizontal or sub-horizontal lag deposit suggests that the channel was not active for long, and did not migrate laterally. Abandonment of the channel and subsequent

recutting of new channels is evidenced by the smaller channels to the north and south of the main one. The channels may be drainage for a beach-ridge-dammed lagoon (cf. Jardine, 1973) such as may occur where a large beach ridge develops due to the rapidly-rising sea level. The location of such a lagoon changes with time, and the channel is expected to re-form in a location such as at Site 3, where erosion through the sandier channel deposits of the previous channel is easier than through the more gravelly beach deposits.

(3) Erosion, perhaps during a storm period, resulting in a horizontal unconformity and, in some places, a well-sorted gravel deposit. The lateral discontinuity of the fine gravel may reflect the northward transport of a storm lag deposit formed as lower sand and gravel was eroded. The fine-grained channel deposits would not provide such a lag deposit.

(4) Deposition of the upper horizontally-bedded sand, was probably on a beach. The lateral southwards extension of this bed from Site 2 to beyond Site 3 suggests that a fluvial origin in unlikely.

The sediments at this site and at Site 2 probably represent sedimentation under conditions of steadily-rising sea level, with beach surface level fluctuating in response to tidal and seasonal changes.

5. <u>Woodside Cottage Quarry, Sites 4 and 4a</u>

<u>Description</u>. The sections (Fig. 10.5) are <u>c</u>. 300 m south of Site 3, near the southern end of the quarry face discussed above. Site 4 is a north- to W.N.W.-facing exposure with the following sedimentary units from base to top:

(i) Medium-grained sand, horizontally-bedded; overlain by <u>c</u>. 0.40 m of cross-bedded sand, dip N., <u>c</u>. 30° in places, horizontal elsewhere.

(ii) Medium-grained sand; at the north end of the section, horizontally-bedded, occasionally appearing massive, with cross bedding near the top; southwards, large-scale cross bedding, indicated by a fine- to medium-grained gravel layer, overlain by cross-bedded sand with a few thin (to c. 0.10 m), moderately well-sorted gravel layers; dip c. 20°. In W.N.W.-facing part of the section, bedding is horizontal.

(iii) Erosion surface, overlain by fine- to medium-grained gravel, which in turn is overlain by differentiated sand and medium- to coarse-grained gravel layers, all horizontally-bedded. At the top, c. 0.60 m coarse sand, dip N.E., c. 10°.

(iv) Horizontally-bedded sand and gravel containing occasional northwards-dipping cross bedding. At the top a former land surface occurs, overlain by massive medium-grained sand containing at least two former land surfaces.

About 75 m to the north, the cross-bedded sand and gravel (unit (ii)) is replaced by a very well-sorted and well-rounded, iron-stained medium to coarse gravel (dip E., 10-15°). The dipping beds are truncated by overlying horizontally- and cross-bedded sand and gravel layers. The gravel overlies sand, dipping both eastwards and westwards.

Interpretation. The landward dip of the cross-bedded sediments suggests a beach origin for these deposits. The suggested sequence of events follows.

(1) Following a possible, unrecorded storm event, a transgressive ridge and runnel landward-migration sequence was deposited. The seaward- and landward-dipping cross bedding (at Site 4a) is similar to the "herring-bone" variety of cross stratification typical of tidal flats (Klein, 1972a). Overlying these beds is sand and gravel representing a ridge with a c. N.N.E.-S.S.W. strike.

(2) Erosion of ridge sediments followed by deposition of a thin lag deposit. Overlying this is horizontally-bedded sand and gravel probably deposited on the beach face. The low seaward dip typical of such sediments (c. 2 to 3°) is difficult to detect, especially since the orientation of this section is closer to that of the beach strike than dip direction.

(3) The landward migration of a smaller beach ridge than the earlier ridge is recorded in the upper cross-bedded sediments (unit iii). Again the section is not perpendicular to the strike but, as indicated by the more gently flattening of the bedding towards the northern end of the section, the strike of this ridge is slightly different from that of the lower ridge, being aligned nearly north-south.

(4) The final beach phase is shown by the horizontally-bedded sand and gravel (unit iv), and probably represents the beach face. The horizontal bedding may represent the very gently seaward-dipping laminations which, commonly, are interstratified with smaller-scale landward-dipping cross-bedded ripple lamination.

(5) Local marine regression was followed by development of a land surface on the beach sand, the later periods of sand dune expansion being interspersed with periods of formation of land surfaces.

6. Woodside Cottage Quarry, Site 5

Description. The site is a series of exposures in a drainage stream for Shewalton Moor Quarry. Much of the sediment is disturbed, but part is *in situ*. The section (Fig. 10.6) is *c*. 110 m in length and faces south-westwards in most parts. The main sedimentary features are given below:

(i) At the base, massive, very stiff blue-grey plastic clay becoming sandier in the top 0.15 to 0.20 m, and the top surface of which appears to be moderately level. A sample from point A (Fig. 10.6), examined for macro- and micro-fossils, appears to be non-fossiliferous.

(ii) Grey sand, in places changing upwards to yellow-orange and higher to yellow-white; contains occasional gravel; at one location there are faint traces of cross bedding, dip S.E. Within the sand there is a 50-100 mm thick layer of organic detritus, containing leaf and wood fragments, and at one place it is replaced by a thin (*c*. 10 mm) layer of fine-grained gravel. At one location, an organic detritus lens (*c*. 0.25 m thick) lies directly on the clay, below the organic layer.

(iii) To the south-east, the basal clay is not exposed. The main sediment is a very coarse-grained gravel, which fines downwards; dip S.E. Overlying the gravel is a thin layer (c. 17 mm thick) of white and yellow sand, overlain by alternating layers of grey and white sand units and layers and lenses of organic detritus.

Interpretation. The following sequence of events is suggested.

(1) Deposition of the basal clay by an unknown process. The sediment is either a glacially-deposited till or a water-deposited clay. The extremely level, extensive upper surface suggests the latter, but such a surface may also have been caused by efficient erosion of till although a more irregular erosion surface would be expected. Assuming the aqueous nature of the sediment, it is not clear whether the clay is a freshwater or marine deposit due to the lack of indicator fossils (Collinson, 1978b; MacDougal & Prentice, 1964) or sedimentary structures (Van Straaten & Kuenen, 1958). The basal clay at Woodside Cottage Quarry is extensive, underlying the quarry floor at most places (Kenneth Bros., pers. comm.). The wide extent and geomorphological setting of the clay suggests that the deposit is probably not a freshwater alluvial or lacustrine clay.

(2) Possible erosion of the clay surface and deposition of the gravel beds, may be associated. The top surface of the clay is not necessarily an erosion surface, but the gravel, deposited by a predominantly landward-flowing current is regarded as a beach deposit, and thus it is highly probable that the clay has been eroded.

(3) Deposition of sand and organic detritus layers. The organic layers consist of inwashed material, in a situation similar to that at Site 2. The discussion for that site is relevant here. Increased reddening upwards within the sand suggests at least partial exposure of the sand and possible development of a soil (cf. Rose & Allen, 1977; Bown, in press); the deposition of organic detritus may have occurred around sea level. The presence of the

large organic lens supports this suggestion, the lens probably having been transported in one piece and thus having a local source.

7. Shewalton Moor Small Quarry

Description of the site. The site is a small disused sand and gravel quarry, c. 70 x 200 m in area (Fig. 10.7). The eastern part of the quarry is largely overgrown and although the floor, lying higher than in the western part, is composed of gravel, it is not clear whether this gravel is *in situ*; the quarry sides are in blown sand or dumped material.

Section 1. There are two main sedimentary units in this section (Fig. 10.8):

(i) At the base, medium- and coarse-grained sand, gravel and organic detritus, dark blue-grey, except near the top where there are "lobes" of iron-staining and above the uppermost organic layer the sand is yellow; dip E., c. 20°; erosion surface between these beds and underlying white sand. Four main layers of organic detritus vary in thickness, dividing and merging; they are very rich in well-preserved remains of tree leaf fragments, *Corylus* nuts, *Menyanthes* seeds, twigs and larger wood fragments, moss fragments and grass-like herb material. To the west is massive, unstratified white-yellow sand.

(ii) Medium- to very coarse-grained gravel; some clasts are greater than 0.20 m in diameter. Overlying the gravel layer is horizontally-bedded sand to coarse-grained gravel, moderately well-sorted and showing a high degree of differentiation into beds comprising clasts similar in grain size.

Section 2. This section (Fig. 10.9) lies c. 30 m south of Section 1.

Unstratified yellow and white sand, containing in its upper parts lenses of organic detritus and occasional gravel clasts, is overlain by blue-grey sand and irregular layers which are very rich in organic detritus, including tree leaf fragments, large wood fragments and *Corylus* nuts. The organic beds apparently dip N., very gently, but a section at right angles shows the dip to be E. These sediments are truncated by a gravel layer and horizontally-bedded sand with occasional gravel.

Section 3 and beyond. About 13 m east of Section 2, a hund-dug pit section (Fig. 10.9) shows approximately horizontally-bedded grey sand together with brown and black organic detritus, overlying well-sorted grey coarse sand.

East of Sections 1 to 3, the quarry floor generally extends downwards to the organic detritus layers. In this area the beds are approximately horizontal, and become thinner and wedge out c. 50 m east of Section 1. The eastward edge of the area is marked by the lack of surface scatter of organic detritus. In places the layers are moderately thick (0.15 to 0.20 m), very compacted and very rich in organic remains. Much of the material probably is primary, although some peat pebbles are included in the debris. Beyond the limit of the organic detritus the quarry is cut into featureless sand, similar to that underlying the organic detritus.

Sections 4 and 5. At the western edge of the quarry (Fig. 10.10) unstratified sand, similar to the basal sand at Section 1 and elsewhere, is overlain by an inclined bed of very coarse gravel, often only one boulder thick, with an apparent dip of c. 1° to the south. Overlying this layer is horizontally-bedded sand with occasional gravel.

Section 6. This is a large section (Fig. 10.11) on a curving face which is south-facing at the east end and south-east-facing at the west end. There are three main sedimentary units, from base to top:

(i) Sand to medium gravel, with occasional organic detritus; horizontal at the west end; dip E., c. 25° elsewhere in the section.

(ii) Coarse to very coarse gravel, to 0.50 m thick, underlying horizontally-bedded yellow sand with thin black layers, occasional gravel and isolated pebbles. At the east end, occasional cross-bedding, dip E.

(iii) Well-sorted sand, consisting of thick white-yellow and thin dark layers, no gravel or small-scale cross bedding; in the south-facing section the sand comprises long, thin horizontal laminae, in the S.E.-facing section, large-scale dune bedding is present.

Interpretation. The evidence from all the sections is discussed collectively. The following sequence of events is suggested.

(1) The main event recorded in this quarry is the deposition of organic detritus, apparently in a shallow pool, elongated north-south, probably with its steeper side seawards. Indications of soil development at the top of the underlying sand exposed at Section 1 suggest sub-aerial exposure of this sand for at least a short period. Some of the sand between the organic layers may be wind-blown, but the presence of the coarser-grained material implies deposition by water. Van Straaten (1957a) describes sediments at Velsen, in the Netherlands, which he considers to be of local significance only. These are coarse sands with intercalated bands of peaty and sandy clay, which split and converge laterally; both marine and freshwater molluscan remains were found, and it was concluded that "the curious alternation of these (beach) sands with fresh water deposits can probably be best explained as having originated on a dune covered beach plain .... The peaty clays were then formed in shallow swampy ponds of fresh or nearly fresh water. The sands may have been transported by westerly winds in the shape of smaller or larger dunes. It is also possible that they have been deposited by the waves of the North Sea themselves, which, during rare but violent storm surges, flowed over the lowest parts of the landscape in inland directions." (Van Straaten, 1957a, p.176). Although there are certain sedimentary differences at Shewalton (no clay nor faunal evidence) the situation is similar to that at Velsen, so the origin of the lower sediments may be explained in a similar manner.

Similar alternations between deposition of (freshwater) peat and marine sediments in East Sussex is interpreted as representing the periodic breaching of coastal barriers during storms and at high spring tides (cf. Steers, 1953), and the subsequent flooding of fresh-water deposits lying in sheltered localities at or slightly below H.W.M.S.T. (Jennings & Smyth, 1982).

(2) The area was flooded, the pre-existing sediments eroded and a storm gravel deposited. The inland extent of this gravel is unknown; gravel does not appear further east in the quarry and, although it may have been removed during excavation, the eastward (landward) limit of the gravel is probably not far from the position of Section 1. With the exception of the organic detritus, the sediments here are similar to sediments representing series of migrating ridges and runnels located in Woodside Cottage Quarry (Chapters 10.2 to 10.5); the elongate hollow, infilled with organic detritus may thus have been an infrequently inundated runnel behind a high beach ridge. The presence of the storm gravel indicates that, whatever the nature of the hollow, it lay near sea level and close to the coast.

(3) Deposition of horizontally-bedded sand and gravel. At Sections 1, 4 and 5 the sand and gravel is not cross bedded, providing no indication of current direction, but the high degree of grain-size differentiation among the layers suggests a beach origin. Slightly higher, at Section 6, the sand and gravel layers dip landwards, and appear to represent an infilling runnel and the landward migration of a beach ridge.

(4) Erosion, deposition of storm gravel and the formation of a sandy beach. The gravel is not present to the west of Section 6, and may be a relatively small lag deposit. Overlying the gravel is a layer of horizontally-bedded sand with occasional gravel, and infrequent eastward-dipping cross bedding, representing a beach face, with laminations dipping very gently seawards and smaller-scale landward-dipping ripple bedding.

(5) Deposition of aeolian dune sand. The internal structure of dunes is poorly known (Collinson, 1978c); generally fossil dunes are recognised by very large scale cross bedding, often with "sweeping" or wedging sets (Walker & Middleton, 1979) and smaller-scale features, frequently indistinguishable from sub-aqueous structural features (Hunter, 1977). The former features are present in Section 6.

8. Shewalton Moor Quarry

Introduction. Shewalton Moor Quarry is a large area with several temporary exposures, mainly around an irregularly shaped "island" (c. 100 m diameter) of sand with a capping of thick peat, dune sand and spoil heaps. Most of it had been removed by Autumn 1981. At the time of the investigation the peat and overlying dune sand were visible but the underlying sediments were obscured by slumping. An east-facing exposure was cleared (Section 1; Fig. 10.12). Section 2 is a south-facing exposure, c. 100 m west of Section 1, from which cores were taken for pollen analysis. Section 2 is considered in detail in Chapter 11.3, but relevant information is presented here. The sediments lying below the quarry floor have been exposed in several temporary drainage ditches and holes, and hand-dug holes were also made. These form Sections 3 and 4. Hand augering, although attempted, was of little use; the water table lies immediately below the quarry floor and the sediments sampled with the auger tend to run together.

Sections 1 and 2. The following sedimentary units are distinguished at Sections 1 and 2 (from base to top):

(i) Basal gravel, medium- to coarse-grained with pebbles to 200 mm in length; overlying white sand, at least 750 mm thick.

(ii) Yellow and white sand; basal 2 m medium- to coarse-grained sand with some fine gravel and occasional coarse gravel (clasts to 50 mm in length); little obvious bedding, although in certain east-west sections nearby, small-scale cross bedding, dip E., is apparent, with thin laminae of coarser sand. The upper c. 1 m is fine- to medium-grained well-sorted white sand; lamination is horizontal in all sections; occasional thin layers and lenses of organic detritus are present.

(iii) White sand; generally structureless, with occasional dune-type or horizontal bedding. Conformable base, unconformable top; at top, signs of soil development and iron-staining of the sand; at Section 2, part of a bleached "A" horizon is present, and in places, the sand contains thick *Calluna*-like roots, occasionally to c. 1 m below the peat base.

(iv) Peat; basal 0.35 to 0.40 m is fine, dark brown peat containing herb detritus, small wood fragments, seeds and nuts; middle 0.35 to 0.40 m is a darker peat containing herb material, nuts and seeds, but typically with much larger wood fragments, with almost entire tree trunks and boles, fragments up to 2 m in length and 0.60 m in diameter and occasionally larger; the upper 0.20 m is sandy peat with sand lenses.

(v) Blown sand, lying unconformably on the irregular and partially-eroded peat surface.

Section 3. During the summer of 1981 water level in the quarry was kept low, extensively exposing an organic detritus layer, c. 0.20 m thick, lying at c. 5 m A.O.D. The layer contains large (to 0.20 m) wood fragments, twigs, tree leaves (some complete), peat pebbles and other unidentified amorphous organic material. In places the organic layer, broken into several layers or lenses, is interbedded with fine- to coarse-grained, iron-stained gravel. Above the gravel are layers of fine to coarse sand and fine gravel with ripple cross bedding in east-west sections. Within the ripple hollows, up to c. 6 m A.O.D., there are organic detritus lenses, containing wood and grass fragments, *Corylus* nuts and peat pebbles. Underlying the organic layer is hard white sand, which contains roots and is leached at the top, browning downwards at about 0.30 m from the top. In places the sand is very hard and contains a high proportion of clay. Approximately 0.30 to 0.50 m below the top of the sand is fine- to coarse-grained well-sorted and, frequently, strongly iron-stained gravel. The organic detritus thins to the west, being absent around Nat. Grid Ref. NS 332 361.

Section 4 (group of sections). Hand- and machine-dug holes east of the south end of the ditches show widespread evidence of the presence of the clay layer underlying the bed of organic detritus. Here the bed of detritus consists occasionally of a greatly-compacted leaf bed which may be an in situ detritus. The top of the clay lies between local datum level (water level in the ditch, on one day) and -0.50 m. The thickness is also variable (0.10-0.70 m, but mostly 0.10-0.15 m). The clay overlies at least 1 m of white or yellow unfossiliferous sand, and underlies white, unfossiliferous, moderately well-sorted medium sand with fine sand to fine gravel. Frequently the clay becomes browner upwards, containing organic material. The clay was examined for microscopic fossils, of which none was found. The clay is extensive, occurring in an area at least 100 m square; the extensive perched water table in the quarry suggests that the effects of this impervious layer is widespread.

Interpretation. The following sequence of events is suggested (cf. Fig. 10.13).

(1) Deposition of the lowest sand, with gravel, and near the top towards the east, clay. This is interpreted as a depositional tidal-flat sequence (Van Straaten, 1954a,b, 1957a, b, 1961; Klein, 1967a, 1971, 1972b). The gravel lying within the lower sand may represent the lag deposit of migrating tidal channels which, if containing marine fossils (absent here) is strong indication of tidal-flat conditions (Van Straaten, 1961). As tidal-flat deposits grow, a fining-upwards sequence is produced as the low, middle and high tidal zones, with increasingly fine sediment, move seawards. At Shewalton Moor Quarry, such a sequence may be represented; from west to east there are: sand

with possible channel lag deposits; sand and some clay; sand with a distinct clay layer. Within the clay layer, the browning upwards and presence of occasional organic matter suggests the development of salt marsh.

(2) Marine regression, followed by a period in which sub-aerial conditions prevailed sufficiently long for soil development to take place (cf. Streif, 1979). The lack of a complete fining-upwards sequence suggests that regression was rapid. Generally, salt-marsh and reed swamp vegetation become well established at H.W.M.S.T. (e.g. Gray & Bunce, 1972) or slightly above it (e.g. Gillham, 1957), in which case, mixed moorland vegetation rapidly replaces the reed-swamp vegetation, and deep peat is deposited within 1 m above H.W.M.S.T. H.W.M.S.T. need not have been lower than c. 4.5 m to 5 m A.O.D. at Shewalton Moor Quarry. The present mean range of spring tides locally is 3.8 m (Hall, 1974) so, assuming no substantial change, the relevant former mean sea level lay at c. 2.5 m A.O.D.

(3) Local marine transgression, with possible considerable erosion; the thin, possibly in situ leaf bed may represent part of the soil profile formed after the regression, but generally there is no in situ soil in the sand, and the organic detritus layer, especially where it is interbedded with gravel, may be the reworked vegetation and soil or detritus brought in from marine erosion of sites inland of this location.

(4) This stage is characterised by deposition of c. 3 m of sand in the middle foreshore, without evidence for beach ridge formation and upper beach storm erosion and deposition, suggesting that sea level rose c. 3 m.

(5) Local, comparatively rapid marine regression and growth of sand dunes. In the thin layer of sand between the beach sand and the upper peat there is occasional dune bedding. Coastal dunes are fragile and severe erosion of the fore dunes and larger yellow mobile dunes is common, so the limited thickness of sand is no problem. If the rate of

rise in sea level decreased, the balance between erosion and deposition may have changed sufficiently for fore dunes to prograde, fed by an increasing source of sand at the same time as the beach, formerly covered by the rising sea, became more susceptible to wind erosion during periods of low tide. The position of the coastline therefore may have been influenced by local conditions, and the regression need not have been due to falling sea level (cf. Hoyt, 1968). The lack of an intervening soil horizon at the base of the dunes suggests that progradation was rapid during the regression, in contrast to the situation elsewhere, where fossil soil horizons indicate a lag between regression and dune progradation.

(6) Development of a soil on the dune surface, its subsequent erosion and deposition of peat, which was later covered by encroaching dunes. Fossil soils are not apparent within the dunes, and it is not clear whether the peat is equivalent to one or other or both of the organic layers of the soils seen elsewhere within the overlying sand dunes.

9. <u>Woodside Cottage North Quarry</u>

This is a disused and partially infilled quarry with limited exposure. At one location, bedded sand overlying a till surface dipping northwards was briefly exposed in an artificial stream. This site was not re-discovered due to slumping and infilling of the quarry. The level of the till surface is estimated as <u>c</u>. 4 to 6 m A.O.D.

CHAPTER 11

SHEWALTON MOOR QUARRIES; POLLEN ANALYSIS

1. Shewalton Moor Quarry, basal organic detritus layer

An organic layer associated with clastic sediments representing changes in sea level is important, since it indicates that the level of H.W.M.S.T. has fallen below the level of this layer (Chapter 10.8; Tooley, 1978b, pp. 18 ff.). The organic material may also provide datable samples. The detritus at Shewalton Moor Quarry, however, has certain disadvantages. It consists of two types of material; *in situ* and re-worked detritus. The former must date from after a regression but before a later transgression; since an erosional transgression appears to have occurred, the top of the *in situ* bed may be missing and there is an unknown time gap between organic deposition and the ensueing marine transgression. The reworked detrital material may be derived from the contemporary vegetation or, alternatively, from erosion of older peat.

Pollen analysis of the detritus bed was used to give an approximate date for the transgressive and regressive events. The *in situ* bed is not extensive and when samples were being collected for dating at this site, the bed could not be re-located. For the purposes of pollen analysis, therefore, a bulk sample of reworked material was collected, although it was appreciated that the age obtained in this analysis would be no more than a maximum age for the transgression. Also, since the material is reworked, the organic layer has no chronologically-significant internal stratigraphy, and analysis therefore reflects an average age of sediments with ages within an unknown range.

The detrital layer lies near the base of a thick succession (3 to 4 m) of beach sediments, so an early Flandrian age was expected. The presence or, less importantly, absence of certain pollen taxa indicates, in sediments of variable age, the minimum age of the sediments involved. The following markers are used:

(1) High tree values, especially of Betula: post-Late Devensian, after c. 10,000 B.P.

(2) High Coryloid: post-Corylus rise, after c. 8,800 B.P.

(3) Presence of Quercus and/or Ulmus: post-Boreal age, after c. 7,000 to 8,000 B.P.

(4) High Alnus: post-Alnus rise, after c. 7,000 B.P.

The dates are approximations (see discussion in Chapter 13.4, etc.; Birks, 1977, 1980; West, 1977, p.329, etc.). Following the Alnus rise no regionally significant influx or increase in any particular taxon may be used. Marker (3) is the least reliable and (1) and (2) are more reliable.

Initially one sample was analysed. The sample is from the organic detritus layer where it is interbedded with gravel, c. 20 m east of Shewalton Moor Quarry Section 1. Pollen is very scarce and generally in poor condition, presumably reflecting the washed nature of this re-worked deposit, and this pollen was exceptionally time-consuming to count. Bearing in mind the low degree of resolution inherent in this particular analysis, further analysis would have required a disporportionate effort for such potentially low-reliability answers. This, therefore, was the only sample analysed. Since only few grains were counted, error limits are present (Maher, 1972).

The results (Fig. 11.1) show significant amounts of Betula (average 21%) and Coryloid (34%), Quercus, Ulmus and, most significantly, Alnus being absent. Other taxa are insignificant, representing contemporaneous nearby marshy conditions (Cyperaceae, Filipendula, Menyanthes, Sphagnum and Pediastrum) or erosion of peat representing such conditions. The presence of the pre-Quaternary spores testifies to the, at least, partially-allochthonous nature of the deposits.

The Coryloid presence and *Alnus* absence suggests a *c.* 1,800 year age range. The high Coryloid values and the lack of *Quercus* and *Ulmus* suggests an early rather than late age. The marine transgression probably occurred during the 9th millenium B.P. Further analysis is unlikely to provide any greater precision and the decision to analyse only one sample therefore is justified.

2. Shewalton Moor Small Quarry

This site is important for two reasons: depending on the interpretation accepted for the origin of the infilled hollow (Chapter 10.7), the sediments at the site may be regarded as the base of the transgressive sediments in this area; this site is regarded as being near the inland limit of the transgression.

Therefore, the age obtained for the deposits may contribute to the chronology of the fluctuations in land-sea level responsible for the deposition of great thicknesses of sediments in this area.

Two box cores were taken from a cleared face at Section 1 (Fig. 10.8). The most noticeable feature of the sediments is the recurrence of coarsening-upwards cycles (Fig. 11.2). In some cases these commence with an organic detritus layer, but in other cases the cycle consists solely of clastic sediment. The regular nature of the cycles suggests sedimentation under regularly-fluctuating water-level conditions; perhaps tidal activity is represented, with water velocity increasing as the tide rises. The hollow was sufficiently sheltered or near the upper limit of the tidal zone for minimal erosion. However, the sediments possibly represent storm events such as described by Van Straaten (1957a) when this site was sufficiently inland or sheltered to receive storm waters but not be eroded by them. The former process (tidal effects) is more probable.

The contained macrofossils (Fig. 11.3) are similar to those found elsewhere in these layers (Chapter 10.7), although Menyanthes seeds are absent. The main fossils are fragments of tree leaves and wood.

The pollen (Fig. 11.4) is generally very sparse and poorly-preserved. Since the organic layers represent in-washed detrital material, the discussion regarding the lack of chronologically-significant internal stratigraphy (Chapter 11.1) holds good here. Consequently, the results from all samples in each layer are amalgamated, providing statistically-acceptable samples, and thus overcoming some of the problems of pollen scarcity. The discussion is based on the lower part of Figure 11.4, although the variability within each layer (upper part of Fig. 11.4) must be borne in mind.

Only a maximum age of the detrital material can be obtained (Chapter 11.1). The deposit is clearly post-Devensian, and was formed under post-Corylus rise conditions. High Alnus values (c. 30%) suggest that part of the diagram represents post-Alnus rise times; low Alnus value (c. 6%) at the base may suggest that the Alnus rise occurs here. A few points query such an interpretation:

(1) The presence of an Alnus fruiting cone indicates the local presence of Alnus. Although Alnus is present at many sites prior to the Alnus rise (e.g. Vasari & Vasari, 1968; Birks, 1975), more probably Alnus macrofossils and pollen would occur together after the Alnus rise.

(2) The presence of Alnus fruits suggests deposition when Alnus pollen was not present, e.g. during the summer or autumn (Hyde & Williams, 1944; Hyde, 1952; cf. Boyd, 1979, pp.43 & 47, 1980). If these sediments were deposited at a high-tidal location, each organic layer may represent only a short period of deposition. Also, it follows that the organic detritus is primary material rather than secondary, re-worked peat, and therefore its age represents the true date of deposition rather than a maximum date.

(3) If deposition occurred after the *Alnus* rise, moderate values (5-15%) of thermophilous tree species pollen, such as *Quercus* and *Ulmus* are expected. Except for small amounts of *Ulmus* pollen, this is not so. The spectra represents local damp conditions, with *Alnus*, *Salix*, *Corylus*, Gramineae, *Menyanthes* and *Sphagnum* represented. In addition, the localness of the source is supported by the presence of clumps of Gramineae grains and the well-preserved condition of Cyperaceae pollen. It follows that the absence of *Quercus* and *Ulmus* pollen, like the low values of *Alnus*, may not be significant in terms of regional trends. Similarly, the absence or minimal presence of *Ulmus* pollen cannot be used to indicate that these deposits date from after the *Ulmus* decline.

In conclusion, the sediments at this site were deposited at an unknown time after *c*. 7,000 B.P.

3. Shewalton Moor Quarry

Introduction. At Section 2 (Chapter 10.10) peat lies within sand-dune sediments that overlie raised-beach sediments. Analysis of the peat here therefore will provide a minimum age for the marine regression.

Results. The peat was collected in two box cores taken from an opened face. The base of the peat, although unconformable, has a "ragged" appearance, occasional peat layers and lenses occurring within the underlying sand. The base, undulating slightly in detail, generally is approximately horizontal at this site, rising gradually to the west. The peat apparently thins out in all directions (Kenneth Bros., pers. comm.) and most of it has been quarried; there are no traces of peat at any of the quarry edges. The peat appears to have infilled a saucer-shaped depression, perhaps 200 m in diameter. The level of the peat base above Ordnance Datum is estimated to be very similar to that at Section 1, i.e. *c*. 8.5 m A.O.D. Sections 1 and 2 are located in the areas of deepest and thickest peat.

The results of the macrofossil analysis (Fig. 11.5) indicate three main strata (Fig. 11.6). The basal 0.18 m is dark woody herb peat with indications of locally wet conditions (seeds of Juncus conglomeratus/effusus, Carex spp. and Cyperaceae), but charcoal and Cenoccocum geophilum may reflect nearby drier conditions. In the middle part (0.18 to 0.48 m above the base) dark woody Sphagnum and herb peat contains indicators of more extreme dampness: small numbers of J. conglomeratus/effusus seeds and many remains of Carex spp., Eriophorum vaginatum, Potamogeton spp., Menyanthes trifoliata, Viola palustris, Sphagnum and other mosses. At the top (0.48 to 0.71 m) lighter-coloured woody peat with sandy lenses contains clear indications of increasingly-dry conditions, such as frequent Calluna remains, an ericaceous flower, charcoal and the absence of Sphagnum. Yellow-orange dune sand lies unconformably on the peat.

By inspection of the pollen diagram (Figs 11.7 & 11.8), the following pollen assemblage zones are defined. All values are percentages of total pollen and pteridophyte spores.

SMQ-81.1 "Quercus-Alnus Local Pollen Zone"

Samples 1 to 3 (5 samples); from peat base to c. 0.22 m above the base.

The main feature is the high level of tree pollen values (48-58%), with Quercus (20-25%) and Alnus (20-30%) providing most of the tree pollen. Betula is low (2-10%), peaking to 22% in the top sample, and Pinus has low but constant presence. Herbs are low in value (5-7%, excluding Cyperaceae and Gramineae) and diversity is low. Gramineae has values of c. 20%, except in the top sample, in which it drops to 4%. Cyperaceae has values of 3-14%.

SMQ-81.2 "Cyperaceae - Gramineae Local Pollen Zone"

Samples 11 to 4 (3 samples); from c. 0.22 m to 0.31 m above the base of the peat.

This zone is characterised by very high Gramineae and Cyperaceae values (to 35% and 30% respectively). Other herbs increase in abundance and diversity. Tree pollen values generally decline, with Quercus and Alnus dropping to c. 7% and c. 5% respectively, values which they tend to maintain throughout the rest of the diagram. Betula fluctuates markedly, temporarily lowering to c. 6%, then rising to 30%.

SMQ-81.3 "Betula - Coryloid - Calluna Local Pollen Zone"

Samples 13 and 14 (2 samples); from c. 0.31 m to c. 0.38 m above the peat base.

Within this zone, Betula values remain high (c. 25%), whereas other trees have low values, except Ulmus, which has its only peak (c. 2%) in this zone. Coryloid values rise to a single peak (c. 30%) remaining at all other times at 10-15%. Calluna values show a temporary rise to 16%, following a reduction, whereas Gramineae and Cyperaceae both have low values. Other herbs have low abundance and diversity.

SMQ-81.4 "Gramineae - Sphagnum Local Pollen Zone"

Samples 5 to 16 (3 samples); from c. 0.38 m to c. 0.48 m above the peat base.

Within this zone, total tree values are dropping to c. 20% and Gramineae values are at a maximum around 30-45%, whereas Cyperaceae values are low (less than 10%). Diversity of other herbs increases, and their abundance also increases noticeably (15 to 20%). Sphagnum values fluctuate, being high to very high (20-80%) and Potamogeton values rise to a maximum of 14% (average c. 9%).

SMQ-81.5 "Calluna - Gramineae Local Pollen Zone"

Samples 6 to 8 (3 samples); from c. 0.48 m to c. 0.71 m above the base of the peat, i.e. to the top of the diagram.

The main feature of this zone is the high value to which the Calluna curve rises (20-30%). Although Gramineae values have fallen from the peak in the previous zone, they still remain moderately high (c. 20%). Cyperaceae maintain moderate to low values (20-8%), whereas other herbs are high in diversity and abundance (to 20% maximum), Potamogeton having values of up to 15%. Tree pollen values are all low, with total values of 10-15%.

Introduction to discussion. There is close correlation between the local pollen zones and the stratigraphical units (Fig. 11.6). L.P.Z. SMQ-80.3 coincides with the level in which the degree of humification (represented by the supernatent colour) is higher than at any other time. The correlation suggests that the pollen spectra, although not composed entirely of local pollen, at least closely reflects the local vegetation.

Quercus - Alnus Local Pollen Zone. The pollen spectra reflect the varied environment typical of a dune area. Alnus is expected, growing perhaps as shrub vegetation, within the dune slacks (Gimingham, 1964a, p.101) whereas Quercus, the other well-represented tree, may belong either to drier dune areas (cf. Newell, in press) or be a regional component. In some cases, the Quercus grains are very well-preserved, suggesting a nearby source. Certainly woody plants were growing at the site, and despite the low Betula pollen values, the occurrence of one Betula fruit indicates nearby presence of Betula. The presence of tree-leaf fragments and bud scales also indicates the local growth of trees.

In two samples, the sizes of 50 Gramineae grains were measured (Fig. 11.9). The size-frequency distributions for Sample 1 show an average of c. 27 $\pm$ 2.5 µm (one standard deviation) and for Sample 2, a bi-modal distribution with means of c. 25 $\pm$ 2 and c. 37 $\pm$ 4 µm. In Sample 9 many large (greater than 35 µm) grains were recorded but measurements were not made. The lower size group possibly identifies the grains as Phragmites type (Faegri & Iversen, 1975, p.254). The larger-size group may represent several Gramineae species typically found on dunes and in dune slacks, such as Ammophila arenaria (c. 32-44 µm) and Elymus arenarius (c. 38-58 µm) (Gimingham, 1964a; Beug, 1961, pp.32 & 33). Although the Phragmites type pollen taxon represents not only Phragmites communis, that species may occur here. However, other grasses such as Agrostis stolonifera, found in damp dune-slack communities, and Agrostis tennuis and Poa pratensis, found in drier dune communities, have similar pollen grain sizes (Gimingham, 1964a; Andrew, 1980).

Many other indicators of the local damp dune-slack vegetation are present: seeds of Juncus spp. and J. conglomeratus/effusus, Cyperaceae seeds and pollen, and Caltha palustris, Filipendula, Galium, Plantago lanceolata, Ranunculus type and Rhinanthus pollen. Seeds and pollen of Potamogeton, Menyanthes pollen and a single grain of Nymphaea also indicate damp conditions. Another indicator is the "Van Geel 128" microfossil, a distinctive globose microfossil indicative of shallow eutrophic fresh water (Pals et al., 1980, p.407). Other recorded herb taxa, such as Cerastium, Ranunculus, Rubus and Taraxacum types, Filipendula, Galium, Plantago coronopus, P. lanceolata, Rhinanthus, Rumex acetosa and R.acetosella represent species found in dune and dune-grassland communities, and several taxa may represent plants from near to or on the beach zone (Cerastium and Galium types, Chenopodiaceae, Plantago coronopus, Rumex acetosa and Scleranthus), or from dune heath (Erica and Galium type) (Gimingham, 1964b). Two grains of Hippophae rhamnoides, a low pollen-producing entomophilous plant, are also local. H. rhamnoides is presently found in Britain almost entirely on coastal dunes; it is regarded (Pearson & Rogers, 1962; Clapham et al., 1968, p.207; Perring & Walters, 1976, p.144) as being indigenous only along the southern part of the east coast of Britain. Its fossil presence at the base of the peat at Shewalton Moor is therefore interesting.

Cyperaceae - Gramineae Local Pollen Zone. Locally-damp conditions are indicated by a suite of herb-pollen taxa representing species found either in dune slacks (Gimingham, 1964a) or in wet or damp places (Clapham et al., 1968). Although certain taxa are absent, others (Filipendula, Plantago lanceolata, Ranunculus type, Potamogeton and Nymphaea) continue to be present, or are recorded for the first time (Hydrocotyle vulgaris, Stachys, Trollius, and Mentha, Potentilla and Senecio types). Local conditions are perhaps wetter and more open than earlier. The Sphagnum spore curve has a small peak here, and macrofossil remains of Sphagnum sp., Viola palustris, Menyanthes trifoliata, Juncus conglomeratus/effusus and Cyperaceae support other evidence, such as the presence of Copepoda spermatophores (Van Geel, 1978, p.75), in showing locally-wet conditions.

Large (c. 45 μm) Sphagnum spores may represent S. tenellum, a moss commonly found on wet heaths, ombrogenous bog and flushes (Dickson, 1973, pp. 60 & 73).

The main characteristics of the zone are the very high Gramineae and Cyperaceae values. The Cyperaceae and Carex macrofossils indicate a local source, as expected in a damp place such as this, for the Cyperaceae pollen. Gramineae grain sizes tend to be small (c. 24 ± 4 μm) (Fig. 11.9), suggesting that the Phragmites type taxon is represented, and so, as discused above, P. communis or other grasses typically found in a damp dune slack probably are represented.

The local openness of the vegetation allows input of non-local pollen. Many of the herb taxa representing coastal or dry-dune plants are still present (Cerastium, Ranunculus, Rubus and Taraxacum types, Chenopodiaceae, Plantago coronopus, P. lanceolata, Rumex acetosa, R. acetosella and Scleranthus) and new taxa are also present (Dianthus and Senecio types and Jasione montana).

The tree pollen curves also indicate increased local openness and dampness. Generally values for tree pollen, especially Quercus and Alnus, are decreasing; Betula becomes the best-represented tree species and the sparse macrofossil evidence indicates the nearby presence of Betula, possibly B. pubescens. The local increase in Betula may be due to increasing dampness, also reflected by the slow rise in Coryloid values. Persistent but minor presence of the more-typically regional components such as Pinus and Ulmus reflect the local openness, as perhaps also does the presence of the pioneer species Fraximus. The low values (less than 0.5% of total pollen and pteridophytes) suggest that these trees were unimportant in nearby woodland and that the regional forest was relatively open. One grain of Sorbus type, a rarely-identified pollen taxon (Godwin, 1975, p.199), if correctly identified here, probably represents S. aucuparia (Birks, 1973; Franks & Pennington, 1961), a possible component in local Betula woodland or nearby Quercus woodland (McVean, 1964; Pennington, 1974, pp.102 & 104).

Betula - Coryloid - Calluna Local Pollen Zone. Substantial changes have occurred between this and the previous zones. Abundant charcoal remains suggest that these local vegetational changes have occurred due to burning of the vegetation. Although damp conditions prevailed - evidenced by the continued presence of Filipendula, Hydrocotyle vulgaris Ranunculus type, Equisetum and Potamogeton pollen, Sphagnum spores and macrofossils, the presence of Assulina seminulum and a Copepoda spermatophore and the abundant macroscopic remains of Eriophorum vaginatum -, abundant dead grass may have been ideal material to burn. The resulting vegetation was significantly different from the immediately-preceding vegetation. Calluna expanded locally, perhaps with other ericaceous plants, probably providing the abundant macroscopic wood remains found at this level. Coryloid pollen, also abundant, may represent Myrica gale which would have expanded and become moderately important during the establishment of a Calluna wet heath (Gimingham, 1964b, p.284). Betula is the only tree to remain locally important.

The vegetational changes may have been induced by human activity, possibly evidenced by the peak in charcoal remains which accompanies these vegetational changes. The origin of such remains is obscure and charcoal cannot be used with certainty as an indicator of human activity (Chapter 13.4; cf. Boyd, 1982; Edwards, in press). None of the herbs indicates with certainty human agricultural activity. Although Chenopodiaceae, Plantago spp., and Rumex spp. are present, they are present in lower and less persistent amounts than earlier or later; these plants are found typically in coastal plant communities and their presence need not imply agricultural activity (Smith, 1970). Although the vegetational changes may have been due to local burning, no evidence indicates that human activity was responsible for the burning.

Gramineae - Sphagnum Local Pollen Zone. The degree of openness is increasing, with total tree values dropping to c. 20%, mostly in response to dropping Betula values. Both Quercus and Alnus become more important, with values similar to those during the early phases of peat growth. Tree leaf fragments remain abundant to common, suggesting local or at least nearby presence of trees. Sporadic presence of other trees - Fagus, Pinus and Ulmus - represent the regional pollen and, with Fraxinus, reflect a regionally-open woodland.

Local dampness is increasing, reflected by high values (20-80%) of Sphagnum spores and moderately high values (7-14%) of Potamogeton pollen, and the presence of macrofossil remains of Juncus conglomeratus/effusus, Eriophorum vaginatum, Potamogeton spp. and Sphagnum spp. Several herb taxa (Mentha and Ranunculus types, Hydrocotyle vulgaris and Menyanthes) represent herbs commonly found in damp dune slacks, bogs and other damp places. On the basis of grain size (c. 57 x 51 µm) two grains of Epilobium are identified as E. palustre (Andrew, 1980).

Other herbs, equally represented, are from surrounding drier dune areas or the beach zone. In addition to taxa previously present are Artemisia and Matricaria type. The main characteristic of this zone is the occurrence of high Gramineae values (30-45% of total pollen). The grains are generally small (less than 30 µm), and the pollen probably represents nearby increasingly open dry dune vegetation. Many of the common grasses provide sufficiently small grains: on dune grassland, Agrostis tennuis (24 µm), Poa pratensis (27 µm) and Holcus lanatus (26 µm); on fixed dunes, Festuca rubra (29 µm) (Gimingham, 1964; Andrew, 1980).

Calluna - Gramineae Local Pollen Zone. The vegetation is perhaps similar to that represented by the Betula - Coryloid - Calluna L.P.Z. The local and regional vegetation is more open than earlier, with total tree values of 10-15% and sporadic and minor presence of Pinus and Ulmus. Tree leaf fragments, bud scales and Betula sp. and B. pubescens fruits indicate occasional locally-growing trees. Conditions remain damp, possibly becoming wetter in places, with Copepoda spermatophores and "Van Geel 128" microfossils both indicating the presence of open water. The curves for both Potamogeton macrofossils and pollen show moderate local presence of this aquatic herb. Macrofossils of Juncus sp. and J. conglomeratus/effusus, Eriophorum vaginatum, Menyanthes trifoliata and Viola palustris, and pollen of Filipendula ulmaria, Hydrocotyle vulgaris, M. trifoliata and Rhinanthus minor also indicate locally-damp conditions.

Several herb taxa represent beach-zone plants (Matricaria, Potentilla, Senecio and Taraxacum types, Jasione montana, Plantago spp., Polygala, Rumex spp. and Trifolium). The Valeriana pollen (greater than 50 μm in size) represents V. officinalis. The main pollen spectral changes reflect vegetational change on the dunes, the rise in the abundance of Calluna pollen, Calluna and ericaceous macrofossils and possibly the wood fragments indicating the development of nearby dune-heath vegetation. A single grain of Arctostaphylos uva-ursi may be from heath on a dry part of the dunes.

The increasing dampness may have been due to a rising water table and/or increased precipitation. The establishment of a dune-heath vegetation may also be due to increased wetness, the dune sand remaining sufficiently dry to allow Calluna to dominate (cf. Newall, in press). Alternatively, the development of dune heath may have been part of the natural succession during the late stages of dune-surface fixation (Gimingham, 1964a), or the vegetational changes may have been due to increased human activity. Furthermore, grassland and heath would replace the increasingly-open regional forest and would spread easily into marginal areas such as the coastal dunes. Local human activity would encourage this, and the Calluna expansion may have followed deliberate or inadvertent human damage to existing vegetation. Within this zone peaks of _Rumex acetosa_, Chenopodiaceae and the _Plantago_ species may represent plants in the coastal or dune vegetation or, as elsewhere, may be indicative of human activity.

The peat at this level contains much sand, which may have been blown in during dry weather or, more probably, during stormy weather, when damp conditions prevailed. Seawards of the site were large areas of sand, capable of being eroded during westerly storms. Alternatively, the sand may be slope-wash from the surrounding dunes, resulting from increasing precipitation. The well-established vegetation, local relief (probably much less than 2 m) and distance (hundreds of metres) between the edges and the centre of this peat-filled hollow suggest that this is unlikely. Erosion by human and associated activity may have provided the sand that was washed or, more probably, blown into the hollow.

The local environment changes, while possibly reflecting natural developments such as dune stabilization and progression of the vegetation to dune heath, seem also to reflect the influence of changing climate (possibly to stormier, wetter weather) and/or increasing human activity.

The age of the peat. Since mainly local vegetational changes are recorded in the pollen diagram, determination of the age of the peat by reference to regional vegetational trends is difficult. Low values of _Ulmus_ suggest an age later than the _Ulmus_ decline. The main tree taxa indicate a regional woodland of _Quercus_ and _Alnus_ with _Betula_.

Several similar pollen assemblage zones have been suggested for areas in western central and south-western Scotland, e.g. Stewart's (1979) "_Quercus-Alnus_" zone and Birks' (1972, 1975) "_Alnus-Quercus-Plantago lanceolata_" zone, both equivalent to Godwin zone VIIb and, in the latter case, zone VIII. West (1977, p.328) suggests that the post-

Ulmus decline (Godwin zones VIIb and VIII) vegetation in in Scotland is characterised by Alnus-Quercus-Betula woodland (cf. Robinson, 1980, fig. 5.1). The steady presence of Fraxinus at Shewalton Moor Quarry further supports this late Flandrian age; although Fraxinus is present only in late zone VIII at certain sites (Durno, 1956) it is generally present after the Ulmus decline (Nichols, 1967; Moar, 1969; Birks, 1972, 1975; Stewart, 1979), and typically occurs where forest has been opened (cf. Robinson, 1980, fig. 5.1). Fagus has been present only within the last 1,000 years (West, 1977); in south-western Scotland it is present during the zones equivalent to Godwin zone VIII (Moar, 1969; Birks, 1972, 1975; Robinson, 1980, p.102; cf. Pennington, 1970, in relation to Cumberland). In the upper part of the peat at Shewalton Moor, only a single grain of Fagus was recorded, but its presence may indicate a zone VIII age for the peat. The lack of any noticeable rise in Pinus at the top of the diagram indicates that the last two hundred years are not represented in this diagram.

At Bloak and Kennox Mosses (Turner, 1965, 1970, 1975), recent extensive clearance of woodland vegetation is recorded. "Extensive clearance" is defined as an event registered by Gramineae values of 100% of total arboreal pollen or more (all Turner's values are percentages of total A.P.), associated with peaks of Plantago lanceolata and Pteridium. At Shewalton Moor Quarry peaks of P. lanceolata (to 14%) and Pteridium (to 12%) occur with two main Gramineae peaks (Fig. 11.8). Although sampling is less dense than at Bloak Moss, correlation between peaks in the curves of these three taxa is as good as in Turner's diagrams. Whether these changes are attributable to human activity is not clear although the similarities with Turner's "extensive clearances" suggest that they are. Correlation between clearance events in the two areas is impeded by lack of chronological control and the fine sampling found so useful by Turner (1975). Shewalton Moor and Bloak and Kennox Mosses are c. 10 km apart, so clearance patterns may be similar. Of the agricultural indicator herbs, high values of Plantago and Pteridium indicate pastoral agriculture (cf. Pilcher et al., 1971), whereas low values of these with high values of Compositae, Rumex, Chenopodiaceae and Ranunculaceae indicate arable agriculture (Turner, 1964, 1965). All these plants, however, are found in the unstable, open coastal and dune environments (cf. Behre, 1980). At Shewalton Moor Quarry, Plantago and Pteridium peak during the Gramineae peaks and the other indicators are more common towards the top of the diagram; therefore, any clearance associated with human activity was initially for pastoral purposes, and later for arable purposes. Smaller peaks of Rumex spp., Chenopodiaceae and Ranunculus type in the lowest clearance phase (L.P.Z. SMQ-81.2) may also represent arable activity. Agricultural activity was probably not practised directly at the site; clearance for pastoral activity will affect a larger area, initially, than that for arable activity, for the same food return. This overall pattern is similar to that at Bloak and Kennox Mosses. Further indication of arable activity is the presence of two grains of Cannabis sativa (Godwin, 1967a; Andrew, 1980), a plant present in Britain since the Dark Ages (Godwin, 1967a, b) or possibly before (Robinson, 1981, pp. 98 & 100). Curves of Humulus type pollen, representing C. sativa, occur near the top of several pollen diagrams (Walker, 1955; Oldfield & Statham, 1963; Birks, 1964; Sims, 1978); C. sativa was cultivated, occasionally under obligation, with flax and cereals from Viking and Anglo-Saxon periods onwards (Godwin, 1978).

The earliest extensive clearance in Ayrshire occurred at c. 1,500 B.P. (Turner, 1975), suggesting that most of the peat at Shewalton Moor dates from within the last 2,000 years. If C. sativa was present, at the earliest, around 2,000 B.P. ("Iron Age"; cf. Robinson, 1981, pp. 98 & 100) and assuming an accumulation rate of c. 0.5 mm/year (Chapter 13.1), the maximum age of the peat base is c. 3,500 B.P. This suggests an early phase of extensive clearance at c. 2,500 B.P., when only small temporary clearances are recorded 10 km away

(Turner, 1975). A minimum age for the peat base is c. 1,000 B.P., assuming an accumulation rate of c. 1 mm/year (Chapter 13.1) and an upper age limit of c. 100-200 B.P. Both these limiting ages (c. 3,500 and 1,000 B.P.) for the peat base are considered improbable, and a basal age of c. 2,000 is more probable. The lower clearance phase may be equivalent to Turner's Dark Age clearance (1,500-1,370 B.P.) and the upper part of the diagram at Shewalton Moor may represent progressive clearance, the regional destruction of woodland and the development of arable and pastoral agriculture during the medieval period. In general terms, the rate of peat accumulation is of the same order as that for peat forming in a sand dune hollow at Luce Bay (0.75 mm/year; Newall, in press). The peat at this site appears to be younger than a wood fragment dated at 3,944 ± 190 B.P., from similar peat lying c. 500 m to the N.W. (Nat. Grid Ref. NS 330 367) (Birm-221, Shotton & Williams, 1971). The latter peat overlies marine sand and there is no indication whether a sand-dune phase is represented. The earlier date suggests that such a phase is not represented. The site is now destroyed.

CHAPTER 12

THE GREAT BEND, RIVER IRVINE

1. The section

At NS 324 372 the following section of raised marine sediments is exposed in the western river bank of the River Irvine at the locality known as the "Great Bend". The section is presented below, from top to bottom, with the sedimentary units numbered to correspond to those given by Smith (1896a; see below).

	thickness (m)
(1) Dune sand; to maximum altitude of 11.10 m A.O.D.	max.5.8
(1)-(2) Unconformity; top of sediments truncated horizontally and vertically by dunes and slumping	
(2) Sand with lenses of coal fragments and medium to coarse gravel; cross-bedded, dip S. and in places W., *c.* 10°	min.1.0
(2)-(3) Gradual change over *c.* 0.20 m	
(3) Shelly sand; yellow-white horizontally-bedded, with layers and lenses of shells, occasionally with fine gravel and *Lithothamnium* fragments. Becomes increasingly coarse-grained towards the base	2.65
(3)-(4) Conformable boundary, slightly undulating	
(4) "Basal Gravel"; yellow sand with layers of gravel, the clasts mostly encrusted with *Melobesia*, shells and *Lithothamnium* fragments. Top at 2.66 m A.O.D.	*c.* 0.30
(4)-(5) Horizontal unconformity	
(5) "*Pholas* Bed"; hard compacted grey sand, bored by *Pholas*; occasional *Pholas* shells in living position	*c.* 0.30
(5)-(6) Conformity	
(6) Grey sand; softer than *Pholas* bed; unfossiliferous	unknown

The exposure has been known since at least 1790 (Smith, 1896a, p.35), and is famous for occasional exposures of whale bones. The section recorded by Smith was:

	feet	inches	equivalent m
(1) Turf, with heather	1	0	0.30
(2) Yellowish sand, without shells (with stones up to within 4 feet of the turf)	8	0	2.40
(3) Grey sand, with numerous sea-shells, stones, and patches of gravel	11	0	3.55
(4) Gravel with much _Melobesia polymorpha_	1	0	0.30
(5) Darkish sand (the Whale Bed)	3	0	0.91
(6) Dark muddy sand, with _Pholas_ in position, peaty towards the east end of the section	2	0	0.61
(7) Dark-greyish sand, the top only seen	...	...	
	26	0	7.92

The exposed cliff at present is smaller than formerly (cf. Smith, 1896a, p.34) and, by comparison of old and new editions of O.S. maps, lies west of its position during the 1890s. Water level in the River Irvine is at present higher than formerly.

The two sections, generally similar, differ in detail: the topmost unfossiliferous sand is thicker in Smith's section, reflecting the highly undulating nature of the unconformity at the base of the dunes; the fossiliferous sand formerly was thicker; the "Whale Bed" is not exposed at present; there is presently no "peat" in the "_Pholas_ Bed"; the section now is exposed at a lower altitude than when described by Smith. These differences suggest that the sediments dip seawards (westwards) and thin in that direction.

2. The macrofauna

Introduction. Shells in the sediments were examined by Bertie (1974) and more recently collected by E. B. Akpan and the writer (Table A.12.1). Shells were described from three units: the "Basal Gravel", layer (4); "gravelly sand", boundary (3)-(4) and the basal part of layer (3); "shelly sand", layer (3), main part.

Pholas Bed. Apart from borings of Pholas and specimens of this bivalve, the bed is unfossiliferous. Pholas bores in many materials, from solid rock to uncompacted sediments (Black, 1970; Bromley, 1970), and is restricted to shallow marine water, being active in the littoral zone. It is often associated, as here, with unconformities. This bed has probably been exposed in the littoral zone, perhaps consolidated there, and bored by Pholas.

Basal Gravel. Laevicardium crassum and Venerupis rhomboides are the most common species, and Dosinia exoleta, Lutraria lutraria, Spisula subtruncata, Venus striatula and Gibbula magus are also present. All live between extreme low tide level or just offshore and a maximum depth of c. 180 m in the case of L. crassum and V. rhomboides. Although some can live in gravel or shelly gravel, others (S. subtruncata and V. striatula) mainly live in clean or muddy sand, suggesting the presence of an inwashed faunal component. Echinocyanus pusillus specimens were found undamaged and in living position. They are fragile and none was successfully collected without being destroyed. They live at levels below extreme low tide.

The shells mainly occur in lenses of coarse-grained sediment which contains many specimens of the coralline calcareous algae, Melobesia and Lithothamnium. These are discussed in Chapter 12.4.

Gravelly sand. The dominant species is Spisula subtruncata, which lives between low intertidal levels and c. 36 m, B.O.D., typically in sand and silty and muddy sand. Other species present, Dosinia exoleta, Ensis spp., Venus striatula and Natica alderi, have similar shallow depth distributions. Single species dominance often indicates stress conditions, such as occur in the littoral zone. S. subtruncata, however, is an opportunistic species, flourishing in high densities in various environments. Preservation of S. subtruncata specimens is good, with little sign of abrasion, and hence of transport, and there is also a large juvenile population.

Shelly sand. This unit is also dominated by S. subtruncata, with a fauna similar to that of the "gravelly sand" unit. There is more Donax vittatus, and Chlamys sp. than in the gravelly sand, Mytilus edulis and Patella vulgata are present. The latter two species live in the upper and middle tidal zones.

Conclusion. The general impression is of initially shallow-water conditions (the Pholas Bed), followed by deeper-water conditions and finally shallowing water. One problem is that much sediment mixing occurs in the littoral and sub-littoral zones, so shells from several environments can be juxtaposed.

3. Analysis of microborings

The interpretation given above is supported by an analysis of microborings in shells and Melobesia (Table 12.1; Akpan, 1981, ch. 7).

Of the species recorded in the "Basal Gravel", Phaeophila sp. and Plectonema tenebrans occur between the intertidal zone and lower part of the photic zone, Eugomontia suculata is exclusively submerged, and Cliona spp. live in the uppermost 25 m of the sublittoral zone. The analysis was carried out on fresh, well-preserved shells, and the presence of undamaged, fragile sponge spicules suggests that the shells and sponges represent in situ conditions. Akpan suggests that the sediment

Table 12.1 The Great Bend, River Irvine: results of Akpan's (1981) microboring analysis of samples

	Basal gravel	Shelly sand
Endolithic algae:		
Green algae:		
Phaeophila sp.	common	most common
Eugomontia suculata	most common	absent
Blue-green algae:		
Hyella caespitosa	absent	present
Plectonema tenebrans	rare	rare
Sponges:		
Cliona celata	present	absent
C. vastifica	present	absent

Table 12.2 The Great Bend, River Irvine; *Lithothamnium* specimens: size mean and distribution characteristics. Measurements are of the longest axes. Each entry gives the mean $\pm$ 1 standard deviation and the range this represents. All values are mm.

	Ellipsoidal	Discoidal
Site 1	26 ± 8.2 (18 - 34)	25 ± 7.7 (17 - 33)
Site 2	26 ± 10.0 (16 - 36)	19 ± 8.1 (11 - 27)

accumulated at a depth of c. 10 m B.O.D.

All the algae recorded in the shelly sand, Phaephila sp., Hyella caespitosa and Plectonema tenebrans, live in the littoral zone. The absence of Eugomontia suculata and the low boring density and high ratio of unbored to bored shells recorded in this unit indicate possible littoral conditions.

4. Coralline calcareous algae

Introduction. The coralline algae are studied here as potential palaeoenvironmental indicators (cf. Orszag-Sperber et al., 1977; Bosence et al., 1980). Although Smith (1896a, p.35) records the Basal Gravel as a one foot thick "layer of gravel with much Melobesia polymorpha", there are present not only specimens of encrusting Melobesia, but also of free-growing, branching Lithothamnium. Little has been published on the ecology of Lithothamnium spp. or Melobesia spp., and the study of temperate-water calcareous algae is still in its early stages (Adey, 1970; Bosence, 1978). Due to difficulties in the accurate identification of the fossil algae (Wray, 1977), only generic names are used here (i.e. Lithothamnium and Melobesia). Thin section identification is possible (Bosence, pers. comm.).

General description of Lithothamnium. Temperature and light are the main growth controls, determining depth and geographical distribution of crustose and unattached coralline algae (Adey, 1970). Maximum growth for Lithothamnium corallioides occurs at 10-12°C., growth is limited by low salinity (Adey & McKibbin, 1970), and the depth limit is where c. 30% of the surface light reaches the sea bed (Bosence, 1976). This limit ranges from 16 m (Mannin Bay, western Ireland; Bosence, 1976) to 25 m (Brittany; Cabioch, 1970) and 27 m in the Firth of Clyde (Clockie & Boney, 1980; E. B. Akpan, pers. comm.). On the Ayrshire coast at Irvine growth is expected from L.W.M.S.T. to similar depths. Distribution within this range is limited, in quiet areas, by mud burial and, in more exposed water, by wave-generated currents.

Growth form may be related to water-current conditions (Bosence, 1976). There are three main groups of shapes: spheroidal, ellipsoidal and discoidal; branching varies from simple (II) to complex (IV). Bosence's quantitative and qualitative observations suggest that discoidal forms are most difficult to move (i.e. high current velocities are required), whereas the ellipsoidal forms are the easiest, especially where the long axis is at right angles to the current. High-density branching (IV) allows transport by low-velocity currents, whereas specimens with low-density branching (II) are most stable. Increased branching density results from increased transport. In the Firth of Clyde, Deegan et al., (1973, p.8) observed delicately-branched forms in sheltered areas, and short, stout, sub-parallel branched forms in more exposed places.

Methods. At two sites, 1 kg samples of sediment were collected from layers or lenses of mixed Lithothamnium specimens, shells and gravel clasts often encrusted with Melobesia, in the Basal Gravel. The following features were recorded or measured in a sample of Lithothamnium fragments.

(1) Shape of specimen (S, E and D; spheroidal, ellipsoidal, discoidal) (cf. Bosence, 1976, plate 53 & text-figure 10). Intermediate groups were recorded where description was difficult.

(2) Lengths of the three mutually-perpendicular axes (L, I and S; "longest", "intermediate" and "shortest"), measured to 1 mm.

(3) Degree of branching, using intermediate (II/III, etc.) as well as Bosence's groups (cf. Bosence, 1976, text-figure 10).

(4) Degree of damage, recorded on a scale of 1 to 5, where 1 = undamaged and 5 = severely damaged. Degree of

breakage, abrasion, and the "completeness" of specimens - whole (W), probably whole (?W), partial (P), probably partial (?P), unclear (?) - were recorded.

(5) Other comments were made, usually records of the presence of "secondary Melobesia" (i.e. Melobesia encrustation) or serpulid tubes on the specimen or part of it, and whether damage was recent.

At Site 1 forty specimens were examined and at Site 2, fifty.

Introduction to discussion. The data (Tables A.12.2 & 3) are discussed under three headings: Form, Branching and Damage. The samples are not necessarily from the same layers; slumping obscures the sediments in places. The results will show trends rather than strong relationships, partly due to the small samples used and partly because of the amount of subjective assessment used.

Form. Each specimen is plotted on a Sneed & Folk diagram (Fig. 12.1), in which two parameters based on ratios of the lengths of the mutually-perpendicular clast axes (Chapter 12.4), S/L and (L-I)/(L-S), are used as axes (Sneed & Folk, 1958, pp. 118 & 119); the form of each specimen is defined as "platy" to "elongate" ((L-I)/(L-S) increasing from 0 to 1) and becoming increasingly "compact" (S/L increasing from 0 to 1). This plot of particle form is regarded as a reliable reflection of the hydraulic behaviour of the particles; since the sediments here are water-deposited and probably water-transported this is a relevant method to employ.

When each specimen is plotted according to shape (Fig. 12.1), the populations of specimens labelled as "ellipsoidal" and "discoidal" are almost mutually exclusive, separated by the value (L-I)/(L-S) = c. 0.60. Specimens labelled as "spheroidal" or as a combination of two types are scattered throughout the diagram and do not appear to have distinctive distribution. Based on these distributions, each specimen is redefined (Tables A.12.2 & 3) as "ellipsoidal" or "discoidal", where the value of (L-I)/(L-S) is greater or less than 0.60 respectively. The ellipsoidal group corresponds approximately with Sneed & Folk's "elongate" group and the discoidal group with the "platy" and "bladed" group. It must be noted that the distribution of form groups on the Sneed & Folk diagram differs from that of Bosence (1976, text-figure 11).

In the preliminary assessment few specimens were described as "spheroidal", and on the plots few fall into Sneed & Folk's "compact" group (S/L greater than 0.70). This suggests that most of the specimens are discoidal and ellipsoidal. They represent Bosence's most stable and least stable forms, and the intermediate form, in terms of stability, is poorly represented. At both sites, the two form-groups have similar size mean and distribution characteristics (Table 12.2), suggesting similarity between the two populations, as is also suggested by the broad scatter of points in Figure 12.1.

Maximum Projection Sphericity (Ψ_p) is an accurate measure of particle sphericity, taking into account the actual hydraulic behaviour of the particle (Sneed & Folk, 1958, pp. 118 ff). It is a function of L, I and S and is read directly from the Sneed & Folk diagram. Ψ_p varies directly with the speed at which a particle will settle or will be rolled in water. In practical cases, Ψ_p and form are complex functions of rock type, pebble size and transport distance; in the case discussed here, the former two do not vary, so variation in Ψ_p is related to transport distance. The minimum values at both sites are c. 4.5 for the discoidal populations and c. 6.0 for the ellipsoidal populations (Fig. 12.2). The mean values are not significantly different on statistical grounds, although at Site 1 there is considerable difference between the means. Although the differences in Ψ_p suggest that the ellipsoidal populations represent conditions of greater transport velocity, it is more plausible to suggest that the two populations, while similar, represent different transport characteristics and histories, of which little detail is yet established.

Branching. At Site 1 the distribution of branching density is approximately normal (Fig. 12.3). At Site 2 the distribution is left-skewed, with much low to medium-density branching. The Site 1 sample represents a more easily transported assemblage than that at Site 2.

Considerable variation occurs within the samples; at Site 1 the ellipsoidal group has slightly higher density branching than the discoidal group, but with a secondary peak of low-density branching. Differences in population sizes (28 and 12 respectively) lowers the validity of comparison. At Site 2 the discoidal group tends to have lower density branching than the ellipsoidal group. If branching density increases as a result of transport (Bosence, 1976), the less stable forms (ellipsoidal) have been further transported than the more stable discoidal specimens. The presence of two ellipsoidal populations suggests varying current strengths. Current velocities, sufficient to transport ellipsoidal forms more readily than discoidal forms, may have been low to intermediate in value, but none of this data allows absolute values for current velocity to be calculated.

Damage. At Site 1 the frequency distributions of breakage and abrasion (Fig. 12.3) suggests the presence of two populations; one has little or no damage, and the other, a similar sized group, has severe damage. Relationships between abrasion and breakage (Table 12.3) indicate two groups in which (1) breakage and abrasion are both minimal, but breakage is more important, and (2) both forms of damage are present, occasionally being severe, the emphasis being on abrasion. At Site 2, two groups are also evident, one with severely-broken and the other with moderately-broken

Table 12.3 The Great Bend, River Irvine; Lithothamnium analysis: frequencies of occurrence of specimens of Lithothamnium, according to degree and type of damage. The values of degree of damage (1 to 5) represent undamaged to severely damaged, as defined in Chapter 12.4.

Site 1

Degree of damage		Breakage					
		1	2	3	4	5	?
Abrasion	1	1	5	1		1	
	2	1	2	4		1	
	3		2				
	4					3	
	5		2	4	4	5	3

Site 2

Degree of damage		Breakage					
		1	2	3	4	5	?
Abrasion	1	2					
	2		3	2		1	
	3		2	9		1	
	4		2	4	5	4	
	5		2	1	2	6	4

specimens. Abrasion tends to be severe, perhaps reflecting current velocities sufficient to move sand, the probable abrasion agent. In some cases degree of breakage is impossible to assess because of the severity of abrasion (Table 12.3).

The suggested mixed populations occur in both ellipsoidal and discoidal groups (Fig. 12.3). Plotting damage against degree of branching (Fig. 12.4) for Site 2 specimens suggests a direct relationship, which is as expected. The unexpectedly high medians for density II branching reflects the presence of fragments of more densely-branched specimens; specimens with low-density branching tend to be partial, and "wholeness" increases with branching density. Patterns at Site 1 are less clear, but two populations, one transported and the other less so, are again indicated, and "wholeness" increases with branching density, perhaps reflecting the lower currents required to move a densely-branched specimen.

Relationship between Lithothamnium and Melobesia. Specimens of Melobesia were also collected. These tend to be larger than those of Lithothamnium, one encrusting a stone measuring 110 x 110 x 60 mm, whereas the largest Lithothamnium specimen recorded is 50 x 44 x 36 mm. Melobesia encrusts cobbles, pebbles and shells, but does not totally encrust Lithothamnium (none found). There are few samples of small amounts of Melobesia growth on Lithothamnium. Also, there are few examples of Lithothamnium with serpulid tubes and algal or sponge borings on the specimen. Commonly Melobesia specimens are riddled with borings and often partially encased with serpulid tubes, and there is evidence for alternating generations of Melobesia growth and algal- and sponge-boring activity on the same specimen.

Conclusions. At both Sites 1 and 2 there are mixed assemblages of badly-damaged and transported, and undamaged and less-transported Lithothamnium. The Lithothamnium portion of the deposits is inwashed, possibly from several sources.

A few specimens seem very undamaged and finely grown, and may have grown in situ or nearby. It is not clear whether the Melobesia grew in situ. It pre-dates the Lithothamnium, being less fresh, and grows on large stones which require strong currents to be inwashed, but scarcely grows on Lithothamnium. No Melobesia-encrusted pebbles were found at the core of Lithothamnium rhodoliths. The large amount of algal and sponge boring on Melobesia, and its crumbly nature, suggest that Melobesia has not been transported to the site, but has grown in situ and been present for much longer than the Lithothamnium.

5. General discussion

The Basal Gravel is similar to one of the three Lithothamnium facies described by Bosence for western Ireland. His description (Bosence, 1980, pp.95-97) of the "Clean Algal Gravel facies" is:

> "The Clean Algal Gravel facies is composed of clean washed and frequently wave rippled, algal debris (78 percent ...) with an average of 17 percent molluscan material ... Most of the dead algal grains are of open-branched corallines and are therefore, thought to have originated from the Bank facies [a stable, quiet water facies] but some is produced within the facies. The corallines growing in this facies are characterized by densely-branched spheroidal and ellipsoidal shaped thalli (rhodoliths) which grow as a response to abrasion during transport by wave currents. The mollusc grains are produced partly from the present-day infauna and are partly derived ...
>
> The distribution of the Clean Algal Gravel facies correlates closely with the areas of high hydraulic energy of the bay ... In these exposed areas wave currents are high enough to transport the algal debris and mud deposition is restricted from near the sediment surface ... Frequently the gravel is transported as ripples ... Formation of the ripples has not been observed as sediment transport probably only happens during storms ... Ripples ... have crests of well-sorted coarse sand to fine gravel sized maerl [Lithothamnium fragments]. No internal structures have been seen in excavated cross-sections. The troughs have a lag deposit composed of poorly-sorted algal and molluscan material which does not extend under the adjacent ripples."

Bosence also suggests three simplified facies models which assume an oblique hydraulic energy input, a marine transgression and no terrigenous sediment input (Bosence, 1980, pp.105-107). Model two, for an area with bays and headlands, suggests a succession of bottom terrigenous littoral deposits, Clean Algal Gravel facies and, on top, offshore sand and gravel. This is essentially the succession found at the River Irvine Great Bend. The Pholas Bed is equivalent to the terrigenous littoral deposits of Bosence, and the shelly sand above the Lithothamnium-bearing "Basal Gravel" is the equivalent of the offshore deposits. The input of terrigenous material in the Firth of Clyde probably was high, and above the "Basal Gravel" at this site, the effects of deepening water (marine transgression) would have been countered by the input of re-worked glacial sedimentary material.

6. General conclusion

The sediments at this site suggest the following succession of events.

(1) Deposition of sand in an unknown depth of water.

(2) Exposure or partial exposure of the top of this sand in the intertidal zone, allowing sediment consolidation and colonization by the sediment-burrowing Pholas. Conditions immediately east of the site were shallow enough at one time to allow the stranding of at least one whale on this intertidal surface. This stage represents a marine regression, with the coastline lying a few hundred metres to the east of the site, if Smith's comments about peat associated with this bed are valid (Smith, 1896a, p.35).

(3) Marine transgression, with the development of a "Clean Algal Gravel" facies and the input of gravel, shells and algae from several places. This represents the deepest water conditions at the site.

(4) Deposition of a moderate thickness of horizontally-

bedded shelly sand.

(5) Shallowing of water, either due to offshore sedimentation in this area or marine regression, until conditions were sufficiently quiet or shallow to allow the formation of current bedding (cf. Harms et al., 1975, figs 2.5 & 2.7). At this stage, cross-bedded sand may have been deposited on the beach face.

(6) Final emergence.

(7) Erosion of parts of the marine sedimentary sequence and development of the sand dunes.

CHAPTER 13

SHEWALTON MOSS

1. Introduction

Shewalton Moss is a large body of peat (c. 2 x 3 km, centred on Nat. Grid Ref. NS 348 354) sitting on deposits of a "High Raised Beach", whose inner margin is cut by a "feature (?Old Sea margin) at about 75' above sea level" (Geological 6 inch Map, 1911). The peat surface is reported (Anderson, 1925, p.99) to lie at c. 50 ft above sea level, and the greatest depth exceeds 30 ft. Anderson (1925) suggested that the peat lies in a depression in the raised beach deposits. Jardine (1971) suggested that Flandrian raised coastal deposits occur as far inland as the "75 ft" feature mentioned above (cf. Jardine, 1975, fig. 2) and that during the Flandrian marine transgression, the sea occupied a large embayment. Although Jardine states that Shewalton Moss "covers a depression in the raised coastal sediments" (1971, p.109) there is no further discussion regarding the relationship between Shewalton Moss and the raised coastal deposits.

Assuming, initially, that the middle Flandrian sea did flood as far inland as the "75 ft" feature, several possibilities follow: firstly, that Shewalton Moss is entirely a late-Flandrian peat moss; secondly, that peat growth on Shewalton Moss commenced during the early Flandrian Age, when sea level lay below c. 6 m A.O.D., and either (a) the area now occupied by the moss was flooded during the transgression when peat growth was interrupted, or (b) peat growth continued throughout the entire Flandrian Age, Shewalton Moss becoming an island within the middle Flandrian marine embayment.

Hansen (1966) and Aaby et al., (1979) have shown that rates of peat growth in Denmark are of the order of 6 to 14 mm/year. Due to compaction, the rate of peat accumulation below the surface decreases rapidly downwards to moderately constant values (Walker, 1970). Aaby _et al._ (1979) suggest a rate of 0.2 mm/year below 280 mm at Draved Moss, Denmark. Aaby & Jacobsen (1979) show that below the top 100 mm, rates of accumulation for hollows and hummocks on a peat moss area are of the same order, that is, less than 1 mm/year. Both in Denmark and in Britain similar average rates of _c._ 0.45 mm/year have been observed at individual sites (Hibbert _et al._, 1971; Aaby & Tauber, 1974; Godwin, 1975, p.35), and at Bloak Moss the rate of accumulation for the top 1.80 m of peat was _c._ 0.47 mm/year (adapted from Turner, 1975). The average rate of accumulation of fen and bog peat at twenty-one large inland basin sites and coastal and estuarine sites throughout Britain is _c._ 0.58 mm/year (adapted from Walker, 1970, table 9), and only at one site has peat accumulated faster than 1 mm/year.

Taking a maximum average rate of 1 mm/year, the thickness of peat at the deepest part of Shewalton Moss would have required most of the Flandrian Age to accumulate. This suggests that the first possibility (Shewalton Moss is an entirely late Flandrian moss) above is unlikely. Further, if this possibility is correct, a rate of compacted accumulation of _c._ 2 mm/year, in the thickest peat suggests that the rate of peat growth at the surface needs to have been _c._ 60 mm/year. This value is an order of magnitude greater than values suggested by Hansen (1966) and Aaby _et al._, (1979). Again this suggests that this situation is unlikely.

Peat growth may therefore have commenced in early Flandrian times, although no evidence yet suggests whether (a) or (b) (see above) is more probable. A study of the stratigraphy may resolve this problem. If Shewalton Moor was flooded, the peat growth would have been interrupted, indicated either by the presence of non-terrestrial sediments or an erosive or non-depositional unconformity. It should be noted that an unconformity may be more difficult to distinguish than the presence of sediments.

Alternatively, if Shewalton Moss formed an island or peninsula during the Flandrian transgression, there would be no major inorganic component within the peat, except perhaps at the edges where peat may have been flooded locally. Continuous peat growth is expected.

If Shewalton Moss originated as an early Flandrian peat body, it may be suggested that, contrary to the main assumption above, the middle Flandrian marine transgression at no time penetrated as far inland as suggested by Jardine (1971, fig. 2), and that Shewalton Moss remained part of the mainland. The postulated penetration of the Flandrian transgression inland of Shewalton Moss perhaps stems from Anderson's suggestion (1925) that Shewalton Moss lies in a hollow in the raised beach deposits, therefore lying largely below the level of the raised beach terrace and hence, by implication, below the contemporaneous maximum sea level. This has not been proved.

Clearly Shewalton Moss provides an important source of information regarding the ages of the surrounding raised coastal deposits and the extent of the Flandrian marine transgression. The main questions which must be answered are:

(1) What is the shape of Shewalton Moss and, especially, what is the shape of the surface up on which it rests?

(2) At what level A.O.D. does the lowest peat lie?

(3) What is the stratigraphy of the moss?

(4) What is the age of the base of the peat?

These questions were approached using a variety of techniques. Initially the peat was augered along several traverses. The main items recorded were: the thickness of the peat; the nature of the sub-peat sediment; the presence or absence of inorganic sediment contained within the peat. Associated with this, an electrical resistivity survey was undertaken along part of one of the auger-hole traverses, to establish whether such a technique may be a valid alternative to augering, and to provide further information regarding the nature of the sediments. The upper and lower surfaces of the peat were levelled instrumentally at all the auger sites, giving an accurate picture of the shape of the moss. In addition, cores were collected at two sites. Subsequent pollen analysis of these cores provided evidence to establish the age of the base of the peat, and also furnished palaeoenvironmental information regarding Shewalton Moss.

2. Auger survey

The outline of Shewalton Moss (Geological 6 inch Map, 1911) is shown in Figure 13.1. Along the northern and eastern edges the outline was checked in the field and the accuracy of the Geological Survey boundaries found to be acceptable. The auger survey traverses and sites are shown on Figure 13.1; the results of the auger survey are presented in Table A.13.1, and the traverses and derived sections are illustrated in Figure 13.2.

It is apparent that Shewalton Moss, rather than sitting in a major depression in the raised coastal deposits, rests on a moderately level surface (Fig. 13.2). To the north and east, the peat is banked against ridges of sand and gravel, in the south-east against a steep cliff cut into solid rock, and to the west the peat thins gradually. The surface upon which Shewalton Moss sits lies generally between 8 and 10 m A.O.D. and rises gently eastwards. Although commonly there is thicker peat towards the centre of Shewalton Moss, reflecting the raised-bog nature of the moss, the deepest-lying peat lies within a few tens of metres from the edge where the base of peat, respectively, 8.35 m (auger site 31) and 8.40 m (site 32) thick, lies at 7.33 m and 7.49 m A.O.D. These are the lowest parts of the known sub-peat surface.

Except at auger hole 7a, no inorganic sediment was found within the peat. The bands of clay at c. 0.50 m below the surface in auger hole 7a are considered to relate to the activity of the nearby Dundonald Burn (c. 5 m away) which presently is depositing clay and silt in the bottom of its channel. Augering at site 7b, 36 m from Dundonald Burn, provided no evidence of clay bands, and the clay layers are therefore regarded as entirely local features.

Since the initial stratigraphical investigation was designed only to indicate absence or presence of deposits other than peat, evidence regarding unconformities within the peat was not collected. Therefore, although non-depositional marine transgressive event cannot be disproved, the possibility that there has been a depositional transgressive event over the entire Shewalton Moss area can be dismissed.

Since areas of raised inorganic coastal deposits to the north and east of Shewalton Moss lie higher than the upper surface of the peat, sea level at the time of accumulation of raised coastal deposits must have lain above the level of all the peat. If the middle Flandrian transgression extended as far inland as the location of these inorganic deposits, the area of Shewalton Moss must have been completely flooded, either initially or after the removal of a peat island. The latter possibility would require there to have been a considerably greater thickness of peat than is present now. This is considered highly unlikely.

From the augering and levelling survey evidence, three possible scenarios emerge. Firstly, given that the peat is early Flandrian in initiation, Shewalton Moss, in its entirity, was flooded in the course of the middle Flandrian transgression, during which there was no deposition of inorganic sediment. Secondly, following the same assumption, Shewalton Moss was not flooded during the middle Flandrian transgression. Thirdly, in the unlikely event that Shewalton Moss dates only from late-Flandrian times, the area may or may not have been flooded at the time of the middle Flandrian transgression. On balance, the second scenario is the most probable and the third is the least probable.

3. Electrical resistivity survey

Introduction to the theory and practice. Electrical resistivity survey methods depend on the fact that any sub-surface variation in conductivity in the soil and sub-soil alters the form of electrical current flow through the ground. In practice a current is passed into the ground via two electrodes, and the drop in potential is measured between a second pair of electrodes placed in line between the first pair. With a knowledge of the drop in potential, current input and electrode spacings, the ground resistivity can be calculated. Electrical resistivity is the reciprocal of conductivity and is a measure of the resistance of a unit volume of material. It is measured in units of ohm-meters (Ω m). Where the material, which in geological surveying is the soil and sub-soil, is not entirely uniform, it is convenient to refer to the resistivity (calculated from a resistance measurement with any particular electrode arrangement) as apparent. The apparent resistivity (ρ_a) is a weighted average of the actual resistivities present in the ground. The theory of electrical resistivity surveying is treated in textbooks on geophysical techniques (e.g. Parasnis, 1979; Griffiths & King, 1981) and is not considered here in detail. Only the relevant parts are discussed.

To measure the apparent resistivity of the soil and sub-soil, there are several arrays of current and potential electrodes. In Britain, and elsewhere in the English-speaking world (Dobrin, 1976), the arrangement commonly used is the Wenner array (Fig. 13.3). To establish whether the ground is laterally homogenous, an array known as the Lee

Partition (Fig. 13.3) can be used. This enables two measurements to be made, for the left and right halves of the spread, without the necessity of moving the current electrodes. The ρ_a values are calculated from the formula $\rho_a = 2\pi aR$ (Wenner array) and $\rho_a = 4\pi aR$ (Lee Partition) (where a = electrode separation distance, and R = measured resistance). In the Lee Partition, if the two ρ_a values are identical, the ground is presumed to be laterally homogenous.

To reveal any change in resistivity with depth, the electrode separation is increased, thus increasing the depth of investigation. The calculated resistivities are plotted against separation distance on log-log graph paper. The depth of the investigation is generally about one third of the separation distance, and the overall array length requires to be c. 10 times the depth of interest.

In homogenous ground, ρ_a does not change with depth or separation (Fig. 13.4). In a two layer situation, ρ_a tends towards the value of the resistivity of deeper layer at large separations, and the shape of the curve therefore varies according to the proportion of the resistivities in the two layers (Fig. 13.4). The resultant curve from the field measurements is generally interpreted by comparison with model curves calculated from values for two horizontal layers of different resistivities drawn in a similar manner to the field measurement curve. These standard two-layer curves are curves of ρ_a/ρ_1 (i.e. the ratio of the apparent resistivity and the resistivity of layer 1) against a/h (separation distance against depth of the boundary between layers 1 and 2). A series of curves is calculated for various values of the ratio (K) of the resistivities of layers 1 and 2. To interpret the measured resistivity curve, assuming that it is a two-layer curve, it must have the same form as one of the standard curves, or a form intermediate between two standard curves. The measured resistivity curve is superimposed on a set of standard curves and, keeping the two sets of axes parallel, it is moved about until a fit is obtained. Where the $\rho_a/\rho_1 = 1$ axis of the standard curve cuts the ρ_a-axis of the graphs of measured values, $\rho_a = \rho_1$; where the $a/h = 1$ axis of the standard curve cuts the a-axis on the measured values graph, $a = h$. The value of K for the best fitting standard curve allows ρ_2 to be calculated.

In the situation where three layers of different resistivities are examined, the shape of the curve is diagnostic of the ratios $\rho_1 : \rho_2 : \rho_3$ (Fig. 13.4). Interpretation of the field measurements curve can be achieved by a curve-matching procedure, as above, either using standard three-layer curves for a limited range of layer thicknesses and resistivities, or using standard curves calculated by computer for given values of $\rho_1 : \rho_2 : \rho_3$ and the thicknesses of the upper two layers. In the latter case, theoretical curves are calculated for estimates of these variables and, following comparison with the field measurement curve, the estimates can be revised until a good fit is obtained.

Electrical resistivity surveying is a method which has been used for both deep and shallow rock surveying (e.g. De Breuck & De Moor, 1962; Tavernier et al., 1967; De Moor & De Breuck, 1976). As a method it tends to generalise, and fine detail is lost with depth. Also if one factor dominates, variation due to other factors will probably not be recoverable. In the Low Countries, for example, electrical resistivity surveys have been very important in hydrological surveys, where the fresh and saline water tables can be mapped accurately (Van Dam & Meulenkamp, 1967; Tavernier & De Moor, 1974). Where the water table, in particular the saline one, is not locally dominant, electrical resistivity surveying can be used to determine the gross features of Quaternary superficial deposits, such as major lithological boundaries or depth of sediment base (De Breuck & De Moor, 1962).

Introduction to the electrical resistivity survey at Shewalton Moss. This technique was used to establish the depth of peat, and to assess the value of this technique as a tool in such field work.

At Shewalton Moss, five sites were surveyed. These are augerhole sites 8 to 12, at which the position of the base of the peat had already been determined, providing controls with which to assess the results of the electrical resistivity survey. From the results, a three-layer situation is expected, with a thin topsoil layer, thick peat layer and basal layer of inorganic sediment of unknown depth. Since the peat is completely saturated, ρ_a should approximately equal that of the fresh water which it contains, i.e. c. 100 Ωm. The top soil may be less saturated, but more porous, so the resistivity may be greater or less than that of the peat. The underlying sediment is expected to be sandy clay or silty clay (Table A.13.1), and to be less porous than the overlying layers. If sand is dominant, then the resistivity is expected to be greater than that of the peat, and if clay is dominant, less than that of peat.

The Wenner array was used. Values for ρ_a were calculated and plotted in the field as the survey progressed. At Site 9, the Lee Partition was used to check lateral homogeneity. The maximum separation used was 40 m. This allowed for a depth of investigation of approximately 12 m, which is sufficiently deep, given an established maximum peat depth at these sites of just over 6 m. The maximum electrode separation width and the distance between the auger holes are similar; the accuracies of the results of the electrical resistivity and auger surveys therefore will be similar.

Results and discussion. The measured results are shown in Table A.13.2, and the curves drawn from these data are shown in Figure 13.5. Two main features are to be noted:

(1) The curves are similar in form, and although they differ in detail, the differences are fewer than the

similarities.

(2) The differences are greatest in the uppermost parts of the curves. When these parts are matched with standard two-layer curves (Fig. 13.6), it can be shown that the differences are accounted for by changes in the resistivity and depth of the uppermost layer (Table 13.1).

Given these features, an average curve can be drawn (Fig. 13.7), which is clearly a three-layer curve, with ρ_1 and ρ_3 = c. 50 Ωm and ρ_2 = c. 10.0 Ωm. To test whether the three-layer curve accurately reflects the sediment succession, and especially the peat depth, theoretical three-layer curves were constructed, calculated on a Hewlett-Packard desk computer, using a program written by Dr. D. W. Powell (Department of Geology, Glasgow University). The parameters used are $\rho_1 = \rho_3 = 50$ Ωm, $\rho_2 = 100$ or 150 Ωm, and $h_1 + h_2 =$ 5.14 m. The latter value is the average depth of peat for the five sites, as established during the auger survey (Table 13.2). A series of curves was produced for situations where $\rho_1 : \rho_2 : \rho_3 = 1 : 2 : 1$ and $1 : 3 : 1$, and the proportion of $h_1 : h_2$ varied from 1 : 9 to 1 : 99. The best fit (Fig. 13.7) has values $\rho_1 = \rho_3 = 50$ Ωm, $\rho_2 = 100$ Ωm, $h_1 = 0.13$ m, $h_1 + h_2 = 5.15$ m. This value of h_1 is similar to the average upper layer depth (0.22 m) established by the two-layer curve matching (Table 13.1)

Although the theoretical curve closely fits the average curve, slight discrepancies occur. $h_1 + h_2$ must be slightly greater than 5.15 m, i.e. the peat base is slightly lower, on average, than suggested in the results of the auger survey. Also ρ_3 must be slightly less than 50 Ωm. At the base of the curve, there is a slight up-turning in the ρ_a value, suggesting that there is a fourth layer with higher resistivity than those of the overlying layers. This has not been modelled since the depth probe has not been carried far enough to indicate the slope of this segment.

The difference between the theoretical and average curves is less than that between the average and individual

Table 13.1 Shewalton Moss: results of two-layer curve matching analysis (Fig. 13.6) of the upper parts of the electrical resistivity field measurement curves, using two-layer standard curves.

Site No.	8	9	10	11	12
ρ_1 (Ω m)	-	66	59	41	38
h_1 (m)	0	0.41	0.27	0.15	0.20
average h_1(m)	0.22				

Table 13.2 Shewalton Moss: peat depth at the sites used in the electrical resistivity survey data from the auger survey data (Table A.13.1).

Site No.	8	9	10	11	12
depth of peat (m)	6.06	6.16	5.35	3.90	4.30
Average depth (m)	5.15				

Table 13.3 Shewalton Moss: values for the best fit computer-calculated theoretical curves, constructed for individual curves at sites 9 to 12. Site 8 values are obtained by a two-layer standard curve matching analysis.

Site No.	8	9	10	11	12
h_1 (m)	-	0.18	0.16	0.18	0.15
$h_1 + h_2$ (m)	6.06	6.16	5.35	3.90	4.30
ρ_1 (Ω m)	-	65	60	40	40
ρ_2 (Ω m)	110	130	120	100	100
ρ_3 (Ω m)	50	50	60	50	50

curves. To explain this, theoretical curves were constructed for each site, using ρ_1 and h_1 as determined by the two-layer matching exercise (Table 13.1), estimating $\rho_1 : \rho_2 : \rho_3$ from the individual curves and using $h_1 + h_2$ from the auger survey data. The best fits obtained are shown in Fig. 13.8. Curves 9 and 10 are well fitted. At the base of curve 9 there is a slight rise in ρ_a values, indicating the influence of a lower-lying highly-resistive layer. Curves 11 and 12 are more difficult to fit, due to their uneven nature. In curve 11, a value of $h_1 : h_2 = 1 : 24$ would provide a better fit at the top. In curve 12, only a very general fit can be made. The values for the best fit curves are given in Table 13.3. This Table also contains values for site 8, where ρ_2 and ρ_3 are established by matching a two-layer standard curve with the field curve (Fig. 13.8).

The general conclusion from this analysis is that, given a known peat depth and measured ρ_a values, a distinctive electrical resistivity curve can be drawn for the sediments at the site. Conversely, the peat depth may be established from an electrical resistivity curve, given limited auger-hole control data, especially if the curve is a smooth one.

The resistivity of rocks and soils varies according to five main properties (McNeil, 1980; Griffiths & King, 1981): porosity, moisture content, water salinity, temperature and phase state of the pore water, amount and composition of clay colloids. From the auger survey, the succession at all the sites comprises peat overlying clay or sandy clay. The uppermost two resistivity layers are therefore both in peat. Since there is no evidence for clay within the peat, the three factors which may account for differences in ρ_1 and ρ_2 values are water salinity, sediment porosity and pore-water content. Water temperature and phase state are unlikely to differ.

Since Shewalton Moss is largely an ombrogenous bog, distant from the sea and its upper surface some 14 to 15 m above sea level, saline water effects are unlikely. Although occasional sea spray may provide a salt input, it is unlikely to be washed through the peat, or accumulate in any significant quantities.

In the upper horizons, peat is less compacted than lower down (Aaby et al., 1979), and where drainage has been artificially developed, the upper peat layers may not necessarily be fully saturated. Differences in sediment porosity and pore-water content therefore may account for the measured resistivity differences between layers 1 and 2. From Archie's Law (Parasnis, 1979, p.130; see also Table A.13.3), if both layers are equally saturated, the lower layer must be approximately twice as compressed as the upper layer (Table A.13.3). Since the local water table lies below the ground surface, the upper layer is not saturated, whereas the lower one is. In this case, the upper layer must be much less compressed than the lower one. If an average value for the porosity of layer 1 is taken as 50% (Bridges, 1970, p.13), the calculated resistivity values of the contained water (ρ_o) may be accounted for by an approximately 0.13% volume NaCl in solution (Table A.13.3). This contrasts with an average value of c. 2.7% NaCl content in sea water (Furon, 1967, p.14). For realistic differences in porosity and pore water content values for the topsoil and lower compressed and saturated peat, the water salinities of layers 1 and 2 are virtually identical (Table A.13.3). These indications of water freshness support the qualitative statements made above.

Clearly the differences in resistivity between layers 1 and 2 represent mainly the presence of the peat topsoil, which is poorly compacted and non-saturated, and the underlying more compacted and saturated peat. The lower boundary of layer 1 may be diffuse since it appears to depend on more than one variable.

The curve matching analysis described above indicates that layers 2 and 3 correspond to peat and sub-peat sediment.

The latter is recorded in most of the auger holes as sandy or silty clay. At Hillhouse quarry, ρ_a values of c. 30 Ω m for (clay-rich) till have been measured (D. W. Powell, pers. comm.). Furthermore, sand is generally more resistive than clay by a factor of 2, and is more resistive than peat. The ρ_3 values of c. 50 Ω m (approximate average value, Table 13.3) are close to the measured value for clay, and therefore suggest that, below the peat, layer 3 consists primarily of clay. If significant amounts of sand are present, the resistivity values would be expected to increase beneath layer 2 rather than decrease as they do.

At the base of curves 8, 11, 12 and especially 9, there is a slight increase in values. Values for bedrock resistivity are much higher than for consolidated sediments (greater than 10^2 Ω m; Tavernier et al., 1967; Parasnis, 1979). The upturn in ρ_a values may therefore represent the presence of bedrock at lower levels.

Conclusion. Given augerhole control data, electrical resistivity surveying, while not recording fine detail, appears to be a suitable tool for establishing peat depth and lateral changes in peat depth at a bog. It may be particularly useful where the peat surface is soft or easily damaged by augering, or where peat is especially deep. In the latter case, it is physically less demanding than augering.

An important result of the electrical resistivity survey at Shewalton Moss is confirmation that the real peat base was reached at all sites by augering; the apparently sub-peat sediments are not thin layers included within the peat. The survey also shows that there is little lateral variation in the sub-peat sediment, it being at all sites a clay-rich sediment, which extends to at least 10 m below the surface.

4. Pollen analysis

Introduction. Two peat cores were collected to be analysed for pollen and spore content. The principal aim is to establish the age of the base of Shewalton Moss, the main question being whether the initiation of Shewalton Moss dates from before or after the middle Flandrian marine transgression.

Both cores were collected using a "Russian" corer (Jowsey,1966), at sites where the altitude of the peat surface above O.D. and the peat thickness and depth had already been established.

The top of core SM-81-I, at auger hole 2, lies at 13.45 m A.O.D., and the peat base lies at 10.75 m A.O.D. The Nat. Grid Ref. is NS 352 360. This site is selected as representative of inland, marginal site to answer two main sets of questions:

(1) If the initial growth of Shewalton Moss occurred during early Flandrian times, was there a later expansion of the moss? If the central part of Shewalton Moss is early Flandrian in age (not yet determined), are the margins, and by implication, the general extent of the moss, also early Flandrian in age?

(2) How probable is it that the surface upon which the peat sits has been flooded during the marine transgression? Can some limits be put on the extent of the Flandrian transgression?

Whereas the first questions bear directly on changes in the terrestrial environment during the Flandrian Age, the latter questions relate to changes in the marine and shore environment. The answer to the latter set of questions will be that either (a) the peat is old (say early Flandrian), and therefore the middle Flandrian coastline was west of Shewalton Moss, or (b) the peat is young, and the inland position of the Flandrian transgressive coastline cannot be placed with certainty east or west of the site. In the latter case, if a succession from the underlying inorganic sediments to the peat can be shown to indicate the development from salt- to freshwater conditions (cf. Chapters 4 & 5), more positive statements regarding the location of the middle Flandrian shoreline can be made.

The top of core SM-81-II, at auger hole 31, lies at 15.68 m A.O.D. The base of the peat lies at 7.33 m A.O.D. The Nat. Grid Ref. is NS 346 346. This site is selected because it represents both the thickest peat and the location where the base of the peat is lowest. Initially such a site was expected to occur near the centre of Shewalton Moss, but the results of the auger survey indicate that the area where the base of the peat is lowest is adjacent to the cliff at Hillhouse (Chapter 13.2), at the south-eastern edge of the moss. The importance of this site is that the peat, being the thickest on the moss, presumably requires the longest period to have grown. This is therefore the site at which a maximum age for the entire moss may be found. Since the base of the peat at this location lies at a level (7.33 m A.O.D.) up to which, and possibly above which middle Flandrian sea level in this area may have reached (Donner, 1970), peat initiation must have occurred either considerably earlier than the transgression, with peat growing to such a level as to be above sea level throughout the Flandrian Age, or, alternatively, after the period of maximum sea level, when ground water again became fresh. In the former situation, if sea level or the local saline water table at any time rose above the peat surface, an interruption in peat growth would have occurred. This would be recorded in a peat core. As discussed above, in either situation (1) or (2), the age of the base of peat core SM-81-II, on general grounds may be regarded as a maximum age for the initiation of peat growth at Shewalton Moss. There are, however, several possible exceptions:

(1) Peat growth started prior to the marine transgression. During the transgression, the sea flooded the low-lying area in which SM-81-II lies, either (a) eroding

and removing all the previously accumulated peat or (b) depositing sufficient inorganic sediment on top of the existing peat to give confusing auger results. In the latter case, a few decimetres of inorganic sediment would be sufficient. In either case, the peat to the north, resting on slightly, but significantly higher surface may have continued to grow, unaffected by the rising sea level.

(2) Peat initiation occurred during the period of high sea level, so that in a situation similar to (1) peat was able to form on the slightly higher surface to the north of the depression. Both this case and (1) have important consequences in terms of altitudes of former sea levels.

(3) Peat initiation occurred either (a) before the marine transgression, peat growth was unaffected by the transgression, or (b) after the transgression. If the depression is part of an infilled channel, it may have served as drainage for the wet bog surface and/or the hilly area to the south. In this case, commencement of peat growth in the depression may have been delayed or the peat may have been overlain by channel deposits whereas, on the neighbouring slightly higher surface, peat growth was able to continue unabated.

Of these situations, (3b) is considered least probable, and (1a), (1b) and (3a) are the most probable. However, on account of the thickness of peat, it is considered that all these cases are improbable.

<u>SM-81-I</u>

<u>The results</u>. The peat was sampled from the surface, where only poor samples were retrieved due to the presence of roots and dry peat, to <u>c</u>. 0.15 m above the base of the peat. The peat base lies at 2.70 m below the surface. The broad snout of the Russian corer is incapable of penetrating into coarse-grained sediment such as that which underlies the peat, but the basal core retrieved is regarded as repre-

sentative of the base of the peat.

The basal 0.80 m section of the peat core was analysed for pollen and spore content. The Troels-Smith description for this section is given in Table A.13.4, and the results of the macrofossil analysis are shown in Figure 13.9. Generally the macrofossil assemblage zones correspond well with the Troels-Smith units. Several points should be noted. Although T.S. 2 is termed the sandy layer, sand is also found throughout T.S. 1 and into T.S. 3. The typical plant remains in T.S. 2 are unidentified moss stems and leaves. T.S. 3 is characterised by the presence of tree remains: leaf fragments, bud scales, and specimens of fruits and fruit scales of Betula spp. Also present are Carex fruits, which are absent in T.S. 2 but are abundant in T.S. 1, together with Juncus and Menyanthes seeds. The boundary between T.S. 3 and 4 lies slightly higher than the changes in macrofossil assemblages would suggest, and is characterised not only by macrofossil assemblage changes but also by the abundant presence of charcoal. T.S. 4 is characterised by the frequent presence of wood and bark remains and tree leaf fragments and bud scales with the continued presence of Cyperaceae fruits. Of note throughout T.S. 4 is the presence of Cenococcum geophilum. The supernatent colour (indicative of the degree of humification) generally corresponds to the humification values in the Troels-Smith descriptions, although the record from sixteen samples shows a more complex picture than the generalization from four Troels-Smith units.

The results of the pollen analysis are shown in Figure 13.10. By inspection, four local pollen assemblage zones are recognised. All percentages are of total pollen plus pteridophyte spores, unless otherwise stated.

SM-81-I.1 "Cyperaceae - Herb Pollen Local Pollen Zone"

Samples 1 to 4 (4 samples); from base of diagram to c. 0.18 m.

This zone is characterised by the abundant presence of Cyperaceae (64-84%). Trees and tall shrubs have very low values (5-10%). Herbs other than Cyperaceae have a moderate presence; of note are Artemisia (to 7%), Menyanthes (to 13%), Gramineae (to 12%) and Filipendula.

SM-81-I.2 "Betula - Salix Local Pollen Zone"

Samples 5 to 7 (3 samples); from c. 0.18 m to c. 0.33 m.

This zone is characterised by peaks in Betula values (10-15%) and in Salix values (to 14%). The Salix peak starts before this pollen zone, continuing beyond it. Cyperaceae has moderately constant values of c. 45-55%. Herbs, while being common, are not as abundant as in the previous zone; there is constant presence of Artemisia and Umbelliferae type. Typical of this zone is the presence of the aquatic plants (2-3%). Pteridophytes rise to and maintain values of c. 15% throughout the zone.

SM-81-I.3 "Pteridophyte - Corroded Pollen Local Pollen Zone"

Samples 8 to 11 (4 samples); from c. 0.33 m to c. 0.57 m.

This zone is characterised by two main features: the high rise of pteridophyte spores (20 to 82%), only identifiable as Filicales, and the predominance of very poorly-preserved pollen grains. Herbs are very uncommon, except for Cyperaceae (mostly 34-69%, but dropping to 5% at the pteridophyte peak). Trees have very low values, although Pinus attains maximum values (to 4%) within this zone. Gelasinospora is present throughout this zone, peaking to 16% during the pteridophyte peak. This is the only zone in which Gelasinospora occurs.

SM-81-I.4 "Coryloid - Betula Local Pollen Zone"

Samples 12 to 16 (5 samples); c. 0.57 m to the top of the diagram.

The rapid rise and subsequent high values (25-50%) of Coryloid and the constant, if lesser, presence of Betula (6-14%) characterise this pollen zone. Alnus peaks twice, once to 17% at the beginning of the zone, and later to 30%. Salix also is represented constantly. Gramineae values remain low, Cyperaceae is variable, but common, and other herbs are low (to 3%) but present. The aquatics are virtually absent, and various pteridophytes are present in minor quantities.

Introduction to the discussion. Figure 13.11 shows the percentages for selected taxa as proportions of the total pollen. Although the pteridophyte curves are absent from this diagram, the local pollen zones presented here are valid for this diagram also. The pollen zones are discussed below.

Cyperaceae - Herb Pollen Local Pollen Zone. The abundance of Cyperaceae and other herbs, with very low presence of trees and tall shrubs, and virtual absence of such taxa as *Ulmus*, *Quercus* and *Pinus*, represents a locally- and regionally-open landscape.

The abundant presence of *Carex* nutlets suggests that much of the Cyperaceae pollen is from locally-growing stands of sedges. Specific identification may be possible (Nilsson & Hjelmqvist, 1967) but this was not achieved here. There are also a few remains of undifferentiated non-*Carex* Cyperaceae fruits, indicating mixed sources for the pollen. No *Eriophorum vaginatum* macrofossils were found so this plant is regarded as locally absent. Although Faegri & Iversen (1975, p.253) provide a Cyperaceae pollen identification key, the differences between types appear to be minimal (Andrew, 1980) and, following the usual practice in British pollen analysis (Godwin, 1975, p.383), no attempt has been made to differentiate Cyperaceae pollen types.

Most of the herb taxa represent plants of open habitat. *Artemisia* rises throughout the zone, peaking at 7%. *Artemisia* species grow typically on dry soils in open situations. The other herb taxa also represent open habitat species: *Cerastium*, *Lychnis*, *Matricaria*, *Ranunculus* and *Galium* types, *Caltha palustris*, Chenopodiaceae, *Filipendula*, *Hydrocotyle vulgaris*, *Menyanthes*, *Plantago coronopus*, *Rumex acetosa*, *R. acetosella* and *Valeriana*. They are not all dry soil species however. *Caltha palustris* is almost entirely restricted to this pollen zone, with values of 2-7%. *Menyanthes*, present throughout this zone and, peaking at 13%, reflects the local presence of *M. trifoliata*. Although *Filipendula* is sporadically present throughout the diagram, its principal presence is within this pollen zone. *F. ulmaria* probably is represented. The abundant presence of *C. palustris* and

M. trifoliata and the lesser presence of F. ulmaria, Hydroctyle vulgaris, Nuphar and perhaps Ranunculus type, Valeriana and Plantago coronopus, indicate locally-wet conditions.

The sparse presence of some trees and absence of others suggests a very early Flandrian or possibly Late Devensian age for this pollen zone. Coryloid values of 4% occur prior to the Corylus rise. Betula values of less than 1% are lower than Donner's (1957), Vasari & Vasari's (1968) and Moar's (1969) values for assemblages prior to those of Godwin zone IV, and at Tynaspirit, near Callander, similar low Betula values occur during the Loch Lomond Stadial (Lowe & Walker, 1977).

Although Artemisia is present throughout the Late Devensian and early Flandrian times at many sites, only at Tynaspirit are values equal to those at this site. In Wigtownshire (Moar, 1969) values are higher (10-20%). After the beginning of the Flandrian Age, Artemisia is absent with only sporadic presence (e.g. Walker, 1975). This general pattern occurs throughout Britain (Godwin, 1975, pp.345-346) with frequent values of 5-10% during the Loch Lomond Stadial, and higher values occurring in areas of drier, more continental climate (Birks & Mathews, 1978; MacPherson, 1980; Sissons, 1980).

Although high values of Filipendula are common throughout Britain during Late Devensian times (Godwin, 1975, p.183), at sites in south-western Scotland Filipendula values tend to be low during this period. During the Flandrian Age, values are typically c. 2%, although at some sites values of c. 10% are recorded (Moar, 1969). Similarly, Caltha palustris and Menyanthes are commonly present in moderate amounts since deglaciation, especially during Late Devensian times. The presence of these three taxa probably reflects marshy Late Devensian environmental conditions, rather than their being solely temporal indicators.

The occasional presence of pteridophyte spores is dominated by the distinctive micro-spores of Selaginalla. S. selaginoides is often represented by high spore counts during Late Devensian times (Moar, 1969; Walker, 1975; Lowe & Walker, 1977). However, it also survives during the Flandrian Age (Robinson, 1980), so the 1% here may not be significant.

Local pollen zone SM-81-I.1 represents a locally-wet site within an essentially open landscape at, or possibly before, the beginning of the Flandrian Age.

Betula - Salix Local Pollen Zone. The beginning of this pollen zone is characterised by a rise in the values of Betula from 1% to 10-15%, coincident with the first appearance of Betula macrofossils, fruits and scales of B. pendula and B. pubescens, with bud scales, tree leaf and wood fragments which also may be from the locally-growing Betula trees. Therefore, the pollen is regarded as local, although the local influx may also reflect a regional increase of Betula woodland. Alnus, rising slightly to 2%, is also present as a minor component. The continuing rise of Salix values indicates locally-expanding Salix stands. If the small fluctuations in the Coryloid curve are significant, there may have been local alternations between Salix and Myrica on the wet bog surface.

The gradual decrease in Gramineae values reflects a general regional decline in grasses as the landscape became more wooded. The rapid decline in Cyperaceae values to c. 50% is probably a local feature, parallelled by the declining presence of herbs such as Artemisia and Filipendula, as Betula and Salix enter the area. A completely closed vegetation was not yet developed; indicators of open conditions, such as Artemisia, Cerastium type, Plantago coronopus and the three Rumex species maintain persistent but minor presence.

Locally-wet conditions are indicated by the presence of aquatics - Nympheae, Potamogeton and Typha latifolia -

and the continued presence of Sphagnum spores. Colonies of Pediastrum, a planktonic alga which generally indicates eutrophic water conditions (Brook, 1964, p.299) also continue to be present. Water-margin herbs - Caltha palustris and Filipendula - become less common, perhaps only reflecting the decreasing local openness; however, conditions remained sufficiently open for Menyanthes to grow locally. The possible identification of Thelypteris palustris type spores is important. This is a marsh fern, at present found rarely in Scotland (Perring & Walters, 1976, p.14), whose spores are easily destroyed (Godwin, 1975, p.94); this record thus represents very local growth of this fern. The other ferns reflect the increasing woodiness, and Blechnum spicant, if correctly identified, may reflect the increasingly oligotrophic conditions on the bog surface. Juncus seeds, not identified to species level, indicate locally-wet and possibly base-poor conditions.

This pollen zone represents the local and probably regional increase in woodland, dominated by Betula, with Salix locally common. At many sites, a rapid rise in Betula marks the beginning of the Flandrian Interglacial. At Muir Park Reservoir (Vasari & Vasari, 1968) the zone III/IV to IV boundary is placed at the Betula rise; as Cambusbeg (Lowe & Walker, 1977) the Betula rise occurs within the first Flandrian pollen zone; in south-western Scotland (Moar, 1969) the beginning of the Flandrian Interglacial is placed immediately after the Betula rise. The rise of Betula has been dated by radiocarbon analysis at Tynaspirit (10,420 ± 160 B.P.; Lowe & Walker, 1977) and at Muir Park Reservoir (10,010 ± 250 B.P.; Vasari, 1977), providing dates which, statistically, are not significantly different.

At Muir Park Reservoir (Donner, 1957), in Galloway (Moar, 1969), near Callander (Lowe & Walker, 1977) and on Arran (Robinson, 1980, p.81) during the vegetational development prior to the main expansion of Betula, Salix is temporarily abundant. This may be a local, if persistent, feature and while not a strong chronological indicator, is consistent with the early Flandrian age suggested for this local pollen zone.

The gradual decline in Gramineae recorded here occurs also at Muir Park Reservoir (Vasari & Vasari, 1968), and at most sites, at the beginning of the Flandrian Age, there is a notable drop in the abundance and diversity of herbs. The pterodophytes, Blechnum spicant, Athyrium and Dryopteris are recorded throughout Late Devensian and early Flandrian times in Skye (Birks, 1973). Beyond stating that these taxa are present during Late Devensian times, Godwin suggests that for Dryopteris at least, "biogeographical conclusions are not practical" (1975, p.93); temporal conclusions are probably also not practical. It is interesting, however, that these pteridophytes are present at Shewalton Moss during the early Flandrian Age.

Pteridophyte - Corroded Pollen Local Pollen Zone. Although a numerical count of corroded and damaged grains was not made, records of the general state of the grains were kept. There is a gradual increase from the base to the top of the zone in the degree of corrosion of the grains. In the top sample, the grains are so poorly preserved that pollen such as Betula and Coryloid can only be identified in polar view. Filicales spores are generally in poor condition and many objects may or may not be pollen grains. One exception is Pinus, whose grains are commonly uncorroded and complete, although some are recorded as being "complete but appearing washed-out".

The degree of preservation of pollen in soil depends mainly on the amount of microbial activity. In Britain the most important single factor influencing the microbial activity is the soil acidity (Dimbleby, 1962); in soil of pH greater than c. 6, microbial activity is sufficient to destroy all the pollen (Moore & Webb, 1978, p.15). As peat dries out, such activity increases. Various workers have investigated the problem of pollen preservation, showing that some taxa are less susceptible to corrosion than others.

The sporopollenin content of the exine appears to be important (Birks & Birks, 1980, p.23) although Southworth (1974) suggests that there are three different groups of molecules, all classed as sporopollenins, which have different solubility characteristics. From the results of several investigations (e.g. Davis & Goodlett, 1960; Sangster & Dale, 1962, 1964; Havinga, 1964, 1974; Cushing, 1967; Vuorela, 1977) a few comments, restricted to taxa of relevance here, will be made. Pinus tends to be best preserved, often undergoing no damage; Ulmus and Quercus seem to be badly preserved in some cases (e.g. Havinga, 1974; Vuorela, 1977), but in others, they survive moderately well (e.g. Davis & Goodlett, 1960; Sangster & Dale, 1964); Corylus, Alnus and Salix undergo moderate to severe change. Vuorela (1977) records that non-tree pollen tends to preserve badly, listing Cyperaceae, Gramineae, Ericaceae, Artemisia, Chenopodiaceae, Ranunculaceae, Rosaceae and Umbelliferae as poorly-preserving taxa. Pteridophytes are typically well-preserved (Dimbleby & Evans, 1974; Birks & Birks, 1980; Southworth, 1974).

Certain problems related to pollen preservation in soil cannot be resolved in such a systemmatic manner. Down-wash and bioturbation of pollen grains can completely alter the pollen stratigraphy, until the vertical distribution of pollen bears no relation to any chronologically ordered vegetational changes (cf. Godwin, 1958). Interaction between physical movements of pollen and fluctuations in the preserving environment can provide unusual distributions and gaps in the pollen record (cf. Havinga, 1968).

The general proportions and values of taxa recorded in this local pollen zone at Shewalton Moss largely reflect the patterns following corrosion as outlined above. Ascospores of Gelasinospora spp. are recorded only in this pollen zone, peaking to 17% at the pteridophyte peak. In the macrofossil diagram (Fig. 13.11) charcoal remains are also recorded only during this zone. Both Gelasinospora spp. (Van Geel, 1978, p.48) and charcoal imply (at least) local dry conditions. During the period concerned, the area may not have dried out completely, since there are a few records of Sphagnum spores and Tilletia sphagni (spores of a fungus which grows on Sphagnum; Dickson, 1973, p.63).

The very low values of tree pollen and virtual absence of herbs (other than Cyperaceae) may be due to differential erosion; Filicales becomes the dominant surviving taxon, thus lowering the relative abundance of the remaining taxa. However, there are several exceptions. Pinus rises to its highest values at this time (to c. 8%) reflecting either the increased representation of a regional component due to reduction of the local pollen input, the expansion of Pinus onto the increasingly dry bog surface, or, most probably, the high degree of preservation of Pinus pollen. With Filicales omitted from the pollen sum (Fig. 13.11), Betula, Alnus and Salix appear to be consistently less common (or absent) than during the preceding and subsequent pollen zones. Coryloid pollen, however, increase rapidly. Given that Coryloid and Betula pollen preserve equally well, this rapid rise (4% to 36% in 0.10 m) represents a real increase in Coryloid values which is possibly more extreme than indicated in the diagram. Similarly, Cyperaceae values increase initially, until they are replaced by high Coryloid values. Again Cyperaceae preserves poorly, so this increase must represent substantial real increases in pollen input.

In this local pollen zone the evidence indicates four notable phenomena: (a) the vegetation appears to become more open, followed by (b) dry conditions; (c) a rapid increase in Coryloid pollen; (d) the presence of charcoal remains. High Coryloid values continue during the period of dry soil, suggesting that Corylus rather than Myrica is represented. The Coryloid pollen rise is interpreted throughout Britain as a rise in Corylus, supported occasionally by macrofossil evidence, although in some cases high Coryloid values clearly reflect the local presence of Myrica (cf. Birks, 1975).

In view of suggestions (cf. Simmons et al., 1981, p.103) that the *Corylus* rise and, more certainly, high *Corylus* values during the Boreal period may be due to human activity, possible interaction between Mesolithic activity and the environment, both in general and at Shewalton Moss, is discussed now.

Traditionally the *Corylus* rise is regarded as a vegetational response to amelioration of climate and/or the rapid migration rate of *Corylus*. However, increasing evidence links high *Corylus* values with archaeological remains (cf. Keef *et al.*, 1965) or, more often, implies that forest clearance and substantial increase in *Corylus* results from human activity (cf. Dimbleby, 1961; Simmons, 1964, 1969; Simmons *et al.*, 1975; Jones, 1976).

Corylus is widely adaptable, shooting quickly after damage, especially by fire. Smith (1970) and particularly Simmons (1975a, b) argue that manipulation of *Corylus* may have been an important element in Mesolithic food management. From estimates of food requirements and Mesolithic populations, Simmons (1975a) suggests that, for normal animal productivity within a habitation site catchment area, there would be no need for either human migration between sites or vegetation management to encourage animal food yield. However, to maintain consumption at normal or falling productivity rates, either or both of these activities would be required. Thus "experience of such episodes [periods of low animal productivity] might have led to long-term measures such as habitat management ..." (Simmons, 1975a, p.10). This largely theoretical acceptance of probable Mesolithic animal and vegetation management strengthens statements of correlations between presence of charcoal and vegetation events such as the *Corylus* rise, short periods of open vegetation, deforestation and blanket peat initiation (e.g. Durno & McVean, 1959; Radley *et al.*, 1974; Jacobi *et al.*, 1976; Dickson, 1980b; cf. Robinson, 1981, p.13). The periodic burning of vegetation over a few years increases the biotic yield (cf. Miller *et al.*, 1966; Dills, 1970; Mellars, 1975; Jacobi *et al.*, 1976), so is regarded as a tool used, deliberately and under control, by Mesolithic people to improve the grazing values of, especially, marginal woodland (Simmons, 1975a; Simmons et al., 1981).

There are larger areas in which no association between the Corylus rise and evidence for human activity can be shown (Smith, 1970). The Corylus rise is probably a natural change which was followed, in some cases, by human management of Corylus woodland at least locally. Mesolithic vegetation management, although important and widespread, cannot yet be shown to be regional in effect. Each site must be assessed on its own merits.

There is evidence for Mesolithic activity in Scotland at the period of the Corylus rise (Coles, 1971; Masters, 1981; see also Mercer, 1970). However, the population during the 9th millenium B.P. was possibly so small that "it is improbable that the vegetation of Scotland's inland and upland areas was subject to major interferences during the period in question" (Edwards, in press, p.4 of unpublished manuscript). In addition, many sites show major changes regardless of presence or absence of evidence of human activity, and peaks in herb pollen, often indicative of human activity, can also be interpreted as natural phenomena.

Important evidence used to suggest human activity is the presence of charcoal within peat. Charcoal is interpreted as indicating the former presence of a surface fire at or near the site and thus, by implication, human activity in the area. Strictly, however, the presence of charcoal indicates that organic matter, frequently wood, has been burnt, not necessarily that a fire has been started by human agency. There is an alternative process which may explain the presence of sub-surface charcoal within peat (cf. Boyd, 1982).

In 1976, the writer assisted in the extinguishing of moor fires in the Kilpatrick Hills, near Glasgow. The fires had been caused by solar heating of the peat at levels below the surface. Surface fires were limited in extent, but large areas of peat were burnt within the profile. During that summer, there also were reports from parts of Wales of considerable areas of soil being destroyed by sub-surface burning.

It is suggested that the heating of peat by the sun during a period of unusually warm weather is a process by which charcoal may be formed within the peat profile. If this claim is valid, certain important implications follow:

(1) After as little as one month of unusually warm weather, large areas of peat can be burnt within the peat profile.

(2) Large areas of peat can be affected without the presence of widespread or large-scale fires, and even without the appearance of surface fires.

(3) Charcoal need not, and probably will not, be produced at the surface at the time of charcoal formation. The stratigraphical position of charcoal will have little chronological significance, other than providing a maximum age for its formation, and may be determined by factors, such as the presence of a sub-surface layer or layers of woody peat. Charcoal at various stratigraphical positions may have been formed during the same event (cf. Tallis, 1975).

(4) To explain the presence of sub-surface charcoal in peat, it is not necessary to invoke large-scale forest fires (cf. Durno & McVean, 1959), frequent burning events (cf. Tallis, 1975; Simmons & Innes, 1981), abnormally high incidence of lightning (the commonly-invoked natural ignition source; Kemp, 1981, pp.14-15), climatic fluctuations (cf. Swain, 1973, 1978) or human interference (cf. Stewart & Durno, 1969), deliberate or otherwise (Smith et al., 1981, p.181).

This method of sub-surface charcoal formation may have occurred only during relatively recent times, when peat has become more easily dried out following increased drainage on bog surfaces either due to human activity (cf. Moore, 1973; Simmons et al., 1975) or natural development (cf. Conway, 1954; Tallis, 1964). However, in the early stages of peat growth, the peat, being relatively thin, may also have dried out and thus in many areas this method of charcoal formation may have been able to operate throughout most of the Flandrian Age.

At Shewalton Moss, the following chronological order of events is apparent: (1) charcoal is present, (2) there is a decline in trees and an increase in Cyperaceae, suggesting an increase in the openness of the site, (3) charcoal is present again, and the Corylus rise occurs, and (4) the soil dries out.

There are several possible relationships between these events. Since the charcoal is very abundant and was previously and subsequently absent, it presumably represents local event(s) and not background, regional dust. The charcoal may have been caused by surface burning. If it is from nearby, its presence is not directly related to the local vegetation, but if it is local in origin, the vegetation may have been cleared during the first period of burning, and the entry and expansion of Corylus either followed continued episodes of burning in this area, or colonized the newly opened vegetation regardless of, but perhaps aided by, the burning. If surface burning is invoked as an explanation, the question still remains whether human interference, deliberate or otherwise, was important or not.

Alternatively, the charcoal may represent peat components burnt in situ by sub-surface burning. The formation of the charcoal therefore post-dates the vegetational events represented at the same stratigraphical levels and probably relates to the period of soil drying. Thus, neither the opening of the woodland nor the subsequent colonization by Corylus is related to the charcoal or the drying period. If the charcoal has been formed by sub-surface burning, explanation of its stratigraphical position may become complex. A final complication would be introduced if the charcoal was formed by a combination of both surface and sub-surface burning. Since the discussion is concerned with only seven samples, too much emphasis should not be placed on fine detail. It is possible, however, that the charcoal curve represents either an upper surface-fire component with a lower sub-surface-fire component, in which case the Corylus rise may be associated with burning, or a lower surface-fire component, representing the opening of the vegetation by fire, followed by an upper sub-surface component related to the dry soil period.

It is considered that there is insufficient evidence to resolve this problem. The problem is conveniently summarized by Simmons (1975a, p.1):

> "... the nature of the evidence usually allows us to infer only the larger scale mutations of the ecology, and we are faced also with the problems of separating man-induced change from natural processes such as autogenic and allogenic succession, let alone deciding whether the former category represents deliberate or unknowing action by man."

The Corylus rise is represented within this pollen zone. In western central Scotland, the only radiocarbon date directly related to the Corylus rise is from Arran (Robinson, 1980, p.82), where the rise occurs immediately after 8,665 ± 155 years B.P. Elsewhere, at Muir Park Reservoir (Vasari, 1977), the rise lies at c. 0.30 m above a sample dated at 10,010 ± 230 B.P., and by 8,732 $^{+510}_{-480}$ B.P., at Dubh Lochan (Stewart, 1979) Corylus values were greater than 65%. Birks (1980) gives a date of c. 9,500 B.P. for the Corylus rise in southern Argyll and by extrapolation from figure 53 in Birks, 1980, a date of c. 8,800 B.P. may be valid for Ayrshire. Although an exact date cannot be given for the Corylus rise at Shewalton Moss, it clearly represents a very early Flandrian event.

Coryloid - Betula Local Pollen Zone. Pollen grain preservation, while not as good as in the lowermost two zones, is better than in the immediately preceding zone. This may be related to an increased dampness, sufficient to reduce only the microbial activity in the soil. There are several indicators of wet conditions. Cenococcum geophilum, a hard mass of fungal hyphae (Brook, 1965, p.493) present in various environments, may be used to indicate either eutrophic wet-bog conditions or relatively dry raised-bog conditions (Van Geel, 1978, p.102). Richer water at Shewalton is reflected in the absence of Sphagnum spores, although one leaf of Sphagnum subgenus Inophloea is recorded in the top sample. A single Menyanthes grain, a small peak in Potamogeton and possibly two Ranunculus grains are further evidence for wet conditions.

There is a mixture of grains showing varying degrees of preservation. For three samples Coryloid pollen is recorded as, for example, "almost all very corroded or else completely fresh". This bimodal population may be explained in several ways. Firstly, there may be two sources of Coryloid pollen. The pollen from both sources may have been transported directly to the site, the degrees of corrosion representing differences in distance of the sources from the site, or the fresh pollen may be local, directly-transported pollen, whereas the corroded pollen may be reworked pollen possibly from eroded peat elsewhere. Alternatively, there has been either bioturbation, leading to mixing of corroded older pollen with fresh, more recent pollen, or downwash of fresh pollen which has been mixed with corroded in situ pollen.

This problem is difficult to solve. As discussed below, a substantial regional pollen component is not present, so a non-local source is improbable. Inwashed material is often recognisable by the presence of inorganic material or pre-Quaternary spores. However, if Flandrian peat is being eroded, such material need not be present, as indeed it is not in the case considered here. If the peat is moderately dry, bioturbation may occur, but more smoothing of the pollen curves than there appears to be is expected. Bioturbation need not be thorough and may produce random distributions of pollen grains. The peat at this level is not stratified, so disturbance cannot be proved nor disproved. Downwash, unless from immediately above, would be expected to provide thermophilous taxa such as Ulmus and Quercus.

The basal boundary of this pollen zone does not coincide with any recognisable lithological boundary, suggesting that the implied dry conditions may only have been short lived or sporadic. Sangster & Dale (1964) indicate that only a few months are required for a significant amount of pollen degradation to occur in a bog. Furthermore, it may be suggested that whereas at an early stage the bog surface was dry for a period long enough to allow considerable grain corrosion, later, alternating shorter periods of dry and wet conditions provided a complex preserving environment, and resulted in the apparent variation in degree of corrosion. To test this hypothesis, closer-spaced smaller-sized and perhaps continuous sampling is required. In the light of earlier discussion, this may hint at Mesolithic vegetational management at Shewalton Moss. The suggestion cannot be taken further without more data.

Betula rises to values similar to those in the Betula - Salix L.P.Z. (6-14%), and since B. pubescens fruits are recorded, the pollen is regarded as at least partially local in origin. Pinus drops to low values similar to those in the Betula - Salix L.P.Z., probably representing a background regional component. Coryloid, representing Corylus (see above) maintains high, but variable values, decreasing slightly upwards; generally a gradual decline after the rather spectacular rise is common.

The two Alnus peaks present a minor problem. The first, appearing at the beginning of the pollen zone, follows shortly after the beginning of the Corylus rise. The second commences at the end of the zone and the diagram, so there is, unfortunately, no indication whether this is another isolated peak or the beginning of a more continuous curve. The first rise may represent the regionally-recognised Alnus rise, followed by local changes in vegetation caused by changes in local conditions such as a fluctuating degree of dampness - the Alnus peak is followed by a rapid succession of Coryloid and Salix peaks, a Cyperaceae peak, a Coryloid peak, and finally high Alnus values. To support this, it requires to be shown that the first peak represents the Alnus rise. Immediately prior to the peak there is a series of high Pinus values, a feature common in many diagrams. At Muir Park Reservoir (Donner, 1957) Pinus reaches values of c. 30% of total pollen and at many other sites (Moar, 1969; Birks, 1975; Walker, 1975; Stewart, 1979; Robinson, 1980) maximum values of 10-20% of total pollen. However, although Pinus at Shewalton Moss represents the regional vegetation, its high values more probably reflect the unusual local conditions and do not fit into the regional trends described at other sites. Furthermore, the diagram appears to reflect local conditions, with low values of regional components such as Pinus, Quercus and Ulmus. Thus representation of the local vegetational changes is expected to blanket out that of a regional increase in Alnus. For a short period, however, the regional Alnus component has an opportunity to be present, while local conditions appear to be moderately open, Cyperaceae being common and tree macrofossils being less common. The succeeding minimal values for Alnus suggest that, regionally, it is not very common, suggesting that the first peak is a local expansion of Alnus as alder carr spread rapidly into the renewed wet habitat, with Betula and especially Corylus following as a natural succession, shading Alnus out. Salix would grow in damper situations. As this woodland developed, Alnus expanded regionally, and the second rise represents the true Alnus rise.

An alternative explanation is that, bearing in mind the differential preservation of Coryloid grains, the early peak in Alnus may be attributable to either bioturbation or downwashing. If so, further interpretation of the pollen spectra is greatly impeded. Despite the impression that the Quercus and Ulmus curves, and to a minor extent the Calluna curve, appear to mimic the *Alnus* curve, the Cyperaceae curve is sufficiently asymmetrical to suggest that this is an unlikely explanation.

Taking a date of *c*. 7,000 B.P. for the *Alnus* rise in western central Scotland and *c*. 8,800 B.P. for the *Corylus* rise (cf. Birks, 1977, p.126, 1980, fig. 53), 0.10 m of peat accumulation between the *Corylus* rise and the first *Alnus* peak seems improbable for a 1,800 year period. Although no evidence indicates whether peat growth was retarded during the dry soil period, it is considered that the *Alnus* peak follows the *Corylus* rise too rapidly to represent the regional *Alnus* rise.

In many diagrams the regional *Alnus* rise is preceded by a smaller, short-lived peak (Durno, 1956; Donner, 1957; Nichols, 1967; Moar, 1969; Birks, 1975; Robinson, 1981). In these cases *Alnus* values rise to less than 25% of the maximum values of the main rise and return briefly to low values. Elsewhere the pattern is different; at Bloak Moss (Turner, 1965) values change from 15 to 50 to 35 and finally to 65% of total tree pollen, whereas at Loch Lomond (Stewart, 1979) and at Craigmaddie Muir (Dickson, 1980a, 1981) the first rise is the *Alnus* rise. The top of the diagram at Shewalton Moss lies immediately above the beginning of the second rise so it is difficult to suggest which pattern is more applicable. The former seems more probable.

In Galloway (Birks, 1975) the *Alnus* rise occurs at 6,805 ± 200 B.P., 6,820 ± 180 B.P. and prior to 6,787 ± 200 B.P., three statistically inseparable dates. At Bloak Moss (Turner, 1975), the dated site nearest to Shewalton Moss, a date of prior to 3,825 ± 110 B.P. is of little assistance, and the date of the *Alnus* rise at Loch Lomond (5,909 ± 170 B.P.; Stewart, 1979) is suspect. On Arran, the *Alnus* rise is dated at 6,630 ± 130 B.P., and the earlier temporary rise in *Alnus* is dated at 7,320 ± 155 B.P. (Robinson, 1981). Extrapolation from figure 53 in Birks, 1980, provides a date of *c*. 7,000 B.P. for the *Alnus* rise at Shewalton Moss.

Conclusion. The diagram represents an unbroken but slightly disturbed record of early Flandrian vegetational development at Shewalton Moss. Although regional trends are recognisable, local changes dominate the diagram. The age of the base of the peat is undetermined; it may be zone III or possibly zone II. Since less than 1 m of peat at this site represents c. 4,000 years a complete Flandrian succession is expected here.

SM-81-II

The results. The peat was sampled continuously from the surface to near the base; the snout of the Russian corer did not penetrate the underlying clastic sediment and thus the basal 0.15 m of peat was not recovered. Initial pollen analysis was carried out on samples from near the base of the peat. As analysis progressed it became apparent that there were strong similarities with SM-81-I, so it was considered justifiable to use only the initial five samples and a more detailed diagram is not presented.

The distribution of the macrofossils (Fig. 13.12) corresponds closely to the Troels-Smith units (Table A.13.5); Sphagnum remains dominate T.S. unit 2 and other macrofossils are common in T.S. units 1 and 3.

The results of the pollen analysis (Fig. 13.13) are presented as percentages of total pollen and pteridophyte spores. From inspection, two local pollen assemblage zones are described, forming the basis of the discussion. Since few samples are used, the construction of such zones may appear dubious, but there are sufficient and clear enough pollen spectral changes to justify the erection of these local pollen zones.

SM-81-II.1 "Cyperaceae - Herb Pollen Local Pollen Zone".

Samples 3 to 5 (3 samples); from the base of the diagram (0.16 m above the base of the core, and 0.31 m above the peat base) to c. 0.37 m above the base of the core.

This zone is characterised by high values of Cyperaceae (60-70%) and the abundance of other herbs, especially Gramineae (c. 10%), Caltha palustris (to 2%), Filipendula (c. 10%) and Menyanthes (c. 10%). Trees and tall shrubs are poorly represented (less than 10%), as are pteridophytes.

SM-81-II.2 "Betula - Filicales Local Pollen Zone"

Samples 6 and 7 (2 samples); c. 0.37 m to c. 0.50 m above base of core.

This zone is characterised by the presence of trees and tall shrubs (together to c. 40%), Betula having values of c. 10%, and the pteridophyte curve rising to 9%. Herbs are present, but are less common than in the previous zone. Of particular note is Calluna (to 5%).

Cyperaceae - Herb Pollen Local Pollen Zone. The abundant presence of Cyperaceae, Gramineae and other herbs, and the low tree values, suggests a locally open landscape and thus, with little apparent regional input, a regionally open landscape. Many of the herbs indicate unshaded conditions (Artemisia, Chenopodiaceae, Empetrum, Matricaria type, Ranunculus, Rumex acetosella, Senecio type and Umbelliferae) and locally damp or wet conditions (Caltha palustris, Filipendula, Menyanthes, Potamogeton and Typha latifolia). Menyanthes is the only herb to provide recognisable macrofossil evidence here. Within this pollen zone, the macrofossil record is almost entirely composed of leaves and stems of Sphagnum subgenus Litophloea in addition to, at the beginning, remains of other unidentified mosses. The complete lack of Sphagnum spores in this Sphagnum peat is unusual; although, due to the small size of the plants, moss spores tend not to travel far, they are usually found where macroscopic moss remains occur. However, mosses do not produce spores in the regular manner in which pollen is produced, and vegetative reproduction is common. Also, some Sphagnum species produce small quantities of spores, and perhaps due to the ease of germination generally few moss spores are preserved (Dickson, 1973, p.60; pers. comm.). The preservation of spores decreases as humification increases (Tallis, 1962).

The spectra of this pollen zone closely resemble those of the Cyperaceae - Herb Pollen L.P.Z. in the SM-81-I diagram. Slight differences in Artemisia (lower here) and Filipendula (higher here) probably are local features. The overall proportions of trees, tall shrubs and herbs are very similar. On this basis, it is suggested that the two zones have similar ages.

Betula - Filicales Local Pollen Zone. Despite the continued domination of the spectra throughout this zone by herb pollen, especially that of Cyperaceae, the Betula, Filicales and Coryloid curve rise notably. Since this zone is based on two samples, little can be stated regarding trends. However, the Betula curve will probably continue at c. 10% and the Coryloid curve continue rising. In this pollen zone other trees - Pinus, Quercus, Ulmus, Alnus and Salix - are continuously present. The moderately high values for herbs suggest that although some of the tree pollen may be local (macroscopic wood, tree leaf and bud scales are present), the vegetation was sufficiently open to allow input of regional components. The woodland, possibly locally dominated by Salix, was still moderately damp. This is indicated by herbs such as Filipendula, Menyanthes and Succisa, and also present are Sphagnum and Tilletia sphagni spores, Pediastrum colonies, spindles of Eriophorum vaginatum and one Juncus conglomeratus/effusus seed.

The Coryloid curve suggests that the Corylus rise may not be far above the top of this diagram. Although there is no evidence of locally-dry soil, as in SM-81-I, the rise in Calluna pollen and charcoal remains at this time suggests that nearby soil was drying out and vegetation was being opened, possibly due to, or associated with, burning. Calluna is found in dry conditions on ombrogenous bogs (Godwin, 1975, p.295) and may be used to infer increased soil dryness (cf. Stewart & Durno, 1969; Birks, 1972; Peglar, 1979).

Conclusion. The diagram is short and clearly parallels part of the longer SM-81-I diagram, probably representing the same period as the basal c. 0.40 m in SM-81-I. Thus the base of the diagram may date from zone III, and the base of the peat may be zone II in age. Some indication of such an age is provided by the macrofossil evidence; below the base of the pollen diagram are two samples in which Sphagnum remains are scarce, and Carex, Gramineae and non-Sphagnum moss remains, and in particular, wood and leaf fragments and tree bud scales are present. During zone II in western central Scotland shrub and wood vegetation gradually increase, although it is doubtful whether closed vegetation was present (Mitchell, 1952; Donner, 1957; Vasari & Vasari, 1968; Moar, 1969; Lowe & Walker, 1977). Woody taxa such as Betula, Juniperus, Salix and Empetrum increase and, regardless of the status of the woodland at the time, it is expected that woody macrofossils were deposited in places similar to Shewalton Moss.

The top of the diagram dates from prior to the Corylus rise (c. 8,800 B.P.; adapted from Birks, 1980, fig. 53).

CHAPTER 14

DUNDONALD BURN

1. Introduction

In Dundonald Burn, at NS 337 372, there is exposure of sediments which has been known since the beginning of the century (Geological 6 inch Map, 1911; Anderson, 1925; Richey *et al.*, 1930). Anderson (1925, pp.98-99) describes the section as:

> "A good exposure of "forest bed" ... The bed is 2ft. in thickness, not much harder than peat, but composed largely of the branches and other remains of trees. It underlies sand probably belonging to the 40 ft. or most recent period of submersion, and overlies material which belongs to an older beach."

Recent work concentrates on the fact that this peat lies under raised beach deposits. The underlying sediment is now regarded as glacial till (cf. Godwin & Willis, 1962). Five radiocarbon age determinations have been made for samples from this bed (Godwin & Willis, 1962; Ergin *et al.*, 1972; Harkness & Wilson, 1979; see Table 14.1). The dates are interpreted as maxima for the local commencement of the Flandrian marine transgression (Donner, 1970; Ergin *et al.*, 1972); the younger ages immediately precede the onset of the transgression (Harkness & Wilson, 1979), and the older ages are unrelated to the transgression.

The bed is of variable thickness, to 0.60 m, and the top is eroded (Bishop & Coope, 1977, p.68). This explains the different ages obtained for samples from the topmost part of this bed at two locations. It should be noted that peat may have been removed during the marine transgression, and there may have been a time interval after erosion but prior to deposition of the overlying beds. Despite the five age determinations from this bed, it is known only that during the early part of the Flandrian Age sea level lay lower than *c.* 6 m A.O.D., and the Flandrian marine trans-

Table 14.1 Dundonald Burn: radiocarbon age determinations

Location	Sample No.	Stratigraphical position	Radiocarbon date	Authors
NS 337 372	Q-642	Wood from organic layer	(9,530 ± 150 B.P. ((9,620 ± 150 B.P.	Godwin & Willis, 1962
NS 337 372	GU-373	Top 50 mm of organic layer	8,950 ± 90 B.P.	Ergin *et al.*, 1972
NS 337 371	SRR-381	Top 20 mm of organic layer	8,070 ± 70 B.P.	Harkness & Wilson, 1979
NS 337 371	SRR-382	Basal 20 mm of organic layer	9,780 ± 90 B.P.	Harkness & Wilson, 1979

gression occurred after _c_. 8,000 B.P.

The potentially valuable dates appear to provide little useful information. To remedy this, a more thorough investigation of the Dundonald Burn peat is required. By detailed study of the micro- and macrofossil content of the peat, the following questions were approached:

(1) What age (or ages) does the peat represent, and how does this relate to the radiocarbon ages that have been obtained so far?

(2) What is the relation between the peat and sediments associated with marine regression and transgression?

Pollen analysis of the peat provides an independent chronological sequence. This approach has several advantages over radiocarbon dating. In the case of pollen analysis, dating is based on a series of samples which are related to the sediment stratigraphy, rather than on one sample as in radiocarbon age determinations. Also, the results of the pollen analysis can be related to regional vegetational trends, providing a series of ages. Furthermore, assuming the range of the radiocarbon ages is correct, the results of the pollen analysis at this site can be compared directly with those of the analyses from Shewalton Moss (Chapter 13.4). The local vegetation may also reflect the proximity (or otherwise) of coastal conditions to the site (cf. Chapter 5).

2. Pollen analysis

The results. A column of peat, together with the lowermost part of the overlying inorganic sediment, was dug out of the river bank within one metre of the site at which samples were collected for the determination of radiocarbon date GU-373 (Ergin _et al_., 1972; W. G. Jardine, pers. comm.). The peat base lies at _c_. 6.2 m A.O.D.

The results of the Troels-Smith analysis are shown in Table A.14.1. The basal, iron-cemented gravel may be an iron pan formed as the land surface, represented in part by the peat, was exposed. Within the overlying clay (T.S. 2) the pebbles are highly weathered, poorly-sorted and many are angular in shape. Occasional wood fragments occur near the top of the clay, and the upper 20-30 mm (T.S. 3) show horizontal lamination with organic-rich layers. The sub-peat sediment was formerly regarded as raised beach sediment (Anderson, 1925), but recently as glacial till (cf. Jardine, 1964). It is more like till ("boulder clay") than beach deposits, no molluscan remains being present, although the surface sediments may have been re-worked and re-deposited. The peat (T.S. 4 & 5) consists of sub-horizontally-bedded detrital material. The uppermost organic stratum (T.S. 6) is part of an organic "pebble" (c. 250 x 40 mm) lying within the overlying sand (T.S. 7) and resting on top of the main peat only in places. Clearly it lies unconformably on the remainder of the peat, and the curves in the macrofossil and pollen diagrams (Figs 14.1 & 14.2) therefore are broken between the adjacent samples in strata T.S. 5 and 6. The overlying sand is moderately well-sorted, with no noticeable sedimentary structures.

Most of the macrofossil remains (Fig. 14.1) are fine, unidentifiable organic material, fine charcoal or wood, bark and twig fragments. The basal part of the organic layer tends to contain less inorganic material ("sand") than the upper part, and Cyperaceae fruits and Juncus seeds are confined to the lower part of the peat. The upper part contains fewer charcoal fragments and a very narrow range of fossils. In contrast, the peat pebble (T.S. 6) contains tree leaf fragments, Eriophorum vaginatum spindles, a Gramineae seed and various moss remains.

From inspection of the results of the pollen analysis (Fig. 14.2), local pollen assemblage zones are described, and used as the basis for discussion. They are based on the total pollen and pteridophyte diagram and, unless otherwise stated, all percentages are of this total. The heights given are from the base of L.P.Z. DB-81.1.

DB-81.1 "*Salix* - *Filipendula* - Filicales Local Pollen Zone"

Samples 8 to 16 (3 samples); 0 to *c*. 0.11 m above the base.

Tree taxa tend to have low values or be absent, except *Salix* which has moderate values (12%) dropping to 2% at the top of the zone. Herbs tend to have low values except *Filipendula* which, in the basal sample, has a value of 32%, and Cyperaceae which has moderate values (8-25%). Pteridophyte spores are common, especially Filicales (to 70%) and, of particular note, *Selanginella* (4%). In the basal sample there are many unidentifiable, mainly crumpled, grains.

DB-81.2 "Cyperaceae - *Betula* Local Pollen Zone"

Samples 6 to 15 (3 samples); *c*. 0.11 to *c*. 0.20 m.

In this zone, maximum values are reached for trees, almost entirely due to the rapid rise (to 36%) in *Betula* values. *Pinus* is constantly present (2%) and *Quercus* begins to appear sporadically. *Salix* has low but significant values (to 8%), and Coryloid rises from 1% to 20%. Herbs are sparse, except Cyperaceae which maintains high values (37-46%) and *Filipendula* (2-4%). Filicales values drop to 2%.

DB-81.3 "Coryloid Local Pollen Zone"

Samples 14 and 13 (2 samples); *c*. 0.20 to *c*. 0.26 m.

This zone is characterised by high values of Coryloid pollen (34-54%). *Betula* values fall to 10%, Cyperaceae values drop rapidly to moderate values (9-17%), and *Salix* values rise. Herbs other than Cyperaceae are sparse, but pteridophytes, especially Filicales, are rising.

DB-81.4 "Coryloid - *Salix* - Filicales Local Pollen Zone"

Samples 3 to 2 (3 samples); *c*. 0.26 to *c*. 0.35 m.

Throughout this zone Coryloid values are moderate (17-32%). *Salix* peaks at 33% then drops rapidly to 4%. Other trees are low in value, and *Ulmus* appears for the first time. Cyperaceae maintains similar values to those in the previous zone, and other herb values rise slightly, with *Filipendula* rising to 4%. Pteridophyte values also rise, with a peak in Filicales, to 45%. *Sphagnum* spores are common (34%) in one sample.

DB-81.5 "*Alnus* - *Ulmus* - *Quercus* Local Pollen Zone"

Samples 10 and 1 (2 samples); *c*. 0.35 to *c*. 0.40 m, i.e. to the top of the diagram.

This zone contrasts strongly with the preceding zones. Despite values similar to the previous ones of *Betula*, *Salix* and Cyperaceae, those of *Alnus*, *Ulmus* and *Quercus* are very different. Both *Alnus* and *Ulmus* have values of c. 15% and Quercus is c. 8%. Herbs and pteridophytes have low values.

Introduction to discussion. The limits of the pollen zones are difficult to place, partly because many of the features overlap (e.g. the Betula and Coryloid peaks) and partly since each pollen zone is based on few samples. The zones can be reproduced on the diagram showing values as percentages of total pollen (Fig. 14.2, upper part), suggesting a certain degree of validity. Clearly, some major and possibly quite rapid vegetational changes are recorded in these diagrams.

Salix - Filipendula - Filicales Local Pollen Zone. The abundance of herbs, especially Cyperaceae and Filipendula, and pteridophytes indicates locally-open conditions, and the general scarcity or absence of trees other than Salix suggests a regionally-open landscape. The moderately abundant wood, bark and twig remains are probably from locally-growing Salix. The damp conditions suitable for Salix are reflected in the presence of pollen of Caltha palustris, Filipendula, Menyanthes, aquatics (Potamogeton and Equisetum), spores of Selaginella and Sphagnum, and the abundant presence of Juncus conglomeratus/effusus seeds.

The sparse presence of trees suggests a very early Flandrian or possibly Late Devensian age. The low Betula values are equivalent to, or lower than, pre-zone IV values elsewhere (Donner, 1957; Vasari & Vasari, 1968; Moar, 1969; Lowe & Walker, 1977), and pre-Corylus rise conditions are represented by the Coryloid values. Filipendula, typically common during the Late Devensian zones (Godwin, 1975, p.183), is not generally as common in western central Scotland as it is here. The moderately open and, in places, damp landscape suggested by the pollen spectra is typical of conditions during the Late Devensian to Flandrian transition period.

Cyperaceae - Betula Local Pollen Zone. The regional landscape appears to be becoming more wooded, indicated by the rise in Betula and perhaps the Coryloid curve. Locally, ferns appear to be replaced by sedges as the dominant plants in the open vegetation. Salix is less strongly represented than previously, but may still be growing at or near the site and providing macroscopic wood and bark remains, and conditions at the site appear to remain damp.

The marked increase in Betula and decrease in openness of the landscape both indicate the beginning of the Flandrian Age (Vasari & Vasari, 1968; Moar, 1969; Lowe & Walker, 1977; Robinson, 1980, p.79). The slow introduction of Quercus also reflects the warming conditions and the subsequent influx of thermophilous plants at the beginning of the Flandrian Age. In western Scotland, the main Betula expansion is sometimes preceded by a temporary abundance of Salix (Donner, 1957; Moar, 1969; Lowe & Walker, 1977), similar to the situation in the preceding pollen zone.

Coryloid Local Pollen Zone. The rise in Coryloid values, immediately following the Betula woodland expansion, probably indicates the regionally-present Corylus rise. The decline in the openness continues throughout this zone until all herbs represent only c. 20% of the total pollen, a value which is maintained from here upwards. The values of the regional pollen components (Quercus, Pinus and perhaps Betula) are depressed during the peak in Coryloid values, probably due to the high pollen productivity typical of Corylus and the major local presence of this plant. Although the Corylus rise is a regionally-significant feature, Corylus appears to have expanded locally to a greater extent than Betula did prior to it. Herb taxa are virtually absent, probably reflecting the shading effects of dense Corylus growth at this site.

Coryloid - Salix - Filicales Local Pollen Zone. After the Corylus rise, Corylus becomes less well represented, as commonly happens elsewhere. The local vegetation appears to become slightly more open, with more herbs - Calluna, Lotus type, Ranunculus, Rosaceae, Rubiaceae, Senecio type, Umbelliferae and, especially, Filipendula - being recorded, Corylus is locally replaced by Salix. Damp conditions prevailed; both Filipendula and Sphagnum values peak in this zone.

Regional components are still not important, although there are some indications of the spread of boreal mixed forest. Both Ulmus and Quercus are recorded, if only sporadically, and Alnus is present at the top of this zone. Alnus is present in small quantities in south-western Scotland from the 9th millenium B.P. (Nichols, 1967; Moar, 1969; Birks, 1972, 1975; Durno, 1976; Robinson, 1980), expanding significantly 2,000 years later (Birks, 1977, 1980); the values of Alnus present here suggest that the zone represents the period before the Alnus rise.

Alnus - Ulmus - Quercus Local Pollen Zone. The pollen spectra of this zone are very different from that of the remainder of the diagram. The high proportion of trees, especially Alnus, Ulmus and Quercus, and the low proportion of herbs and pteridophytes suggest that the landscape is more wooded than previously. Local vegetation is dominated by Corylus, although there may have been nearby open space, both dry (providing Artemisia and Senecio types, Calluna, Chenopodiaceae, and Rumex acetosella pollen) and damp (Filipendula and Ranunculus pollen and Sphagnum and Tilletia sphagni spores).

The tree pollen spectra are typical of the period after the Alnus rise but before the Ulmus decline, i.e. between c. 7,000 and 5,000 B.P. (Godwin, 1975, p.245; Birks, 1980). The values of 30% of arboreal pollen for Ulmus are much greater than those prior to the Ulmus decline at Bloak Moss (Turner, 1970) and on Arran (Robinson, 1980, p.90).

3. General discussion

The diagram is very similar to the SM-81-I (Shewalton Moss) diagram (Fig. 13.10). The patterns of expansion and contraction of, for example, Salix and Cyperaceae and, to a lesser extent, Filicales, suggest that the local vegetational patterns were moderately widespread. The two sites are c. 2 km apart. The Dundonald Burn succession represents a slightly shorter time interval than that at Shewalton Moss, starting at the close of Late Devensian times and ending before the Alnus rise.

The two topmost samples (10 & 1) are important. They are from an inwashed pebble, so their stratigraphical position within the pebble is not significant; they should be treated as two small, randomly-chosen samples. The presence of the peat pebble, and the interpretation of its contained pollen suggest that the peat pebble is much younger than the top of the detrital peat. Moreover, the pebble has been eroded from peat and transported to this site after the peat had become sufficiently compacted to remain cohesive during transport. The pebble, therefore, may have been deposited at this site long after the parent peat was formed. The top of the detrital peat has been eroded, and so an unknown thickness of this peat has been removed. The ages of the detrital peat top and the peat pebble are very different, but that difference may have little significance, since the date at which deposition of the detrital peat ceased is unknown.

On the basis of these points, a wide range of interpretations is possible, of which four extreme versions are outlined below. Dates suggested are general approximations.

(1) Accumulation of organic detritus terminated around 8,000 to 7,000 B.P. due to flooding, followed by minimal net deposition or erosion. Later erosion of peat elsewhere provided peat pebbles and these were deposited as clasts around 6,000 to 5,000 B.P., as inorganic sedimentation was occurring.

(2) Peat accumulation continued until c. 6,000 to 5,000 B.P., when the detrital peat layer was flooded, the surface was eroded and peat pebbles from contemporaneous

erosion elsewhere were deposited at the Dundonald Burn site.

(3) The detrital peat layer was flooded at an early stage, say 8,000 to 6,000 B.P., but deposition of the peat pebbles occurred very much later, say c. 5,000 to 3,000 B.P., a peat cliff having been eroded elsewhere to provide peat pebbles.

(4) Detrital peat continued to accumulate for a long time, until, say, 5,000 to 3,000 B.P., when it was flooded, severely eroded, and then covered by sand containing peat eroded from elsewhere. Both this and interpretation (3) could involve erosion and deposition to the present day.

Returning to the original questions posed (Chapter 14.1) the first can be answered readily. The detrital peat dates from c. 10,000 B.P. to perhaps 8,000 B.P. and the peat pebble from between 7,000 and 5,000 B.P. The dates for the detrital peat suggested by pollen analysis generally confirm the radiocarbon analysis ages, although they suggest a slightly wider range. The question regarding the relationship between the peat bed (sensu lato) and the sediments associated with marine regression and transgression, is more difficult to answer. Clearly, at c. 10,000 B.P. sea level lay lower than 6.2 m A.O.D. Since no indications of a salt-tolerant flora occur at the base of the diagram, and the peat lies conformably on the underlying clay, the H.W.M.S.T. lay lower than the level of this junction. Elsewhere, the peat base lies at a lower-measured level (Harkness & Wilson, 1979), suggesting that H.W.M.S.T. possibly lay lower than c. 4 m A.O.D. at a similar time.

Dating the local middle Flandrian marine transgression is difficult. As shown above, the ages of both the detrital peat and the peat pebble provide inadequate evidence to date a transgressive event at the site. Deposition occurred after c. 7,000 B.P., although an erosional transgression may have occurred any time after the 9th millenium B.P.

Although Bishop, Jardine and Munro (in Godwin & Willis, 1962; Ergin et al., 1972; Harkness & Wilson, 1979, respectively) all assume the basal part of the overlying sand to be marine in origin (presumably by indirect association with raised beach deposits elsewhere) there is no local proof of this. The base of the sand is an unconformity, there being no evidence for salt marsh or other coastal conditions between the peat bed and the overlying sand. The sand is water-deposited, containing some inorganic gravel clasts and the peat pebble but, with no fossil faunal remains in it, it could be marine or fluvial in origin. If the sand is marine, it must be middle Flandrian in age and be related to the high sea level. In such a hypothesis, after c. 7,000 B.P., probably much later, sea level at this site lay at or above c. 6.5 m A.Q.D.

If, however, the sandy sediments are fluvial in origin, they must have been deposited after 7,000 B.P. If the river was responding to a base-level change controlled by sea-level change, a higher sea level than at present is implied. The river level may be related to a fluctuating sea level in several ways. If the river flooded the site as sea level was rising, and sea level subsequently rose above c. 6.5 m A.O.D., the fluvial deposits may have remained uneroded. Alternatively, sea level may not have risen above 6.5 m A.O.D. If fluvial flooding occurred during the period of maximum sea level, sea level lay lower than c. 6.5 m A.O.D. Thirdly, fluvial deposition may have occurred after the period of maximum sea level, following erosion of marine sand and/or peat. Therefore the local flooding chronology may be related in various ways to the timing of the marine transgression, but the age of the peat bed (sensu lato) provides only a maximum age for these events.

It should be noted that base-level change need not have been controlled solely by sea level. At Shewalton Moor a thick body of raised beach sediments, deposited during the Flandrian Age (Chapters 10 & 11) may have effectively dammed the River Irvine and raised the base level long after sea level fell. The present river is still deflected c. 2.5 km northwards by some of these sediments.

In all the cases suggested above the river need not have submerged the area at times of flood, but cut channels as it meandered. The peat pebble may represent a lag deposit, examples of which frequently contain peat clasts and commonly are found in the bottom of meandering river channels (B. J. Bluck, pers. comm.)

The only certain conclusion to be reached is that deposition of water-lain sand, associated directly or indirectly with a higher sea level than that at present (cf. Hageman, 1972), has occurred after c. 7,000 B.P.

CHAPTER 15

LONG DRIVE BRIDGE

1. Introduction and description of the site

Immediately west of the Long Drive bridge at Nat. Grid Ref. NS 340 373, a c. 12 m long section of sediments is exposed in the south bank of the River Irvine (Fig. 15.1). The base of the section lies at an estimated level of c. 4 m A.O.D. From base to top there are three main sedimentary units:

(i) Succession at eastern end of section from base upwards: gravelly sand; silty clay; organic detritus; coarse gravel; hard sand. The hard sand contains hollows resembling Pholas burrows in similar sediment at the "Great Bend" site (Chapter 12).

(ii) Succession at western end of section from base upwards: grey sand; gravel with peat pebbles; horizontally-bedded fine gravel and white sand.

(iii) Overlying (i) and (ii): horizontally-bedded sand with occasional gravel layers.

(i) and (ii) are apparently separated by an unconformity; unit (ii) consists of deposits in a channel cut into unit (i).

2. Discussion

The upper part of unit (i) is a transgressive sequence; the organic detritus is terrestrial, and the Pholas-burrowed sand is an intertidal or shallow marine deposit. The intervening coarse gravel may represent a storm lag deposit typically found at the base of beach sediments (cf. Chapter 10). To date this transgression, a sample from the organic layer was analysed for pollen and spore content (Fig. 11.1). This method provides only a maximum date for the transgression since the amount of erosion of the land surface prior to marine deposition is unknown. The spectrum suggests a pre-Alnus rise, Flandrian age; the Coryloid values suggest deposition either before or possibly during the Corylus rise. The spectrum is broadly similar to the lowest part of the Dundonald Burn diagram (Fig. 14.2; Chapter 14). Overall, a very early Flandrian age is assigned to the organic layer, and so the transgression is Flandrian in age.

The sediments beneath the organic material are more difficult to interpret. The silty clay contains frequent, small organic remains which probably are plant roots. Samples examined under a low power (x 8) binocular microscope contain no other macro- or microfossil material. The clay is similar to that beneath the peat at Dundonald Burn and is interpreted as glacial till, weathered or washed at the top. This similarity is further enhanced by the presence of hard, iron-cemented gravel similar to that at Dundonald Burn lying, at this site, immediately below water level and forming a resistant ledge where river erosion is most severe.

The unit (i) sediments have been eroded and partially removed by the cutting of a channel, in which there are lag deposits containing coarse-grained inorganic and organic fragments. The unconformity is equivalent to the surface of the Pholas-burrowed sand, and therefore the channel may have been formed in the intertidal zone. Alternatively, the channel may represent a renewal of freshwater conditions subsequent upon the lowering of sea level and the sedimentary units thus may be fluvial deposits. It seems more probable that unit (ii) represents an intertidal channel, and that unit (iii) represents beach deposits as sea level rose above the previous level of the site.

CHAPTER 16

GEOMORPHOLOGY IN THE DRYBRIDGE-DUNDONALD AREA

1. Introduction

The growth of Shewalton Moss commenced in early Flandrian times or earlier and the moss appears not to have been flooded substantially during the Flandrian Age (Chapter 13). It is still unresolved whether, during Flandrian times, Irvine Bay extended inland to the Drybridge-Dundonald line (Jardine, 1971) around a freshwater peat island or peninsula, such as may have been present in parts of the Forth valley (Sissons & Smith, 1965) and in part of Wigtown Bay (Jardine, 1975a, b). Although evidence suggests that a shoreline, associated with the rising Flandrian sea, remained stationary to the north and north-west of Shewalton Moss (Chapter 10), a tidal estuary may have existed to the north and north-east of Shewalton Moss. In the absence of exposed sediments in this area, a study of the geomorphology may confirm this.

Various problems exist. The Quaternary sediments north and east of Shewalton Moss are mapped by the Geological Survey as raised beach deposits, an interpretation which has been accepted, more recently by Jardine (1971, etc.). North of the Annick Water, similar sediments in a similar geomorphological setting and resting on and against till are interpreted by the I.G.S. (Goodlet, 1970) and the Soil Survey (Unpublished 2½ inch Soil Map) as glacio-fluvial and lacustrine sediments, despite being originally mapped (Geological 6 inch Map, 1911) as glacial sand and gravel. Although the two areas are not directly connected, their geomorphological similarity raises some doubt regarding the exact nature and definition of the sediments in these areas. The sediments east of Shewalton Moss may be: (1) entirely Flandrian in origin, in which case their location makes it highly probable that they are raised beach sediments; (2) Late Devensian in age, in which case they may be beach or fluvio-glacial sediments; (3) Late Devensian sediments, of whatever origin, reworked during the Flandrian Age.

2. Description of the geomorphology

Immediately east of the Drybridge-Dundonald road (B730) lie three drumlins. The northernmost one (Girtridge Mount) is aligned E.N.E. to W.S.W., and the southern two (Ploughland and Palmer Mounts) coalesce and are less obviously aligned. The western end of Ploughland Mount (the middle drumlin) appears to be truncated.

Around both Girtridge and Palmer Mounts there is a distinctive break in slope, the gradient decreasing down-slope, and a small notch or cliff has been cut into the drumlins. This is most noticeable around the western edge of Girtridge Mount. The break in slope lies immediately below the 100 ft (31 m) contour and slightly below the inland mapped limit of raised beach deposits (Geological 6 inch Map, 1911). This feature is mapped as "Feature (?Old sea margin) at about 90' above sea level". Between here and Shewalton Moss there are several steps or small cliffs and terraces in the land surface. The most persistent is mapped as "Probable old coastline" and "Feature (?Old sea margin) at about 75' above sea level". These persistent cliff lines lie at about 28 m and 23 m A.O.D. Immediately west of Drybridge, extending southwards from the road towards the railway line, is a rise of c. 1 m at an estimated level of 20-21 m A.O.D., and c. 500 m further west a similar rise, lying at c. 18 m A.O.D. extends to c. 200 m south of the road. To the south, approximately following the 50 ft (15 m) contour, another feature curves round the eastern edge of Shewalton Moss, merging into the south-eastern side of a distinctive ridge. This ridge is oval in plan (c. 250 x 175 m) and its top lies about 2 m above the surrounding surface. Orientated approximately N.E. to S.W., it lies c. 400 m north of Old Auchans Farm. East of the ridge, at Kilnford, the "75 ft" feature turns westwards, becomes less clear and merges with a rock cliff at Hillhouse.

The Hillhouse cliff, aligned approximately N.E. to S.W. is cut into a teschenite sill, and is best developed north of Hillhouse quarry, where it is c. 20 m high. To the south-west, it merges into a moderately steep till-covered slope, and to the north-east and east, towards Dundonald Castle, it is also less distinct, with till apparently emplaced against it. Results of the auger survey on Shewalton Moss (Chapter 13.2) suggest that the cliff extends downwards to at least the base of the Shewalton Moss peat, i.e., to c. 8 m A.O.D., and possibly to a lower level.

Throughout the area between Dundonald and Drybridge the soils are sandy and mostly gravelly. This type of soil extends to a little above the "90 ft" feature, and at one locality, to the west of Kilnford, the soil appears to be developed on till; in places the sand and gravel forming the parent material of the soil may only be a thin veneer on top of the till. In a narrow strip around the northern and eastern edge of Shewalton Moss, the soil is a peaty-stoney soil; the peat of Shewalton Moss appears to lie on similar sand and gravel to that occurring at the surface to the north and east.

The entire area under discussion lies at levels higher than the edges of Shewalton Moss, and most of the area lies higher than the central, slightly domed part of Shewalton Moss. The sedimentary surface underlying the peat rises above the level of the peat beyond the moss edge (Fig. 13.2, traverse 1) and the peat clearly is built up against the side of the ridge north of Old Auchans (Fig. 13.2, traverse 3). Westwards, along the northern edge of Shewalton Moss, the sand and gravel surface drops gently, until around Little Shewalton and Oldhall Farms (no longer in existence), the surface is approximately at the same level as the surface of the peat. Westwards, much of the sand and gravel surface, where it has not been disturbed by recent workings, is covered by sand dunes.

3. Discussion

The small cliffs and terraces described above show a certain degree of parallelism with the present coast, and are not confined within a river valley. It is suggested, therefore, that these features are marine-cut cliffs. Since all the features are above the level of Shewalton Moss, and there is no evidence of a marine inundation of the moss during the Flandrian Age (Chapter 13), these coastal features must be, at latest, Late Devensian in age. The gravelly sediments may be *in situ* non-marine, possibly fluvio-glacial sediments which, as sea level dropped, have been reworked into a series of successively lower beaches; alternatively they may be "primary" beach sediments, emplaced during a period of high, but dropping relative sea level.

The highest break in slope, with gravel above and below it, is interpreted as a high level shore, placed against the steep drumlin side, and probably representing a high tide level of *c.* 28 m A.O.D. Below this level are fragments of four smaller cliffs cut into a gently-sloping surface. These "cliffs" are better described as "areas of accentuated slope" (Jardine, 1981b, p.69, 1981c, p.298). Lying below the 28 m feature, they are assumed to be younger than that feature. They resemble it and are presumably also marine-cut cliffs, representing shoreline positions during a period of falling sea level.

The presence of these small areas of accentuated slope within an area which is characterised primarily by a gently-sloping sediment surface suggests that there have been fluctuations in the environmental factors which influenced coastal development and the processes which formed that sediment surface. In this case, the main changes would have been in the rate at which sea level fell and/or local environmental factors. The former may have involved periods of sea-level still-stand or short periods of sea-level rise, each with or without transgressive activity, and the main environmental factors are local energy levels and the rate and/or type of sediment input.

The model envisaged is similar to Curray's (1964) in which transgression and regression are classified according to direction of sea-level change and degree of erosion and deposition; during a period of falling sea level, regression may be erosive or depositional without fluctuations in the rate of sea-level change. In the case of the Drybridge-Dundonald area, it is thought that the simpler and, therefore, more probable fluctuations which would occur are those involving environmental factors. Irregularities in erosive and depositional patterns in fossil raised coastal features have long been explained in this manner (Zenkovich, 1967, p.535), and sea-level fluctuations need not be postulated to explain the formation of erosion benches. A still-stand in sea level may be difficult to recognise but, on the other hand, a transgression consequent upon sea-level rise may be recognisable. Although coastal erosion is expected as sea level rises (Bruun, 1962; Swift & Palmer, 1978, p.10), an erosive event produced in this way may only be postulated with evidence of "... the existence of an ancient shoreline maintained for a considerable distance along a coast and represented by various formations (benches, ridges, barrier beaches)...." (Markov, 1934, p.231, quoted in Zenkovich, 1967, p.534; emphasis in the original). This is not the case east of Shewalton Moss. Alternatively, the presence of buried terrestrial deposits may be used as evidence of a transgression (cf. Tooley, 1978b), although not necessarily of a sea-level change (Jelgersma et al., 1970, p.148; Kidson & Heyworth, 1978; De Moor, 1978; Devoy, 1982; Jennings & Smyth, 1982; Tooley, 1982). In the Shewalton Moss area, lack of exposure hinders a test for such evidence, although with coarse beach sediments occurring here, the probability of terrestrial deposits surviving is minimal. Likewise, survival of such deposits is limited if an erosive transgression occurred.

Given a constant rate of fall of sea level, changes in the composition of sediment input can cause fluctuations in beach form (Zenkovich, 1967, p.535). In the western part of the Forth valley, three buried shorelines and associated shore deposits (Sissons, 1966; Sissons et al., 1966) are explained in terms of successive regressions and transgressions. The sediment source changed considerably during the formation of these shore deposits and it is equally, if not more, plausible that the intensity of deposition and erosion fluctuated due to changes in sediment supply, as sea level fell steadily than that transgressions and regressions rapidly followed each other due to fluctuating sea levels.

Parker (1975) suggests a model for fluctuating deposition and erosion on the south-western Lancashire coast resulting from variation in the sand budget on a multi-barred shoreline. A feature of this model is that due to present fluctuations in sediment supply and erosion, the underlying sediment is eroded, forming a terraced surface, which, while resembling a series of fossil beach levels or marine-cut terraces, would be interpreted erroneously as such.

Sediment input fluctuations may influence changes in, and effects of, local energy levels. A reduction of both sediment input and grain size frequently allows more wave energy to be available for erosion. Changes need only be moderately small for the threshold between deposition and erosion to be crossed. On a high wave energy, coarse-grained clastic beach, there are typically no major morphological features (Elliott, 1978, p.149), and the gently-sloping surface east of Shewalton Moss probably represents such conditions. The threshold between conditions of net deposition and net erosion in such conditions is probably easily crossed, following a minor environmental change. The minor cliffs east of Shewalton Moss may represent, for example, single storm events, and the cliffs, therefore, may be only locally significant. Beach profiles also change predictably during the year; during summer, high tide beach terraces are built, whereas during winter, the profile can be severely eroded (Komar, 1976, p.289). Unusual, occasional seasonal fluctuations in weather may upset the balance.

The geomorphological features east of Shewalton Moss represent an initial shoreline, cut into the drumlin side, accompanied by formation of a gravel beach. This site is at the highest altitude at which beach sediments occur. Following this high sea-level position, sea level dropped and successive beaches were formed in moderately high wave energy conditions, during which slight changes in sediment supply and/or weather conditions influenced the balance of deposition and erosion. The areas of accentuated slope, the area of till exposure and possibly the gravel ridge at the southern end of the area bear witness to this. It is more probable that local environmental factors controlled deposition and erosion than did complicated sea-level fluctuation.

CHAPTER 17

MOUNT HOUSE, KILMARNOCK

1. Discussion of the site

Introduction and description of the site. Near Mount House (Nat. Grid Ref. NS 408 369), about 3 km west of Kilmarnock, a series of boreholes sunk during commercial site investigations proved the presence of a body of laminated clay infilling a deep valley in till. The clay lies at various depths, the top being at c. 26 m A.O.D. There are no geomorphological indications of the presence of this deposit, and the exact position of the limits of the clay would have to be established by extensive augering.

The deepest occurrence of the laminated clay is near the edge of the deposit, in bore hole B1/2A (Table 17.1). Samples collected from this and other cores by the site engineer were so disturbed that no indication of sedimentary structures, such as laminations, was apparent. Two disturbed bulk samples were examined: No. 7 and No. 12, at 23.12 m and 20.72 m A.O.D. respectively. The samples were cleaned and separated in hot water and hydrogen peroxide, wet-sieved through a 75 μm sieve, and examined for fossil remains, especially foraminifers and ostracods, under a low power (x 8 and x 32) Leitz binocular microscope. The samples have a low fossil content, although No. 7 contained many root and possible wood fragments. The microfossils present are shown in Table 17.2.

Leptocythere castanea is a brackish-water animal, being the most low-salinity tolerant *Leptocythere* species (Whatley *et al.*, 1971). The fossils are *in situ*: young and adult *Leptocythere* are present, as also are undamaged carapaces. The unkeeled *Elphidium* species (represented here) are also brackish to saltwater animals, being found in tidal marsh, lagoonal and nearshore environments in water depth of less than 20 m (Fisher *et al.*, 1969; Murray,

Table 17.1 Mount House, Kilmarnock: bore log for borehole B1/2A. Only the top part of the bore log contained in the (commercial) site report is shown. The basal sediment is till.

	Depth below surface (25.72 m A.O.D.) (m)	Sample number	Sample depth (below surface) (m)
Brown, organic, clayey, sandy SILT - TOPSOIL			
	0.40		
SOFT, brown, mottled, sandy, very silty CLAY with a little gravel and organic traces			
	1.30		
SOFT to FIRM, greyish brown, laminated, very silty CLAY with occasional sand partings 1. Root traces in upper part 2. Evidence of fissuring at base		7 12	c. 2.6 c. 5.0
	5.30		
STIFF becoming HARD, brown, very sandy, very silty CLAY with fine to medium, predominantly subangular, gravel and occasional cobbles and boulders			
	8.10		
etc.			

Table 17.2 Mount House, Kilmarnock: faunal list for samples 7 and 12. Number of specimens counted shown in brackets.

Sample No. 7	Sample No. 12
Foraminifera : *Elphidium angelicum* (4) *E. williamsonii* (4) *E. clavatum lobatulum* (1) *E. magellanicum* (1)	Foraminifera : *E. clavatum*, at least 4 subspecies (48)
Ostracoda : *Leptocythere castanea* (Sars), young, left (1)	Ostracoda : *L. castanea* (Sars) adult, left (3) right (1) carapace (2) young, left (1) right (1) carapace (4)
1 Gastropod	

Table 17.3 Locations of sites recorded in Geological Survey literature (1911 Edition, Geological 6 Inch Map; Anderson, 1925; Richey *et al.*, 1930) with sediments similar to those at Mount House.

	Nat. Grid Ref.
Caprington Tile Works	NS 403 359
Gargieston Brick & Tile Works (& surrounding area)	NS 412 367
Bankhead (Corsehill Tile Works)	NS 3675 3845
Damdyke Bridge	NS 377 353
Caprington Burn (Drummuir Farm)	NS 3635 3955

1973, p.249; Boltovsky & Wright, 1976, pp.141 ff); E. anglicum and E. williamsonii, found in No. 7, are common in brackish-water marsh and estuarine conditions, typically on sandy intertidal flats (Murray, 1973; Abou-Ouf, 1974). The E. anglicum specimens are all in good condition, showing little signs of abrasion. The E. magellanicum specimen is badly damaged and therefore probably derived. E. clavatum lobatulum is a nearshore animal found in low arctic to middle boreal conditions (Wilkinson, 1979) and E. williamsonii is a warm-water species (Murray, 1973). Sample 12 yielded four E. clavatum subspecies, which were not identified further, although the absence of the middle to high arctic subspecies E. clavatum terminatum and warmer condition subspecies E. clavatum lidoense, indicating middle or low arctic to boreal conditions, was noted.

Conclusion. The laminated clay is marine in origin, representing brackish-water creek or tidal-flat conditions. There is little indication of sea level at the time, although a maximum H.W.M.S.T. level of c. 26 m A.O.D. is suggested on the basis of the upper altitudinal limit of the laminated clay. The contained faunas, although they are limited, suggest warmer conditions at the top than at the base of the deposit.

2. Other similar sites

Sites with similar sediments have been reported from the area (Fig. 19.1, Table 17.3). All quotations in this section are from the 1911 Edition of the Geological 6 inch Map, unless otherwise stated.

One of the nearest sites is at Caprington Tile Works, about 1 km south of Mount House, where an "old clay pit in stoneless clay (raised beach) under capping of sand" was formerly worked. Here 6 ft (2 m) of "brown sandy clay" and 6 ft (2 m) of "better plastic clay, of a darker colour" overlay till (Anderson, 1925, p.100). The top of the clay lies at 80 or 90 ft (24.4 or 27.4 m) A.O.D. (Richey *et al.*, 1930).

About 0.5 km to the south-east of Mount House, a large area (*c.* 1 x 1.5 km) of raised beach deposits is mapped as "gravel resting on stoneless clay". In this area the Gargieston Brick and Tile Works were formerly in operation and occasional marine shells have been collected in the clay at *c.* 70 ft (21 m) A.O.D. (Richey *et al.*, 1930).

At Bankhead, *c.* 6 km west of Mount House, Richey *et al.*, (1930) report the presence of similar sediments worked at the Corsehill Tile Works down to a depth of *c.* 40 ft (12 m) A.O.D.; in a hollow in till, laminated clay containing some gravel and occasional layers of shells (none identified) was overlain by laminated sand and clay, which in turn was overlain by gravel. Again the surface lies at 80 ft (24.4 m) A.O.D. About 50 m southwards, "gravel resting on clay with marine shells" is mapped on the Geological 6 inch Map (1911), and from here southwards to the Carmel Water there are "sandy, raised beach deposits".

Immediately south of Damdyke Bridge, about 6 km south-west of Mount House, is a record of a "site of old clay pit which showed about 20' [6.1 m] laminated and stoneless clay (⁀) and supplied an adjacent tileworks". The Geological Survey has interpreted the clay as recent freshwater alluvium (⁀).

At Caprington Burn, near Drumuir Farm, *c.* 7 km north-west of Mount House, Richey *et al.*, (1930) also report brick clay lying under gravel at about 80 or 90 ft (24.4 or 27.4 m) A.O.D. The marine origin of this clay is doubted by Anderson (1925).

No sediments are presently exposed at any of these sites, and the old clay pits at the tileworks have been in-filled.

A recent commercial bore-logging survey of the area was undertaken during the A71 road development. The logs contain occasional reference to sediments similar to those described above in this chapter. The bore log sites (Fig. 19.1, Table A.17.1) are in hollows or valleys bounded by higher areas in which till is recorded. The sediments at none of these sites have been examined by the writer, and samples collected during coring, as is standard practice, have not been preserved.

The distribution of "deposits of raised beaches (sand, gravel and stoneless clay)" indicates widespread occurrence, although in places in the field, they are seen to be thin and discontinuous. The deposits are mainly clay, occasionally with a capping of coarser-grained material, and generally occupy locations not readily identifiable on the basis of geomorphological study, in places occurring on the moderately-steep valley slopes of till.

3. General conclusion

A detailed description of the sediments and their locations requires an extensive auger survey. It seems probable that the extent of these deposits is greater than previously mapped by the Geological Survey.

At some period during Late Devensian times, as climate and water temperatures were becoming warmer, relative sea level rose and lay at about 25 to 26 m A.O.D. A marine incursion which, progressively eastwards in the Irvine Valley east of Girtridge (Drybridge), was expressed as an increasingly less saline, low energy environment estuary towards the present site of Kilmarnock, produced fine-grained sediments. The rather erroneously named raised beach deposits emphasise the need for careful use of terminology (cf. Jardine, 1967; Jardine & Morrison, 1976).

CHAPTER 18

MISCELLANEOUS INFORMATION FROM COMMERCIAL BORE-LOG DATA

Introduction. Despite the general unsuitability of commercial bore-log data in a study such as this (see Chapter 10.1), in some cases bore-log data provide useful information (Fig. 18.1). The following descriptions of this information are kept brief, and all possible problems are not discussed. This reflects the low degree of certainty with which this material should be regarded. The data are second-hand records and the original sediment samples are no longer available for inspection and assessment by the writer.

Warrix Farm (Nat. Grid Ref. NS 338 374). From the south-eastern corner of Warrix Farm, are four bore logs containing records of peat and occasionally timbers within the so-called raised beach sand and gravel. The peat lies at the following levels A.O.D.: (1) 3.78-5.98 m; (2) 5.30-6.80 m; (3) 4.30-6.75 m; (4) 5.50-6.00 m.

These records suggest that the peat recorded at similar levels under sand and gravel at the Dundonald Burn and Long Drive Bridge sites (Chapters 14 & 15) may be extensive.

Irvine Chemical Works (Nat. Grid Ref. NS 312 377). At the Irvine Chemical Works, data from 29 boreholes indicate the presence of various thicknesses of shelly and non-shelly sand which overlie gravel on a seawards-sloping till surface. Near the eastern limit of the surveyed area, one bore log contains a record of 4 ft (1.2 m) of "grey fine gravel and coarse sand with shell fragments", overlain by 3 ft (0.9 m) of "firm grey-brown peaty clay with pockets of sand", lying within grey fine- to medium-grained sand (Fig. 18.2).

As this is the only borehole containing such sediments, caution must be exercised; it is not certain whether the shelly gravel and peaty clay are in situ. However, these two sediments occur together and so are regarded as being in place. The peaty clay implies terrestrial or semi-terrestrial conditions. Although the shells immediately underlying the peaty clay may be either marine or fresh-water, the deeper shelly horizon (c. 2 to 8 m B.O.D.) is probably a marine sediment. This sequence of sediments represents a marine regression during which H.W.M.S.T. dropped to 4 to 5 m A.O.D., probably followed by trans-gression.

Gailes (Nat.Grid Ref. NS 322 362). South of Gailes Golf House and east of the railway line, in an area 0.5 km (E.-W.) by 1 km (N.-S.), fifteen boreholes have been sunk. The unconsolidated sediment at the base are till, lying in hollows in the undulating solid-rock surface and overlain by clay, and above this, sand and gravel, which includes a distinctive gravel and sandy gravel bed whose top-surface contours are shown in Figure 18.3. The rockhead contours and records of bedrock type (Fig. 18.3) indicate the presence of a high (to 4.9 m A.O.D.) ridge with steeply sloping sides, resembling a crag-and-tail, the crag being composed of basalt and the tail of sandstone and mudstone. The ridge is aligned W.S.W. to E.N.E. and is approximately parallel to the orientation of the drumlins at Drybridge (Chapter 16) and other glacial features in the area (Richey et al., 1930; Holden, 1977, p.117). The gravel bed repre-sents a beach of coarse-grained sediments which rises from 2 m B.O.D. to 6.6 m A.O.D. and curves round the bedrock ridge.

At this site the glacially-eroded rock surface may have been exposed during the early Flandrian period of low sea level, perhaps in the tidal zone in a manner similar to the Stinking Rocks (c. 2 km to the south) at present. The rock ridge formed a focus for the development of a coarse-grained beach which was subsequently buried by sand.

Byerstonhill (Nat. Grid Ref. NS 344 364). In an area c. 600 m square, centred on Byerstonhill, data from 38 borholes provide the following picture. From east to west (between Nat. Grid Ref. lines 348 and 342) the "high raised beach" sand and gravel becomes thicker (c. 5 ft to 20 ft; 1.5 m to 6.1 m). The sand and gravel, of uniform appearance throughout the area, to the east lies on till and occasionally on bedrock, and to the west lies on sediments containing occasional marine shells which occurs in rockhead hollows. The latter deposit is dark brown to grey soft and sometimes plastic silty clay, in places overlain by light brown to grey silty sand, and is interpreted as shallow still-water estuarine sediment. It becomes thicker (to 40 ft; c. 12.2 m) north-westwards. The ground surface (A.O.D.) drops from c. 60 ft (18.3 m) in the south and east, to c. 30 ft (9.1 m) in the north-west, and the basal marine deposit lies between 30 ft (9.1 m) B.O.D. and c. 20 ft (6.1 m) A.O.D.

Without samples, interpretation is difficult. There are certain parallels with sediments elsewhere. The sand and gravel appear to be an extension of the probably Late Devensian high raised-beach sediments and erosion features occurring further east (Chapter 16). The westward thickening of the deposits and the continuation of the surface support this suggestion. The lower-lying marine sediments may be equivalent to similar clay, overlain by coarser material, in the Irvine Valley (Chapter 17.2). The sediments represent two Late Devensian environments, and intertidal beach and a deeper water estuary.

Millbank, Dreghorn (Nat. Grid Ref. NS 347 378). In an area c. 300 m (E.-W.) by c. 100 m (N.-S.), west of Dreghorn, 14 trial pits have been dug. The general succession is till overlain by gravel and sand, becoming finer upwards. Contour maps for the tops of the main sedimentary units (basal gravel, intermediate medium- to coarse-grained sand, and uppermost fine- to medium-grained sand) (Fig. 18.4) show a series of beaches developed along the edge of the hill slope. They lie between c. 15 m and c. 18 m A.O.D., and occur north of the coarse-grained sediments at Byerstonhill (this chapter). Perhaps more importantly, they occur immediately down-valley and at the same altitude as the high-level marine clay and sand described by the Geological Survey at Bankhead (Chapter 17.2). The beaches of coarse-grained sediment are part of the gradation of depositional environments which existed during the period of Late Devensian high sea level, from the quiet, sheltered upper estuary, through a more-open estuarine situation to the high-energy estuary mouth.

Barassie and Gateside (Nat. Grid Ref. NS 334 330 & 336 337). In a large area of the railway line and south of Barassie, prior to the construction of a housing estate, many trial pits and boreholes were excavated. Relevant information also comes from the area east of Gateside.

From the end of the Hillhouse cliff extending south-westwards down the till slope, a minor break of slope corresponds to the boundary between till, at higher elevations, and sandy gravel at lower elevations. The latter deposit is presumed, both by the Geological Survey and the commercial site surveyors, to be raised beach sediment. The gravel appears to be a beach sediment which sits on a shallow hollow in the till, and is replaced downslope by a till surface following the same slope (Fig. 18.5). At lower elevations, both the till and the gravel are covered by sand. The beach surface can be traced over an extensive area (Fig. 18.6) to a maximum altitude of 17.8 m A.O.D.

The sand overlying the beach on the lower part of the slope occurs up to c. 13 m A.O.D. A series of elongate shallow peat bodies lay within the sand, extending north-south, and were connected by east-west peat-filled hollows. All the peat has been removed.

The sediments are either Late Devensian or Flandrian in age. The high elevation of the coarse-grained deposits suggests similarity with the Late Devensian beaches in the Drybridge-Dundonald area (Chapter 16). This section of coast would have been exposed during the period of the middle Flandrian high sea level so, alternatively, the sediments may represent storm deposits of that age. The nearby presence of Shewalton Moss and its apparently uninterrupted growth at a much lower altitude argues against a high (storm) sea level, although the sediments may only represent one severe storm event. The age of the beach remains unresolved, although it is considered more probable that it is Late Devensian than middle Flandrian in age.

The overlying sand also represents a beach. It occurs up to slightly above the maximum elevation at which Flandrian beach sediments are found at Shewalton Moor (Chapter 10) and so may be of similar age. The inclusion of peat within the sand suggests a high probability that the sand is Flandrian in age, although this is by no means proved. The elongate peat bodies may be beach ridge slack deposits (cf. Curray & Moore, 1964) or dune slack deposits similar to those at Shewalton Moor Quarry (Chapters 10.8 & 11.3).

Auchengate (Nat. Grid Ref. NS 339 345). Three trial pits dug along the peat boundary north-east of Auchengate indicate that along this western edge of Shewalton Moss, peat has been covered by sand which is probably windblown. In this area, 0.10 to 0.30 m of peat is covered by up to 1 m of sand. This probably only occurs in a moderately limited zone at the edge of Shewalton Moss, and may be related to the period of dune development in which peat at Shewalton Moor Quarry (Chapter 11.3) and possibly the peat at Barassie was covered.

CHAPTER 19

IRVINE-KILMARNOCK AREA: DISCUSSION

1. Introduction

On the basis of the evidence presented in the preceding chapters, a model of coastal environmental change in the Irvine-Kilmarnock area may be constructed. It is emphasised that the model is a conjectural interpretation. Some aspects are capable of verification by further fieldwork, but many parts will be difficult to check due to the absence or obscurity of evidence. Nevertheless, the model is considered to be soundly based on sufficient evidence to make it an acceptable "third approximation". Smith (1896a) and Jardine (1971) provide the first two approximations.

2. Glacial history

The glacial history of the area has not been studied in detail by the writer, but some comments can be made. Based on incidental observations, they are presented as background to the geology of the coastal changes in the area.

The Irvine valley is situated in an area in which the most recent phase of glacial activity was characterised by deposition rather than erosion (MacGregor & MacGregor, 1948; Price, 1975; Holden, 1977). The glacial till forms drumlins which are aligned approximately N.E. to S.W. Westwards, the till surface drops below present sea level, and the till cover is less complete than further inland. In places glacial erosion of bedrock has occurred. A major bedrock feature is the Hillhouse cliff, which pre-dates both the raised coastal deposits and the glacial till, and therefore may be interglacial or interstadial in age. This major geomorphological feature has probably been produced by the cumulative effects of erosion throughout the late Quaternary sub-Era.

To the north, an area of sand and gravel was interpreted by the I.G.S. (Goodlet, 1970, p.48) as fluvio-glacial in origin, dating from the period of ice wasting during Late Devensian times. The sediments were deposited when the Firth of Clyde contained a body of decaying ice or a body of ice whose front was retreating, and presumably contemporaneously there was either effective damming of the sea by the ice, or sea level stood lower than 15 to 20 m A.O.D.

3. Late Devensian high sea level

Following deglaciation of this area, and during a period of ameliorating climate, sea level rose to a maximum altitude of at least 26 m A.O.D. Figure 19.1 shows the conjectural configuration of the Irvine Estuary at that time. It is based on two main forms of evidence: the Drybridge-Dundonald high-level raised-beach sediments and geomorphological features, and the Mount House and allied sediments. Several sources of potential error should be noted:

(1) The location of the 26 m contour is estimated, being interpolated between given contours on Ordnance Survey maps.

(2) The sediments in the two main areas represent different environments. At Mount House, quiet estuarine conditions prevailed. A minimum value of 26 m A.O.D. for the maximum sea level has been established here and this level is used in Figure 19.1. South of Drybridge, the beach sediments lying at _c._ 28 m A.O.D. indicate high energy conditions, and therefore mean sea level or even H.W.M.S.T. probably lay lower than this altitude.

(3) Mean sea level and H.W.M.S.T. changes within an estuary, typically being higher inland (Jardine, 1975a, b; Devoy, 1979, p.401) depending on the estuary shape (Van De Plassche, 1982, p.13). The postulated Irvine Estuary is

moderately small (c. 8 km long) and changes in sea level therefore may not be large, so this variable is not included in the model. The errors from this omission are probably smaller than those associated with other variables.

(4) Subsequent fluvial sedimentation and erosion may have altered the outline of the estuary. In the area now occupied by parts of the town of Kilmarnock, for example, there are extensive spreads of fluvial sediments, which may have infilled low-lying ground, thus reducing the size of the area now lying lower than 26 m A.O.D. Again the errors involved are probably not substantial.

Figure 19.1 must be used with caution. Nevertheless, certain evidence shows that in general outline, the map is valid. All the sites for which information has been taken from the Geological Survey Memoirs and commercial survey work (Chapters 17.2 & 18) are located within the estuary and almost all the areas of sediment mapped by the Geological Survey as deposits of raised beaches fall within the limits of the estuary. South and west of Caprington Castle are three exceptions, which can be accommodated by slight changes in the limits of the estuary.

Three main coastal environments that existed in the Irvine-Kilmarnock area at this time can be recognised:

(1) The estuary. From approximately Nat. Grid Ref. line 365 eastwards, the environment was that of a relatively quiet, low-energy tidal estuary. Within the estuary and behind drumlin islands, which probably sheltered the estuary mouth, fine grained sediments were deposited. Although in places marked thicknesses of clay have been recorded, at many locations the presence of this estuarine clay has not been recognised previously, and the raised estuarine deposits are more extensive than previously known. In places, the till surface has no cover of estuarine clay. The 26 m altitudinal limit used to draw the shoreline of the Irvine Estuary is based on the sedimentary boundary between estuarine clay and glacial till and is regarded as a

minimum elevation, since the till surface above the sedimentary boundary also may have been inundated (cf. Jardine, 1981b). Erosion within the estuary appears to have been minimal, there being few, if any, traces of marine-cut terraces, and local relief has been reduced by sedimentation rather than by erosion.

(2) The open coast. This may be divided conveniently into two parts. Along the Hillhouse cliff, bedrock was exposed and perhaps was being eroded by the sea. Little evidence suggests that erosion was severe, and erosion was probably limited to trimming of an earlier cliff. The main feature located on the open coast was the beach of coarse-grained sediment. A small terrace was cut into the glacial till, and coarse-grained sediments, mainly gravel and sandy gravel, were deposited. In places the gradation from quiet-water clay deposition behind the drumlin islands to deposition of coarser grained sediments along the coast can be recognised.

(3) The open bay. Evidence is minimal, but borehole data from Byerstonhill suggest that in deeper water, beyond the high-energy, open-coast beach zone, sedimentation consisted primarily of fine-grained clastic deposition, producing the possible equivalent of what are known elsewhere in western Scotland as the "Clyde Beds" (Brady et al., 1874, p.47; Price, 1975; Rose 1980, pp.27 ff; Gray & Lowe, 1977, p.174; Peacock et al., 1977, p.89; Peacock, 1981, p.225). The clay-rich sediment underlying Shewalton Moss (Chapter 13.3) may also represent the Clyde Beds.

4. Late Devensian falling sea level

Figure 19.2 shows the conjectural coastline during a phase in the period of falling sea level. A sea level of c. 17 m A.O.D. used in the construction of Figure 19.2 was chosen partly as an arbitrary middle point between high and low relative sea levels, but also because of a coincidence in the levels of landforms are three sites. At Millbank and

Barassie, beaches of coarse-grained sediment lie at 15 to 17 m A.O.D., and in the sandy gravel deposits in the Shewalton-Drybridge area an accentuation in slope on the ground surface occurs at c. 18 m A.O.D. It is not claimed that these three features are in any way directly connected, especially since the ages of all three are unknown. The coincidence in level, however, may be significant.

The presence of these three features along the former coast may satisfy or partially satisfy Markov's requirements for evidence of a sea-level still stand or rise (Zenkovich, 1967, p.534; Chapter 16.3). On the other hand, even if these features are related, they all can be explained as the results of local environmental change. The map therefore must not be taken to represent a period of sea-level still-stand.

The three main coastal environments present during the period of Late Devensian high sea level (Chapter 19.3) may be present during this phase also:

(1) The estuary. This has shrunk markedly in area. Although clay deposition still may have occurred, there is little evidence for it. As sea level fell, sediments of slightly coarser grade were deposited over the estuarine clay, and gravel frequently is the uppermost sediment; this may represent a change from estuarine to freshwater alluvial conditions, prior to the onset of fluvial downcutting. In Figure 19.2 alternative courses of the River Irvine are marked. The present River Irvine flows in a steep-sided valley, its direct exit at Drybridge being blocked by coarse-grained beach sediments of the phase of the high sea level. The whole of that part of the River Irvine valley east of Drybridge, shown as part of the "17 m" estuary, is filled now with fluvial sediments. The valley floor is expected to have lain higher above sea level than at present. It is suggested that the present valley of the River Irvine is of comparatively recent origin, having been cut as sea level was dropping at the end of Late Devensian times, or

perhaps during the early Flandrian Age. A more direct outflow may have been towards the Carmel Water (route "B" on Figure 19.2).

(2) The open coast. The open coastline prograded considerably more slowly than the estuarine coastline, primarily due to the relatively steep underlying till surface. Sedimentation was still of coarse-grained beach deposits, with occasional erosion occurring. As sea level dropped and the coast prograded westwards, the beach was extended northwards from Drybridge, restricting the mouth of the estuary. This restriction is still enforced at present, the River Irvine being deflected c. 1 km northwards by the body of sand and gravel at Drybridge.

North of the Annick Water, the coastline was located in sand and gravel deposits which probably were fluvioglacial in origin. As sea level dropped, the beach zone must have migrated across these sediments, and it is possible that re-working and transportation of these sediments in the surf zone provided the minor environmental changes required to shift the balance between sedimentation and erosion on the high-energy beaches of coarse-grained sediments. Alternatively, as sea level fell, the configuration of the coastline and the inland drainage patterns changed markedly, and these changes, together with the increased sediment input produced as fluvial downcutting increased erosion of inland glacial and fluvial sediments, altered the hydrodynamic characteristics of this part of the coastline.

The Hillhouse cliff remained a sea cliff during this period, and continued as such until sea level fell to around 7 m A.O.D., by which time most of the terrain now covered by Shewalton Moss was above sea level.

(3) The open bay. There is no evidence of the environmental conditions that prevailed beyond the open coast at this time. However, some areas in which fine-grained sediments (the possible equivalents of the Clyde

Beds) had been deposited, later were sites of deposition of coarser-grained sediment as the open-coast beaches prograded.

5. Early Flandrian, and possibly Late Devensian, low sea level

Figure 19.3 shows the conjectural shoreline during a period in which sea level fell to a few metres above present sea level. The position of this coastline is only estimated in general terms for two main reasons. Firstly, it is based on few sites, most of which do not provide direct evidence for either the elevation A.O.D. of the low sea level itself, or for the exact location of the coastline. Secondly, due to subsequent sedimentation, the coastline is now a buried feature for which the geomorphologically-based type of reconstruction used above (Figs 19.1 & 19.2) cannot be undertaken. The line of the coast has been extended northwards, using Smith's (1896a) sites, at which formerly-exposed sediments bore similarity to sites south of Irvine. They have been classified as lying landward or seaward of the coastline (Table 19.1).

At the Great Bend in the River Irvine and Woodside Cottage Quarry (Chapters 12 & 10.6) the relevant sediments indicate that the tidal zone lay at c. 2 to 3 m A.O.D., whereas similar sediments at Shewalton Moor Quarry (Chapter 10.10) lie at c. 5 m A.O.D. At the latter site, terrestrial organic detritus and evidence for the development of a soil on a land surface is present, so 5 m A.O.D. may represent an upper altitudinal limit for the low sea level, whereas the sediments at the former two sites probably represent levels near to L.W.M.S.T.

The age of this period of low sea level is difficult to establish with certainty. By the beginning of the Flandrian Age and towards the end of the Late Devensian sub-Age, local relative sea level lay lower than 6.2 m A.O.D., possibly two metres lower, and in early Flandrian times, sea level lay lower than c. 5 m A.O.D. The altitudes

Table 19.1 Additional sites used to construct Figure 19.3. From Smith, 1896.

	Approximate Nat. Grid Ref.
Sites lying seaward of the shoreline	
Northern bank of Irvine Water, short distance below the Glasgow and South-Western Railway bridge (p.29)	310 398
Bartonholm sandpit, exposed in 1881 (p.32)	304 411
Caledonian Railway cutting through Byrehill Farm, near Kilwinning (p.33)	295 424
Site lying landward of the shoreline	
Eastern bank of the Irvine Water, opposite Williamfield (p.31)	316 397

probably approximate to H.W.M.S.T. Thus the low sea level represented at these sites may have occurred during the early Flandrian Age.

The tidal-flat environment, with wide expanses of sediment which becomes sandier towards the sea, is the only coastal offshore environment represented at this coast. Small tidal or semi-tidal islands, such as the solid-rock outcrop at Gailes, with its beach of coarse-grained sediment, and perhaps the sand and peaty clay at Irvine Chemical Works, were also present.

Onshore, the coastal vegetation was affected by two main factors. Throughout the early part of the Flandrian Age, immigration of new plant species, as elsewhere throughout Britain, took place. Locally, however, the damp, poorly-drained conditions on the emerged raised-beach surface, especially in the areas underlain by till and other clay deposits, encouraged the establishment of open, marshy vegetation and, in places, damp woodland. Inland, richer mixed forest probably became common on the better-drained hill slopes.

6. Middle Flandrian high sea level

Figure 19.4 shows the conjectural middle Flandrian shoreline. Its location is difficult to estimate for the same reasons as those given in Chapter 19.5. Furthermore, it represents a highly dynamic environment in which sea level, beach level and sediment supply were changing, and consequently the shoreline position probably did not remain static for long. During the period of sea-level rise, sediment input was considerable and, although sea level rose some 10 m, the shoreline moved inland only _c_. 500 m. The limit of the transgression was controlled by the extensive development of successively higher beaches one upon another, forming a coastal barrier. The inland extent of these beaches was limited by the Late Devensian beach deposits, Shewalton Moss and possibly a dune system located immediately behind the beaches.

The majority of the sediments are coarse-grained deposits representing moderately high-energy environment. The maximum elevation at which they occur therefore will be at, or slightly above, the elevation of the contemporaneous H.W.M.S.T. In Woodside Cottage Quarry, the raised-beach deposits lie up to a maximum altitude of c. 13 m A.O.D., commonly occurring at c. 12 m A.O.D., suggesting a maximum sea level (H.W.M.S.T.) of 12 to 13 m A.O.D.

The timing of the Flandrian marine transgression is difficult to determine. The succession at Dundonald Burn (Chapter 14) indicates an episode of sedimentation related to a rising sea level, at a time after c. 6,000 B.P. At Shewalton Moor Quarry, peat growth at an altitude above, but not directly upon, the raised beach deposits, was initiated perhaps around 2,000 B.P., but possibly as early as 3,000 to 3,500 B.P.; a radiocarbon age determination from nearby (Shotton & Williams, 1971) suggests that terrestrial conditions prevailed at around 3,900 B.P. (Chapter 11.3.). Allowing an estimated lag for the 3-4 m drop in sea level at Shewalton Moor, the period of maximum sea level may date from approximately 6,000 to 4,000 B.P. This very approximate date must be treated with caution.

Three coastal environments are recognised:

(1) The open coast. This is represented by the extensive sand and gravel deposits at Shewalton Moor. The environment was such that successive sand and gravel beach ridges were formed offshore and migrated inland, forming the ridge and runnel topography typical of beaches on an open coast such as this part of the Ayrshire coast. In places slacks and lagoons were formed behind the beach. The effects of high energy storm erosion were counteracted by the effects of rising sea level and a substantial sediment input.

(2) The open bay. Offshore, sedimentation kept pace

with rising sea level and at the Great Bend site there is evidence of extensive infilling of the bay, a substantial thickness of sand being deposited. This may have been solely a local effect, since the mouth of the River Irvine must have been located near here at one time.

(3) The estuary. The areal extent of the Irvine Estuary is difficult to establish. Much of the area up-stream from the Long Drive Bridge site is covered by fluvial sediments, which in places are very thick (to c. 20 m; Robbie, 1969). During the period of low sea level, the River Irvine would have been eroding to a low base level, and as sea level rose, the valley would have been infilled. Much of the sediment in the present river valley therefore may date from middle Flandrian times, and the valley floor may have been lower during the period of rising sea level than it is at present. The middle Flandrian marine transgression may have penetrated eastwards as far as Drybridge. By middle Flandrian times, the former peat-covered surface at Long Drive Bridge had been inundated by the sea, and sandy tidal-flat conditions prevailed.

The mouth of the Irvine Estuary may have been narrow, and perhaps similar to the present mouth of the River Irvine. Such a reconstruction depends on the interpretation of the evidence at the Dundonald Burn site (Chapter 14); since the buried peat lies below the maximum Flandrian sea level, the simplest explanation is that the sand that overlies the peat is a raised beach deposit, and that the succession represents the erosion of a land surface and subsequent deposition of sand in middle Flandrian times, when sea level stood at or above 7 m A.O.D. If such an interpretation is accepted, there is no need to postulate a restricted Irvine Estuary mouth.

7. Late Flandrian falling sea level and marine regression

The rate of fall of sea level since the middle Flandrian high stand is unknown, although it must average c. 0.2 m per

100 years. In places regression perhaps was initiated, and the rate of regression was increased, by progradation of aeolian sand dunes.

The rapid marine regression may have been responsible for the creation of landforms described by Smith (1896a) as "certainly the most peculiar feature of the raised-beach formation in the district" (Smith, 1896a, p.38). This is a series of about 30 sub-parallel sand ridges, approximately parallel to the present coast, extending from Meadowhead Farm southwards to Auchengate (Nat. Grid Refs NS 336 341 and 339 345 respectively; Fig. 19.5). The ridges are 1 to 2 m high, about 2 to 3 m wide and spaced 10 to 20 m apart. In many cases they have been removed in the course of recent building and land development, but traces can be found in the area between Shewalton Moss and a line about half way between the A78 road and the coast. Smith considers "that these ridges were thrown up by the action of waves ... the action of the wind being to destroy them" (Smith, 1896a, p.39) and that they were preserved due to the reinforcing presence of a greater gravel content than the sediment in the surrounding areas. Recently-cut sections across several ridges indicate that they have no noticeably greater gravel content than the sediments in the surrounding hollows. Reade's interpretation differed slightly from Smith's: "By the Gales Farm the ground lies in parallel ridges which to me seem to be the marks of tidal margins." (1896, p.126). No erosion by wind was suggested. It is probable that the ridges are regressive coastal sand ridges (Curray & Moore, 1964; Curray et al., 1967), formed when sediment input and deposition dominate coastal change. Under such conditions, sea level may continue to rise or remain static, and moderately rapid regression may occur (Hoyt, 1968; Evans, 1979). The ridges at Meadowhead lie on a surface which slopes gently westwards from c. 10 m to 8 m A.O.D. Assuming that a marine origin for these ridges is a correct interpretation, this suggests that the marine regression was fully in progress in this area in the early stages of the period of sea-level lowering.

Three coastal environments are identified:

(1) The open coast. Sedimentation along the prograding beaches was mainly of sand; on average, finer-grained sediments were deposited in this environment than during early to middle Flandrian times. This suggests changes in the sediment supply source, with perhaps the reworking of older beach and open bay deposits by wind as land emergence occurred.

(2) Coastal sand dunes. Encouraged by the presence of large areas of freshly-exposed beach sand, sand dunes were widely developed, covering much of the Flandrian raised-beach sediments and in places encroaching upon the edges of Shewalton Moss. The initial formation of these dunes, however, may have occurred earlier, as sea level rose during the Flandrian transgression (cf. Jelgersma et al., 1970, p.147). To the north, they contributed to the barrier of sediments which dammed the course of the River Irvine and deflected it northwards shortly after the period of maximum sea level. Within the sand dunes, peat growth may have been common in dune slacks and hollows. The vegetation in this area was relatively open, and most of the coastal strip west of Shewalton Moss may never have been substantially wooded.

(3) The estuary. Despite the rapid rate of marine regression along the open coast, tidal waters may have penetrated upstream along the River Irvine for a long distance, and regression in the estuary may have occurred at a more regular rate than along the open coast. It is only during the last century that the inland extent of the tidal waters has been limited by the building of a weir at the town of Irvine. At an unknown time, the area of the estuary may have become enlarged as the River Irvine was deflected northwards (Fig. 19.5).

8. Sea-level curve for the period since deglaciation

A time-sequence of sea level change in the Irvine-

Kilmarnock area is evident. Graphic representation of this allows comparison with models of sea-level change established elsewhere. Changes in sea level can be presented as a time-elevation graph, in which index points show sea-level altitude at a given time, and as a sea-level curve, in which, at the index points, the direction of sea-level change is also shown (Jardine, 1982, p.32). Certain factors may reduce the accuracy of such diagrams:

(1) The accuracy provided by dating techniques is important. The most accurate, commonly used measure of age is provided by analysis of the radiocarbon content in organic material. However, several factors introduce uncertainty into the age obtained (Burleigh, 1975; Harkness, 1975; Shotton, 1977; Bowen, 1978, pp.110 ff.; Jardine, 1978; Saarnisto, 1979) and ages obtained by radiocarbon assay represent only the distribution around a mean. The model presented here contains a further level of generalization: most of the chronology used is based on palynological stratigraphy. Although this is calibrated on the basis of radiocarbon-dated pollen stratigraphy established elsewhere, the statistical errors involved in the use of such a chronology are greater than those involved in "straightforward" radiocarbon dating. For this reason, throughout the above discussions, statements quoting exact dates have been specifically avoided, and wide ranges have been deliberately given, perhaps slightly over-emphasising the uncertainties involved.

(2) The exact relationship between the measured level at a site and the contemporaneous sea level may be difficult to establish. Since peat is the only potentially datable material at many of the sites discussed here, frequently it is the maximal level of H.W.M.S.T., for example, that is estimated, although in many cases the level in question may be well above H.W.M.S.T. These maximal levels may be inaccurate due to post-depositional compactions of the sediments (Streif, 1974). The problems associated with compaction have not yet been studied in sufficient

detail to provide correction factors (Devoy, 1979, p.393). However, it may be expected that greater compaction occurs where there are significant thicknesses of buried peat than occurs where coarse-grained clastic sediments are present.

(3) Related to the previous problem is the difficulty of establishing the position of mean sea level. Although mean sea level and mean tide level are not necessarily always equal, the latter serves as a useful and practical substitute for the former (Jardine, 1975a). In most of the cases included here, the level concerned is probably H.W.M.S.T., occasionally a higher level related to low-frequency storm events and, in a few other cases, L.W.M.S.T. or some intertidal level. In the model, allowance is made for the use of more than one level of the sea. It should be noted that tidal range probably changed during the Flandrian Age (Heyworth & Kidson, 1982), especially since the configuration of the coastline, both locally in the Irvine-Kilmarnock area and regionally throughout the Firth of Clyde, has changed considerably. It may be possible (Doodson & Warburg, 1941) and necessary (Heyworth & Kidson, 1982) to calculate tidal range changes, but given the variables in dating and measurement of former sea levels, the degree of uncertainty inherent in the sea level curve presented here does not warrant the making of such calculations.

Fifteen points are used to construct a generalised sea-level curve (Table 19.2). All the dates are discussed below, except those for points 1, 2 and 15. The dates for points 1 and 2 are estimated from a model of deglaciation in the Firth of Clyde (Price, 1980). Between c. 18,000 B.P. (time of the maximum extent of the Late Devensian ice sheet) and c. 13,000 B.P. (time of almost complete deglaciation), ice had wasted in the higher ground (now dry land) but remained in the Firth of Clyde. An approximate date of 15,000 B.P. is therefore given for the sea-level position associated with the period of fluvio-glacial deposition north of the Annick Water (Point 1). Point 2 relates to

Table 19.2 Points used to construct the curves of sea-level change in central Ayrshire (Figs 19.6 & 7).

	Approximate date	Comments	Source/site
1	? 15,000 B.P.	s.l. below 15 m, ice still in the Clyde	Price (1980)
2	? 13,500 B.P.	s.l. (H.W.M.S.T.) rising to a maximum of 26 to 28 m A.O.D., during period of deglaciation and climatic amelioration	Price (1980), Mount House, Dundonald-Drybridge area
3	c. 13,000 - 10,500	s.l. falling more or less steadily to below 7 m A.O.D. (H.W.M.S.T.)	Drybridge-Shewalton area
4	Loch Lomond Stadial c. 10,500 B.P.	s.l. below 7 m A.O.D. (H.W.M.S.T.)	Shewalton Moss
5	c. 10,000 B.P.	s.l. below 6.2 m A.O.D. (H.W.M.S.T.)	Dundonald Burn
6	c. 8,800 B.P. (the *Corylus* rise)	s.l. below 6.4 m A.O.D. (H.W.M.S.T.)	Dundonald Burn
7	Early Flandrian ? 9,500 - 9,000 B.P.	s.l. below c. 5 m A.O.D. (H.W.M.S.T.)	Long Drive Bridge
8	Early Flandrian ? 9,000 - 8,000 B.P.	H.W.M.S.T. at c. 5 m A.O.D., M.T.L. c. 2.5 m A.O.D.	Shewalton Moor Quarry

(Continued)

Table 19.2 (continued)

	Approximate date	Comments	Source/site
9	Early Flandrian	s.l. (L.W.M.S.T. or higher) dropping and rising to c. 2.3 m A.O.D.	Great Bend, Woodside Cottage Quarry
10	After 7,000 B.P.	s.l. above 5 m A.O.D. (H.W.M.S.T. or storm surge)	Shewalton Moor Small Quarry
11	c. 7,000 B.P.	s.l. below 6.8 m A.O.D. (H.W.M.S.T.)	Dundonald Burn
12	After 7,000 B.P.	s.l. high	Dundonald Burn
13	Middle Flandrian, ? 7,000 - 4,000 B.P.	s.l. rising and dropping to and from a maximum level of 12-13 m A.O.D. (H.W.M.S.T. or storm surge)	Shewalton Moor quarries
14	Before c. 2,000 B.P.	s.l. at c. 9 m A.O.D. and dropping (H.W.M.S.T.)	Shewalton Moor Quarry
15	Present	H.W.M.S.T. 1.90 m A.O.D. M.T.L. 0.02 m A.O.D. L.W.M.S.T. 1.90 m B.O.D.	Hall, 1974, for tidal ranges at Irvine

the high sea level present as the climate ameliorated, i.e. at the end of a period of glacial or periglacial conditions. There is evidence that at the end of the Loch Lomond Stadial sea level in this area was low (Points 4 and 5, Table 19.2) so the relevant high sea level relates to the end of the main Late Devensian glaciation. The high sea level, therefore, is dated at c. 13,500 B.P. Point 15 is sea level at the present day (Hall, 1975).

The tidal range used for all parts of the sea-level curve is a best approximation, being the tidal range which occurs at present. Problems regarding changes in tidal range are mentioned above (this chapter; Chapter 8.5). In early Flandrian times, tidal range may have been similar to that at present, since sea level and coastline configuration in the Irvine area were similar to those at present. Likewise, the middle Flandrian coastline in the area was similar to that at present. There may, however, have been major regional differences in the shape of the Firth of Clyde and in the area of the Clyde Estuary, caused by, for example, the marine flooding of Loch Lomond (Dickson et al., 1978; Rose, 1981) and the Linwood-Paisley area (Chapter 8.5), which must have influenced the patterns of tidal activity. Locally, the greatest changes in tidal range may have occurred during the period of Late Devensian high sea level when tidal ranges along the open coast and within the Irvine Estuary may have differed not only from the present range, but also markedly from each other. Of importance at this time may also have been the increased tidal circulation in the Firth of Clyde consequent upon the marine breaching of the Mull of Kintyre at Lochgilphead (Peacock et al., 1977) and at West Tarbert (Steers, 1973, p.91).

The data from Table 19.2 is plotted on Figure 19.6, which includes indications of the direction of change. Figure 19.7 portrays what is a simplified picture, but given the wide variety of uncertainties, it is regarded as moderately accurate.

The conjectural present rate of relative lowering of sea level in this area (2.5 mm/year; Valentin, 1953, fig. 2) is similar to the average rate of sea-level lowering since the culmination of the middle Flandrian transgression in this area (c. 2 to 3 mm/year; Figure 19.7). This suggests that the final part of the curve (c. 4,000 B.P. to present) should be straighter than is shown in Figure 19.7. However, it should be noted that the rate given by Valentin is purely conjectural and is based on minimal evidence in Scotland, and that there is little chronological and altitudinal control from the Irvine area for the final part of the curve (Figs 19.6 & 19.7). This part of the curve should be treated, therefore, with caution.

The main features of the sea level curve to note are:

(1) A high sea level at c. 24 to 28 m A.O.D., during the Windermere sub-age.

(2) A rapid fall in sea level during the Late Devensian sub-age.

(3) A low sea level, at c. 1 to 5 m A.O.D., during the early part of the Flandrian Age.

(4) A middle Flandrian maximum sea level of around 8.5 to 12.5 m A.O.D. at c. 5,000 B.P.

9. Comparison of model with earlier "approximations"

This model is described above (Chapter 19.1) as a "third approximation". The "first approximation" is Smith's (1896a, 1898) interpretation of the superficial deposits of Ayrshire. In Smith's 1896 publication, he describes a succession of drift deposits which represent high-level (200 ft (c. 61 m) and 120 ft (36.5 m) A.O.D.) Late Devensian sea levels, followed by periods of lower sea levels (40 ft (12 m) and 25 ft (7.5 m) A.O.D.) during the Flandrian Age. There were intervals of very low sea level, perhaps below O.D., during which peat beds were deposited and gravel beaches, now submerged offshore, were formed. Two years later, Smith (1898) modified this model to include most glacial deposits within the sediments deposited during a great marine submergence. He suggested sea levels of over 1,000 ft (305 m) A.O.D. and proposed evidence for former submergence of up to 2,764 ft (842 m) A.O.D. at the summit of Merrick Hill, Galloway.

Jardine's (1971) interpretation of sea-level and coastline changes, the "second approximation", is slightly more conservative than Smith's. Jardine's Late Devensian sea level lies at a maximum elevation in this area of c. 24 m A.O.D., and the coastline lies at the inland edge of the so-called Irvine Embayment, along a line of coarse-grained sediment regarded as a coastline here, and extending c. 2 km up the River Irvine valley. In the Flandrian Age, following an early period of low position, sea level rose to c. 12 m A.O.D., the sea transgressing to occupy a large embayment, the coastline of which lay not far to the west of the Late Devensian shoreline, although the River Irvine valley was not flooded (see Figure 1 in Appendix 6).

The "third approximation", presented here, differs from the first two on the following points:

(1) The Late Devensian maximum sea level is slightly higher than Jardine's, but lower than in Smith's first model. Smith's later ideas of a great marine submergence, while not disproved directly by the work here, are thought to be incorrect. Its acceptance relies on the agreed origin of till and other glacial depositional and erosional features. Smith's ideas are not widely supported at present. In the model presented here, there is some indication of a lower sea level, prior to the period of Late Devensian high sea level.

(2) Sea-level fluctuations are less complicated than implied by Smith.

(3) The areal extent of the Late Devensian high sea has been underestimated by Jardine, especially inland.

(4) The areal extent of the middle Flandrian trans-

gressive embayment has been considerably overestimated by Jardine, although the maximum sea level proposed by Jardine is accepted.

10. Comparison of sea levels and the sea-level curve with models from elsewhere

Sea-level curves for Late Devensian and Flandrian times from throughout Scotland, have been shown together on one diagram (Jardine, 1982, fig. 2).

The shape of the curve in Figure 19.7 conforms to the trends shown in other curves, i.e. two maxima with an intervening minimum, but there are differences in detail. As discussed above (Chapter 16.3), the complex fluctuations in falling Late Devensian sea level, which were postulated for the western part of the Forth Valley (Sissons & Brooks, 1971) are not found here. The sharp sea-level upturn during Late Devensian times at Ardyne and Lochgilphead (Peacock et al., 1978) also is not recorded here and, although evidence relating to this period is sparse, there is no indication that such a trend of sea-level change should be expected.

The rate of sea-level change (fall) in this area during Late Devensian times is similar to that elsewhere (Peacock et al., 1978; Synge, 1977). This, however, may not be of great significance; given the magnitude of sea-level change (say 20 to 25 m) and the relatively short time for it to have occurred, only major differences in either variable (sea level and time) would produce noticeable changes of rate. Elsewhere in the sea-level curve for the Irvine area, the curve gradient (equivalent to rate of change of sea level) could be altered if the curve was constructed in a different manner.

There are several shoreline isobase maps for parts of Scotland (Smith et al., 1969; Sissons, 1976a, b; Gray & Lowe, 1977). The general pattern is that of a shoreline lying at successively lower altitudes outwards from a central area in western Scotland. Maximal and minimal values of sea levels in the Irvine area conform to the general pattern. The generalised isobases for the "Main Postglacial" raised shoreline (Sissons, 1976b) indicate that the middle Flandrian high sea level at Irvine should lie at a little under 12 m A.O.D., and if the "Main Perth" shoreline (Late Devensian high sea level) isobases for eastern Scotland (Smith et al., 1969) are interpolated southwards to Ayrshire, following the general trends of isobases for later periods, the 30 m A.O.D. isobase lies immediately south of the Irvine-Kilmarnock area. These values (12 m, 30 m) are sufficiently close to the maximal values on Figure 19.7 to suggest that this sea-level curve conforms to the general trends already established in Scotland, and therefore that these established trends are further reinforced by the evidence from Ayrshire.

11. Archaeological significance of the new model of changing sea level and changing coastline position

Replacing the coastline of the middle Flandrian high sea level from the inland position suggested by Jardine (1971) to a position some 1 to 1.5 km seaward (Appendix 6, Figure 1) has some important consequences for archaeological study in this area.

It is becoming increasingly apparent that coastal regions were important locations of Mesolithic activity, whether as part of a semi-nomadic lifestyle (Simmons, 1975a; Cullberg, 1980) or a more settled lifestyle (Palmer, 1980). In Cumbria and south-western Scotland it has been demonstrated that Mesolithic sites are clustered immediately above the inland limit of the middle Flandrian coastline (Cormack & Coles, 1968; Cormack, 1970; Bonsall, 1980; Morrison, 1980a), and a model for the expected locations of coastal Mesolithic activity has been proposed (Jardine & Morrison, 1976).

The area around Shewalton has a large concentration of Mesolithic finds, which fall into two groups. The first group comprises finds from the Shewalton Moor area (Smith, 1882; Lacaille, 1930, 1931, 1937) in lag gravel within sand dune hollows. The finds are not <u>in situ</u> stratigraphically, but clearly must post-date the period of high Flandrian sea level (cf. Smith, 1908). The typology suits such an interpretation of age (A. Morrison, 1980b, in press, pers. comm.). The second group has provided more problems. The relevant artifacts are scatter finds from an area seaward of Jardine's middle Flandrian coastline, but landward of the coastline proposed here (T. Affleck, pers. comm.). From their distribution, they appear to lie upon the higher (Late Devensian) raised beach deposits, and frequently very close to, but not upon, the present river terraces. Formerly the distribution of such material on the seaward side of the middle Flandrian shoreline was puzzling, not fitting the model (Jardine & Morrison, 1976) which is applicable elsewhere. Consequently, these finds were interpreted until now as implying a late presence of Mesolithic activity, after the period of maximum sea level rather than during it as appears to have been the case elsewhere in south-western Scotland.

The revised position of the coastline provides several points of interest for further archaeological interpretation (cf. Boyd, in press):

(1) Mesolithic finds and implied Mesolithic activity around Shewalton Moss and in the River Irvine valley need not be late Mesolithic in age.

(2) The distribution of finds in this area may now conform to the models produced for sites elsewhere.

(3) The environmental reconstruction provides a wider range of suitable habitats than formerly envisaged. Such a wide range of habitats would have encouraged Mesolithic activity in this area (cf. Bonsall, 1980).

Finally, from the point of view of the model of coastal change and, in particular, that part of it which is concerned with the location of the former middle Flandrian coastline, the archaeological material from this area provides an independent source of evidence which supports the model.

12. Radiocarbon dates

The following radiocarbon dates have been obtained for samples from core SM-81-I (Shewalton Moss):

lab. no.	years B.P.	m below surface
SRR-2025	9,250 ± 110	2.11 - 2.15
SRR-2026	10,400 ± 190	2.41 - 2.45
SRR-2027	10,510 ± 120	2.51 - 2.55

The initial assessment regarding the age of Shewalton Moss, and the interpretation of the pollen data (Chapter 13), are both supported by the radiocarbon age determinations. Likewise, the radiocarbon dates confirm the parts of the geological model which are related to the growth of peat in this area. In the sea-level curves (Figs 19.6 & 19.7; Table 19.2), the estimated dates for points 4 and 5 appear to be sound, and the date for point 6 may be 400 years too young.

The two earlier dates are statistically inseparable. SRR-2027 provides an age (10,510 ± 120 B.P.) for the base of the pollen diagram, its parent sample being taken from peat in which the pollen spectra are interpreted as representing Loch Lomond Stadial conditions. The date suits such an interpretation of the pollen spectra. SRR-2026 is from a sample just below the *Betula* rise, and as such, provides a date which is regarded as too old. Given that the Shewalton area is a considerable distance from the limits of the Loch Lomond Stadial ice sheet, the rise in *Betula* pollen may reflect the local (and regional?) expansion of *Betula nana* during the later part of the Loch Lomond Stadial.

The sample from which SRR-2025 was obtained represents the Corylus rise. Although there are problems in the interpretation of the pollen spectra due to severe pollen degradation in this part of the peat, it is notable that the date, 9,250 ± 110 B.P., is statistically inseparable from that for the Corylus rise at Linwood Moss (SRR-2028, 9,290 ± 90 B.P.). Of further interest are two (statistically separable) dates from Girvan (c. 40 km south of Shewalton), where peat deposited after the Corylus rise is dated at 9,020 ± 150 B.P. (Q-640), and a date of 9,362 ± 150 B.P. (Q-641) is obtained for peat probably deposited prior to the Corylus rise (Godwin & Willis, 1962; Jardine, 1962, 1964). The Corylus rise on the eastern coast of the Firth of Clyde appears to have occurred, moderately synchronously, at around 9,200 B.P. If Corylus migrated from the west of Scotland (Deacon, 1974; Rymer, 1977; Birks, 1980; cf. Moore, 1971), the later expansion of Corylus on Arran (8,665 ± 155 B.P., Robinson, 1981, p.82) suggests migration around the (northern seaboard of the) Firth of Clyde, rather than across it. The dates discussed here suggest that migration southwards towards Galloway, at least along the coast, was rapid. If this migration route is a valid one, the early presence on Arran of long-distance transported Corylus pollen at c. 9,250 B.P., some 600 years before the main expansion of Corylus (Robinson, 1981, pp.82-82), may be expected.

PART C:

SYNTHESIS

CHAPTER 20

SYNTHESIS

1. Local and regional geology

Contributions presented in this thesis. The major contributions to the local geology of the two areas studied in this work are the models for changes in the coastal environments and sea levels during Late Quaternary times. In the course of construction of the models much information also is provided which contributes to the establishment of post-glaciation vegetation histories of these areas. Primarily, the palaeobotanical data provide inputs for the geological models, but an important secondary outcome is the new evidence and discussion regarding possible prehistorical human land use, despite the lack of direct links between the palaeobotanical data and the local archaeology in both areas.

In regional terms, the models conform to postulated Late Quaternary geological models produced for other areas in Scotland, thus contributing support to research results obtained elsewhere in Scotland. The research in the two coastal areas considered in this thesis indicates, as does other research at, for example, Flanders Moss (Sissons & Smith, 1965; Sissons & Brooks, 1971), Lochar Moss and Palnure Moss (Jardine, 1975b, 1980) and on Colonsay (Jardine, in progress), that large areas of low-lying, raised coastal sediments need not have a simple or similar geological history. The presence and growth of peat bodies in these areas appear to have been important, variously influencing the development, form and location of shorelines associated with the fluctuation of sea levels during the Flandrian Age.

Possible future research. The Shewalton Moss area may be a valuable location of Late Devensian sediments. The base of the peat at Shewalton Moss appears to be pre-Flandrian in age, and in places may date from the Windermere Interstadial. This offers a location for the study of the non-glacial terrestrial environment of the Loch Lomond Stadial. At the onset of this research, it was hoped to examine "Clyde Bed" sediments (Peacock, 1981). Exposure of such sediments, however, was found to be minimal, but they may occur, perhaps extensively, beneath Shewalton Moss. Although there were problems in coring during peat sampling at Shewalton Moss, different techniques may allow the collection of basal peat and the underlying clay-rich (possible Clyde Bed) sediment.

Both Shewalton Moss and Linwood Moss contain apparently complete Flandrian peat successions, and these, therefore, may be useful locations for the establishment of long pollen diagrams for the respective areas. Although the relevant sites occur within large areas of peat, and therefore may provide only relatively-local vegetation histories, the results of pollen analysis at Shewalton Moss and Dundonald Burn show that, in the Irvine area at least, local vegetation patterns expressed in the pollen diagrams were moderately widespread. Perhaps of greater importance may be further work relating palaeobotanical study to the local archaeology. This may be especially valuable in the Irvine-Kilmarnock area, where a detailed palaeoenvironmental model now exists, and there is strong evidence for concentrated Mesolithic (at least) activity in the area. At Linwood Moss, pollen analysis from sites nearer the moss edge than discussed in this thesis may be of considerable interest with respect to the archaeology of N.E. Renfrewshire (cf. Turner, 1970).

The Shewalton Moor area, with extensive exposure of sediments, and the established geological model, appears to provide good potential for the study of late Flandrian sand dune stratigraphy, especially in relation to former alternating periods of dune and soil formation, and regional climatic fluctuation.

The models presented here require to be extended areally and tested regionally. Although further refinement of the models may be undertaken easily in the areas already studied, it is considered that this would be an inefficient use of research resources, and more positive advancement would be gained by "lateral" extension of the research. For example, given the model for the Irvine area, is the extent of the embayment formed during the middle Flandrian marine transgression around Ayr (c. 20 km south of Irvine) similarly less extensive than previously considered? Also, can the model for the Irvine area be applied to other areas, such as that around the Esk estuary (N.W. England), in which both the palaeogeography and the archaeology (Bonsall, 1980) show certain similarities with the Ayrshire situation? To test the model produced for Linwood Moss, research may be extended to Barochan Moss, using a methodology similar to that employed at Linwood, or extended to other nearby areas in which peat is not present, concentrating on, for example, geomorphological evidence.

The newly-introduced suggestions regarding the sub-surface formation of charcoal in peat (cf. Boyd, 1982) require to be examined and tested. If the proposed process is valid, it may be highly significant in certain research.

2. Methods and concepts

Introduction. Several new and established methods and concepts have been introduced, used and discussed within this research. Although these occur within the local context, all may be developed and extended, being of significance in a wider context than that in which they appear in this thesis.

Methods. In the course of the research a wide variety of methods has been employed. Most of the methods are standard, are in common use in Quaternary research, and require little comment here. Two methods, however, were introduced which are rarely used in such research. The morphological analysis of fossil calcareous algae offers a good potential tool for the elucidation of coastal shallow-water palaeoenvironments.

As research into the environmental conditions of modern Lithothamnium progresses, the use of this palaeoenvironmental tool may be refined. As far as the writer is aware, this method has not previously been applied to Quaternary sediments. The second method, electrical resistivity surveying, already in use in archaeological studies, is perhaps more widely applicable than the first. As illustrated by the use of this method at Shewalton Moss, it is potentially valuable and useful stratigraphical research tool, although it requires to be developed and refined for the specific demands of remote sensing of superficial sediments.

Multidisciplinary approach. This approach has been found to be invaluable in the Quaternary research presented in this thesis. It allows a flexible approach to the study of the multi-faceted problems which typically occur in Quaternary science. The breadth of raw data is matched by the breadth of methodological application, thus allowing maximum exploitation of the available data. The necessity of such an approach is well illustrated by the open-ended discussion regarding the nature and implications of the double marine event in Loch Lomond, and the constructive value of this flexible approach is illustrated at Linwood Moss, where, in an investigation of former sea levels and shoreline positions, the absence of fossiliferous and structured marine sediments and geomorphological evidence, together with the presence of freshwater peat, demands the application of an alternative stratigraphical and chronological research strategy. The application of a multidisciplinary approach also allows the independent testing of models to be undertaken, the clearest example in this research being the interaction between the archaeological data collected in the Shewalton Moor area by other researchers, and the model for that area presented in this thesis. The latter example also illustrates the symbiotic relationship which may exist between apparently widely separate fields of research, and which may be recognised as one of the major strengths of Quaternary science.

Although a possible disadvantage is that a multi-disciplinary approach may produce a less-specialized result with several "loose ends", especially if a problem is investigated by one researcher or a small group of researchers, it is considered that, compared with the highly specialized results of a single-discipline study, the broadly integrated results are more widely applicable and more relevant to the broad base upon which Quaternary science rests.

Theoretical models. The multidisciplinary approach to this research includes the construction of theoretical models, both during the establishment of working hypotheses -- e.g. the sedimentological model for beach sedimentation at Shewalton Moor, and the model for the rate of peat growth at Shewalton Moss -- and in assisting interpretation and discussion of the processed data -- e.g. the model of coastal development in areas of peat, used in the Linwood Moss discussion. The value of such models is that they are designed and constructed to a prescribed degree of complexity and accuracy. In this way, unnecessary detail is omitted, and although the models appear to be moderately generalized, they are widely applicable and adaptable. Further refinement may be counterproductive. These models have been found to be more applicable to Quaternary data than the frequently more complex, non-Quaternary geological facies models, based on situations in which change frequently is slower and longer-lasting and sediment preservation is more complete than in their Quaternary equivalents.

3. Finale: past, present and future

During the last century and a half, Quaternary research in the area of the Clyde Estuary and the Firth of Clyde has been representative of the general development of field investigation and thought in Quaternary geology. Early records of fossiliferous marine shells near Paisley (Laskey, 1814) and the sceptical interpretations of submerged peat (Fleming, 1823) mark the beginning of this development:

> "A permanent rising of the sea has not been resorted to by any of the writers whom we have had an opportunity of consulting. Indeed it is contrary to all those known laws which regulate the movements of the ocean and receives no support from any circumstances which have been observed on the maritime shores of this country." (Fleming, 1823, p.422)

The challenge was rapidly taken up by James Smith of Jordanhill who, by extensive and astute observation in the Clyde region, developed major and long-lasting theories regarding change and oscillation of land (and sea) levels, climatic fluctuations and former glacial activity in Britain (Smith, 1836 ff.), contributions for which Crosskey (1867d) later claimed a "high place in the history of geology" (Crosskey & Robertson, 1877, p.29). During the 1850s to 1870s, a small group of geologists followed the lead provided by Smith, and were active in the Clyde region. The most notable of these were Crosskey and Robertson ("who are the best authorities on the subject of the Clyde brick-clay deposits", Geikie, 1877, p.256), the Geikies, Brady, Bell, Bennie and Jack. The research and development of ideas progressed, as elsewhere, through periods of optimism:

> "The Canadian [glacial] beds justify the conviction I have long entertained and endeavoured to work out in the field, that our clay beds can be classified, and therefore there exists a definite order to reward patient research." (Crosskey, 1867a, p.134)

periods of caution and uncertainty:

> "Without attempting to give anything approaching to a final and complete sequence we simply submit an arrangement in the direction of which our investigations have led us, for the purposes of furnishing a tentative grouping of a large number of deposits which it is impossible to study when they are miscellaneously intermingled." (Brady <u>et al.</u>, 1874, p.93)

and periods of purely sceptical disbelief in scientific thought:

> "... here, if adaption of means to an end be proof of design, we have a marked evidence for the work of God preparing the earth for man's habitation." (Watson, 1864, p.540, in reference to the origin of shelly drift in Arran)

This path of geological research resulted in the detailed glaciation and post-glaciation geological histories of Jamieson (1865), Bennie (1867a), Bell (1874) and Geikie (1877). Following these publications, research in the Clyde region continued, but at perhaps a slightly lower level of intensity. Much information was gathered and interpreted, in some cases providing support for earlier theories and in other cases fuelling controversy. Old debates were re-opened:

> "From a study of the Ayrshire drift, I think we are warranted in abandoning all ideas of great "mountains of ice" conjured up for us by the imaginations of some geologists in trying to account for certain scratches on hills, and for the positions occupied at high levels by erratic stones and boulders." (Smith, 1898, p.121)

and new debates were undertaken:

> "I know of no evidence of any kind to support it ... This is a grand theory, and if poetry and romance could be adduced as arguments in its favour, it ought to be true." (Neilson, 1906, p.277, in a criticism of Bell's (1874) idea of an ice-dammed Clyde lake)

During the greater part of the twentieth century there has been little progress in the field of Quaternary geological research in the Clyde region, and it is only in the last two decades that detailed studies have advanced the knowledge of Quaternary events, both in the Clyde region and elsewhere in Scotland, beyond the conclusions reached by the turn of the century. Despite periodic and broad-ranging research, primarily by staff and students of the University of Glasgow and by officers of the Geological Survey and the Institute of Geological Sciences, there is a general scarcity of publication relating to the Clyde region during Quaternary times. With a few exceptions (e.g. Dickson et al., 1976), the research concerned has been carried out largely on an individual basis, the emphasis being on geological, geographical or botanical aspects, or, occasionally, on a combination of geological and geomorphological facets of Quaternary science.

It is hoped that this work will stimulate further research (and publication) both as a consequence of the problems which have been raised here, and by the example set by the successful application of the multidisciplinary methodology.

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THE STRATIGRAPHY AND CHRONOLOGY OF LATE QUATERNARY RAISED COASTAL DEPOSITS IN RENFREWSHIRE AND AYRSHIRE, WESTERN SCOTLAND

VOLUME TWO

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LIST OF CONTENTS (VOLUME 2)

Note: References to items of literature in Appendices 1 to 4 are included in the reference list in Volume 1

APPENDIX I

Preparation of clay-rich samples for pollen analysis

An important problem in the pollen analysis of clay or clay-rich sediments is that of producing samples with a sufficiently high density of pollen grains for valid analysis to be undertaken. If the sediment sample is not prepared well, pollen grains are sparse and obscured by inorganic material, and counting becomes a long and arduous task. Conventionally, standard preparation methods for organic-rich sediments (Faegri & Iversen, 1975) have been adapted for the preparation of inorganic sediments by the addition of a stage such as one involving dissolution of silica in hydrofluoric acid (HF). This frequently does not remove clay, and can badly damage pollen. Two main methods of preparation have been proposed to overcome these problems. Specific-gravity separation (Brande, 1976) appears to influence pollen spectra resulting in the over- or under-representation of certain taxa; there are too many inherent variables which influence the final pollen spectra, and so the method should be used with caution. A more recently proposed method involves the use of sodium pyrophosphate ($Na_4P_2O_7$) to deflocculate the clay, followed by sieving through fine mesh sieves (5 to 15 µm) to remove the deflocculated clay (Cwymar, 1977; Cwymar et al., 1979). Although this method is effective and greatly improves the efficiency of pollen analysis of clay-rich sediments, the preparation is a lengthy and delicate one (D. Stewart, pers. comm.). An adaption of this method overcomes this disadvantage (Bates et al., 1978). The deflocculated clay is removed by centrifuging rather than by sieving. This method follows standard preparation procedures (Faegri & Iversen, 1975) with $Na_4P_2O_7$ treatment(s) undertaken immediately prior to and, in some cases, after HF treatment. Pollen does not appear to be chemically damaged by the $Na_4P_2O_7$, nor is pollen lost during centrifuging (Bates et al., 1978).

It is considered that this latter method may be of value in the preparation, for pollen analysis, of the lower portions of cores such as MC-80. Since it was planned to sample other cores from nearby, it would be interesting to assess this method.

Prior to the HF treatment, all the samples from the sub-peat clay in the Flanders Moss core were divided into two parts: (a) to be treated twice with $Na_4P_2O_7$, and (b) to be stored in water and prepared in the standard fashion. After each $Na_4P_2O_7$ treatment the supernatents were examined for the presence of pollen grains. Although a few grains were present after the first centrifuging, the supernatents contained essentially no pollen. The proportion of these grains to the total pollen count is probably much less than 0.1%. During pollen counting the state of the grains was recorded, and the time required to count a normal quantity of pollen (average 550 grains per sample) and measure an average of 57 Gramineae grain sizes was recorded. This value is presented as a rate of minutes per 100 grains.

The results are presented in Figure A.1.1. The general spectral trends are reproduced in a similar manner whether treatment with $Na_4P_2O_7$ was undertaken or not. The difficulty in assessing these data is that the spectra are dominated by Gramineae values, and thus the other taxa generally have values of less than 5%. The most noticeable feature, however, is that the Gramineae values are very similar, there being only an average difference of c. 1% in 73 to 83%. This difference must be within the probable range of counting error.

The main difference between the treatments is that the samples treated with $Na_4P_2O_7$ took consistently longer to count than those not treated. This is due to the grains being more severely damaged by $Na_4P_2O_7$ treatment; in all the samples, fragments of pollen grains were more common after treatment, and although this is the most common form of damage, corrosion, folding and crumpling also appear to be more common.

It must be stressed that the experiment has been undertaken using a very small sample, neither the pollen spectra nor the sediment type being varied substantially. Although the treated samples are "cleaner" than the untreated samples, the disadvantage of increased grain damage makes this method of preparation unsuitable for sediments with abundant pollen. Where pollen is sparse, however, the advantages obtained by removing the clay efficiently are probably greater than the disadvantages of increased damage to pollen.

APPENDIX 2

Terminology of the Troels-Smith sediment description as used in this thesis

The use of this terminology is discussed in Troels-Smith (1955), Tooley (1978, pp.10 ff.) and Birks & Birks (1980, pp.39 ff.). To standardize descriptions, the scheme for the description of sediments proposed by Troels-Smith (1955) has been used for most of the cores or sections of cores for which pollen analysis has been undertaken. The scheme characterises the unconsolidated deposits in terms of the physical nature of the deposits, the constituent elements of the deposit, and the degree of humification of the organic elements. Although the scheme is designed for field description of sediments, the descriptions presented in this thesis were made in the laboratory.

The stratigraphical descriptions given in this thesis are presented in standardized format. For each core, each stratum identified is assigned a number (T.S. 1, 2 etc., Troels-Smith unit 1, 2 etc.). The heights of the unit base and top are given in m or mm above or below a local datum point or level (usually the base of the peat or the core). The Troels-Smith formulae list the following properties (note that only the properties used in this thesis are described here):

nig., nigror, degree of darkness, 0 to 4, very light to very dark.

strf., stratificio, degree of stratification, 0 to 4, homogeneous through coarsely layered to very finely layered.

elas., elasticatis, degree of elasticity, i.e. the ability to regain shape after deformation, 0 to 4, non-elastic to highly elastic.

sicc., siccitas, degree of dryness, 0 to 4, pure water to air-dry sediment.

colour and structure, informal descriptions given in this thesis.

lim. sup., lim. inf., limes superior, limes inferior, upper and lower boundary, degree of sharpness measured of a five-point scale, 0 to 4, very diffuse (over 10 mm) to very sharp (less than 0.5 mm). The measured thicknesses of the boundaries are also given. Note that the lim. sup. of one unit is the lim. inf. of the unit above.

humo., humositas, degree of humification, 0 to 4, unhumified to very humified.

calc., calcareousness, 0 to 4. This property is used only occasionally in this thesis.

The following constituent elements are used in the Troels-Smith description presented in this thesis:

Sh, Substantia humosa, humous substance; completely disintegrated organic material.

Turfa, peat; mainly formed from the underground parts of plants. Three main types are recognised:

Tb, Turfa bryophytica, moss peat, in some cases identified as TbSphagni (Turfa Sphagni, Sphagnum peat);
Tl, Turfa lignosa, wood peat;
Th, Turfa herbacea, herbaceous plant peat.

Detritus consists of above ground parts of plants not directly attached to roots. Three main types are recognised:
Dh, Detritus herbosus, fragments (over 2 mm in size) of herbaceous plants, in some cases identified as DhPhragmiti (Phragmites detritus) or DhEriophori (Eriophorum detritus).

Dl, Detritus lignosus, fragments (over 2 mm in size) of wood and bark, in some cases identified as DlCallunae (Calluna fragments).

Dg, Detritus granosus, small (0.1 to 2 mm) wood and herbaceous plant fragments.

Other constituent organic elements, often occurring as accessories, are rami (branches), in some cases identified as *rami Betulae* or *rami Callunae* (*Betula* or *Calluna* branches), *cortex* (bark), and *lignum* (wood). Thickness of branches (*rami*) is denoted by I (less than 5 mm) to IV (greater than 50 mm).

Inorganic constituent elements are:

As, *Argilla steatodes*, clay (less than 0.002 mm);

Ag, *Argilla granosa*, silt (0.002 to 0.06 mm);

Ga, *Grana arenosa*, fine sand (0.06 to 0.6 mm);

Gg, *Grana glareosa*, small to medium gravel (greater than 2 mm in size) in some cases identified as Gg (min.), *Grana glareosa* (*minora*), less than 6 mm, and Gg (maj.), *Grana glareosa* (*majora*), greater than 6 mm in size.

Each constituent element is recorded as either (1) a main component, on a five-point scale of 1 (25% of the stratum comprises that element) to 4 (100%), with + denoting minor presence, or (2) an accessory element, which may be important, but does not occur commonly. The accessory elements are expressed outside the sum of the main components, and placed in square brackets in the formulae.

The degree of humification of the peat (*turfa*) constituent elements is denoted, on a four-point scale, 0 (slightly humified or unhumified) to 4 (very humified) by a superscript number in the formulae. Sh is very humified (4), and the humification of the detritus elements is minimal (0).

The final statement in each formula presented here is a simplified verbal description of the stratum being described.

A P P E N D I X   3

LONG TABLES

Table A.3.1 I.G.S. core from Linwood Moss; IGS-LMP-80: results of the Troels-Smith analysis. The height given are over core base, with the bulk sample excluded

Unit No.	Height (mm)	Troels-Smith analysis
10	900 to 1310	nig. 4, strf. 0-1, elas. 1, sicc. 3 colour: very dark brown to black, darkening to black on exposure to air structure: fine- to coarse-grained granular lim. sup. top of core, lim. inf. 4 humo. 3 Sh2, $Th^2$1, $Tb^3$1, Dh+, Dl+, anth.+, with occasional layers (to 10 mm thick) of $Th^2$2, Dh2, rami Betulae II+, rami Callunae III+ "Dark herb and moss peat with some detritus"
9	860 to 900	nig. 0, strf. 0, elas. 0, sicc. 3 colour: light grey structure: fine- to medium-grained granular lim. sup. 4, lim. inf. 4 humo. 0 Ag2, As1, Ga1, Gg(min)+, Dg+ "Light grey clayey silt with some sand".
8	760 to 860	nig. 4, strf. 0, elas. 1, sicc. 3, colour: black structure: very fine-grained massive lim. sup. 4, lim. inf. 0 over 25 mm humo. 3 Sh2, $Th^3$1, Dg1, Tl^2+, [anth. 1] "Very dark, decomposed herb peat"
7	610 to 760	nig. 4, strf. 3, elas. 1, sicc. 3 colour: black structure: fine- to coarse-grained massive lim. sup. 0 over 25 mm, lim. inf. 4 humo. 2-3 Sh1, Dh1, Dl(cortex et rami)1, $Th^3$1, $TbSphagni^2$+, [anth.1] "Very dark, bedded herb and wood detritus peat"
6	480 to 610	nig. 4, strf. 1, elas. 1, sicc. 3 colour: black structure: fine-grained massive lim. sup. 4, lim. inf. 1 over 10 mm humo. 3 Sh1, Dh1, Dl(cortex et rami)1, $Th^3$1, $TbSphagni^2$+, [anth.1], [rami Betulae III 1] "Very dark herb and wood detritus peat"

Table A.3.1 (continued)

Unit No.	Height (mm)	Troels-Smith analysis
5	440 to 480	nig. 4, strf. 1, elas. 0, sicc. 3 colour: black structure: fine-grained massive lim. sup. 1 over 10 mm, lim. inf. 1 over 10 mm humo. 2-3 Sh1-2, $Th^2$2, Dl+-1, anth.+ "Very dark herb peat"
4	420 to 440	nig. 4, strf. 2, elas. 1, sicc. 3 colour: black structure: coarse-grained granular lim. sup. 1 over 10 mm, lim. inf. query, junction of cores humo. 2-3 $Th^2$2, Sh1, Dl1, rami Betulae II et cortex + "Very dark herb peat with wood detrital fragments"
3	110 to 420	nig. 2-3, strf. 1-2, elas. 2-3, sicc. 3-4 colour: medium-dark brown, turning darker on exposure to air structure: fine-grained massive to coarse-grained granular lim. sup. query, junction of cores, lim. inf. 0 over 20 mm humo. 1-2 Sh1, $Th^2$1, Dl2, anth.+, Dh+, [rami et cortex 1] "Wood detritus and herb peat, with large wood fragments in parts"
2	40 to 110	nig. 3, strf. 0-1, elas. 2-3, sicc. 3-4 colour: very dark brown structure: fine-grained granular lim. sup. 0 over 20 mm, lim. inf. 4 humo. 2-3 Sh2, Th^{3-4}2, Dl(cortex)+, [anth.1] "Dark-coloured herb peat"
1	0 to 40	nig. 0, strf. 0, elas. 0, sicc. 3 colour: grey structure: fine- to medium-grained granular lim. sup. 4, lim. inf. base of core humo. 0, calc, 0 As1, Ag2, Ga1, Gg(min)+, Dg+ "Grey clayey silt with occasional sand and fine gravel"

Table A.4.1 Moss Cottage, Linwood Moss; MC-80: tentative identification of pre-Quaternary spores from Local Pollen Zone MC-80.1.

Spore	Description	Tentative identification and references
A	Subtriangular; trilete, with trilete rays not extending to the border, which in some cases appears to be absent; maximum recorded equatorial diameter is *c.* 36 µm and body diameter is *c.* 25 µm	Resembles certain species of genus *Densosporites* (Sullivan & Marshall, 1966; Smith & Butterworth, 1967), such as *D. hispidus* (Felix & Burbridge, 1967), *D. vulgaris* (Neeves, 1961) or *D. striatiferus* Hughes & Playford, 1961 (Playford, 1962)
B	Diameter *c.* 40 µm; stains darkly, giving the impression of being heavy, and making identification difficult	Resembles certain *Densosporites* species, such as *D. sphaerotriangularis* Kosanke, 1950 (Smith & Butterworth, 1967)
C	Borderless trilete spore with distinctive ornamentation	Resembles *Anapienlatisporites concinnus* (Playford, 1962)
D	Unclear trilete spore	Resembles *Knoxisporites inconspicuus* (Felix & Burbridge, 1967)

Table A.4.2 Moss Cottage, Linwood Moss; MC-80: results of the Troels-Smith analysis. Heights given are below the core top (surface)

Unit No.	Height (m)	Troels-Smith analysis
16	0.20 to 0.35	nig. 3, strf. 0, elas. 0, sicc. 3 colour: medium-dark brown structure: fine-granular massive lim. sup. top of core, lim. inf. 1 over 3 mm humo. 3-4 Sh3, $Tb^{3}1$, Dl+, $Th^{3}+$, anth.+ "Highly decomposed moss peat"
15	0.35 to 0.64	nig. 2, strf. 0, elas. 1-2, sicc. 3 colour: light to medium brown structure: coarse-grained granular lim. sup. 1 over 3 mm, lim. inf. 0 over 20-40 mm humo. 1-2 $TbSphagni^{1}3$, $Th^{1-2}1$, anth.+ "Light coloured _Sphagnum_ peat"
14	0.64 to 0.92	nig. 3, strf. 0, elas. 1, sicc. 3 colour: medium to dark brown structure: coarse-grained granular lim. sup. 0 over 20-40 mm, lim. inf. 1 over 10 mm humo. 2 $TbSphagni^{2}2$, Sh1-2, $Th^{2-3}+-1$, DlCallunae+, [anth.1] "Slightly decomposed _Sphagnum_ peat"
13	0.92 to 1.05	nig. 3-4, str. 0, elas. 0, sicc. 3 colour: dark brown structure: coarse-grained granular lim. sup. 1 over 10 mm, lim. inf. 1 over 10 mm humo. 2 $Th^{2}1-2$, DlCallunae1, $TbSphagni^{2}1$, Sh+-1, [anth.1] "Dark coloured herb and moss peat"
12	1.05 to 1.40	nig. 4, strf. 0, elas. 0, sicc. 4 colour: very dark brown turning to black on exposure to air structure: fine- to medium-grained granular lim. sup. 1 over 10 mm, lim. inf. 0 over 15 mm humo. 1-2 Sh2, $TbSphagni^{1}1$, DlCallunae1, $Th^{2}+$, DhEriophori+-1 , [anth. 1] "Dark coloured _Sphagnum_ and _Calluna_ peat"

Table A.4.2 (continued)

Unit No.	Height (m)	Troels-Smith analysis
11	1.40 to 1.70	nig. 4, strf. 0, elas. 0, sicc. 3-4 colour: black structure: fine-grained granular lim. sup. 0 over 15 mm, lim. inf. base of core section humo. 2 Sh2, Th^{2}1-2, Dl+-1, TbSphagni$^{2-3}$+, anth.+, DhEriophori+ "Very dark *Sphagnum* moss and herb peat"
10	1.70 to 1.75	Not recorded; 50 mm section removed for radiocarbon analysis
9	1.75 to 1.85	nig. 4, strf. 0, elas. 0-1, sicc. 3 colour: dark brown to black structure: fine- to medium-grained granular with some coarse grains lim. sup. not defined, lim. inf. not defined: both samples above and below this unit have been removed for radiocarbon analysis humo. 2-3 Th$^{2-3}$2, Sh1, Dl1, anth.+, rami II + at 1.84 m, TbSphagni^{2}+ "Very dark herb peat with woody detrital material"
8	1.85 to 1.95	Not recorded; 100 mm section removed for radiocarbon analysis
7	1.95 to 2.20	nig. 4, strf. 0, elas. 0, sicc. 3 colour: dark brown to black structure: fine- to medium-grained granular with some coarse grains lim. sup. not defined, lim. inf. base of core section humo. 2-3 Sh2, Th^{3}1, Dl1, anth.+, Tb^{2}+ "Dark coloured herb and woody detrital peat"
6	2.20 to 2.34	nig. 4, strf. 0, elas. 0, sicc. 3 colour: dark brown to black structure: fine- to medium-grained granular with some coarse grains lim. sup. top of core, lim. inf. 0 over 20 mm humo. 2-3 Sh2, Th^{3}1, Dl1, Tb^{2}+, Dh+, anth.+, [rami II-IV 1] "Very dark partially decomposed woody herb peat"

Table A.4.2 (continued)

Unit No.	Height (m)	Troels-Smith analysis
5	2.34 to 2.47	nig. 4, strf. 0, elas. 0, sicc. 3 colour: very slightly greyish dark brown structure: fine-grained massive lim. sup. 0 over 20 mm, lim. inf. 0 over 15 mm humo. 3-4 Sh3, $Th^{3}1$, Dl+, Dh+, anth.+ "Well decomposed herb peat"
4	2.47 to 2.81	nig. 2, strf. 0-1, elas. 0, sicc. 3 colour: brownish light grey structure: fine-grained massive lim. sup. 0 over 15 mm, lim. inf. 0 over 20 mm humo. 0-1, calc. 0 As3, Ag1, Ga+, Sh+, Dh+, Dl+, anth.+, rami II-III+ "Slightly bedded brownish grey silty clay with some organic detritus"
3	2.81 to 2.88	nig. 1-2, strf. 0, elas. 0, sicc. 3 colour: slightly green-brown grey with brown patches structure: coarse- to medium-grained massive lim. sup. 0 over 20 mm, lim. inf. 2 over 5 mm humo. 0-1, calc. 0 Ag2, As1, Ga1, Sh+, anth.+, [Dh1, in places] "Medium-grey clayey and sandy silt with organic detritus"
2	2.88 to 2.95	nig. 1, strf. 0, elas. 0, sicc. 3 colour: slightly pink light grey with brown patches structure: fine-grained massive lim. sup. 2 over 5 mm, lim. inf. 2 over 2.5 mm humo. 0, calc. 0 As3, Ag1, Dh+, Dl+ "Light-grey silty clay with occasional organic detritus"
1	2.95 to 3.20	nig. 1, strf. 0, elas. 0, sicc. 2-3 colour: slightly yellow-brown light grey with darker brown patches structure: massive lim. sup. 2 over 2.5 mm, lim. inf. base of core humo. 0, calc. 0 Ag2, As1, Ga1, Dg+ "Light-grey clayey and sandy silt with occasional organic detritus"

Table A.5.1 Flanders Moss; FM-81: results of the Troels-Smith analysis for the section of core containing the basal part of the peat. Heights given are above and below the peat base.

Unit No.	Height (mm)	Troels-Smith analysis
3	300 to 40	nig. 0, strf. 0, elas. 0, sicc. 2-3 colour: very dark brown to black structure: fine- to medium-grained granular, with occasional coarse fragments lim. sup. not determined, lim. inf. 2-1 humo. 3-4 (Th^3 or Dh)2, Sh1, Dl1, [rami I-II 1] "Very dark woody herb peat"
2	40 to 0	nig. 4, strf. 0, elas. 0, sicc. 2-3 colour: very dark brown to black structure: fine- to coarse-grained granular lim. sup. 2-1, lim. inf. 0 over 30 mm humo. 3-4 Sh2, Th^{2-3}1, DhPhragmiti1, [anth.+-1] "Very dark, decomposed Phragmites peat"
1	0 to -400	nig. 1, strf. 0-1, elas. 0, sicc. 3 colour: slightly blue light grey, turning to orange-grey on exposure to air, with brown patches structure: fine-grained massive lim. sup. 0 over 30 mm, lim. inf. base of core humo. 0-1, calc. 0 As2, Ag1, Dh1, Ga+ "Light-grey silty clay with some organic detritus"

Table A.6.1 Linwood Moss Wood, Linwood Moss; LMW-80: results of the Troels-Smith analysis. The heights given are above and below the peat base.

Unit No.	Height (m)	Troels-Smith analysis
5	c.1.00 to 0.095	nig. 4, strf. 1, elas. 0-1, sicc. 3 colour: medium-brown, darkening to black on exposure to air structure: mostly medium-grained massive, with occasional coarse-grained layers lim. sup. top of core, lim. inf. 1 over 10 mm humo. 2-3 $Th^{3}2$, $Tb^{2-3}1$, Sh1, Dl+, rami I-II+, DlCallunae+, [DhEriophori1-3, in occasional layers], [anth.+-1] "Brown herb peat with occasional woody fragments and layers of <u>Eriophorum</u> remains"
4	0.095 to 0.025	nig. 4, strf. 0, elas. 0-1, sicc. 3 colour: medium to dark-brown, darkening to black on exposure to air structure: fine-grained massive with occasional coarse fragments lim. sup. 1 over 10 mm, lim. inf. 2 over 1.5 mm humo. 3 Sh3, $Th^{3}1$, Dl+, anth.+, Dg+ "Brown decomposed herb peat"
3	0.025 to 0	nig. 3-4, strf. 0, elas. 0-1, sicc. 3 colour: slightly greyish dark brown structure: fine-grained massive lim. sup. 2 over 1.5 mm, lim. inf. 2 over 2 mm humo. 3-4 Sh2, $Th^{3}1$, Ag1, Dg+, Dl+, anth.+, $Tb^{2-3}+$, Ga+ "Dark brown silty decomposed herb peat"
2	0 to -0.013	nig. 1, strf. 0, elas. 0-1, sicc. 3 colour: very light sandy brown clay structure: fine-grained massive with coarse-grained lenses lim. sup. 2 over 2 mm, lim. inf. 0 over 20 mm humo. 0, calc. 0 As2, Ag1, Ga1, Dg+ "Light-grey sandy silty clay"
1	-0.013 to -0.025	nig. 1, strf. 0, elas. 0-1, sicc. 3 colour: very light slightly blue grey, turning to slightly orange-brown on exposure to air structure: fine-grained massive lim. sup. 0 over 20 mm, lim. inf. base of core humo. 0, calc. 0 As3, Ag1, Dg+ "Light-grey silty clay"

Table A.7.1 Linwood Moss, Site LM-13; section of core containing the basal boundary of the peat: results of the Troels-Smith analysis. Heights are above the base of the core.

Unit No.	Height (mm)	Troels-Smith analysis
3	450 to 160-170	nig. 4, strf. 0, elas. 0, sicc. 3 colour: medium-dark brown, darkening on exposure to air structure: granular lim. sup. top of core, lim. inf. 4, not horizontal humo. 2, calc. 0 Sh2, TbSphagni^{3}1, Tl1, Th^{1}+, Dl+ "Dark, moderately decomposed wood and moss peat"
2	160-170 to 50-70	nig. 1, strf. 0, elas. 0, sicc. 3 colour: very light brown, turning slightly yellow on exposure to air structure: massive lim. sup. 4, lim. inf. 0 over 20 mm humo. 0, calc. 0 Ag2, As1, Ga1, Gg(maj)+, Dh+ "Light coloured clayey, sandy silt"
1	50-70 to 0	nig. 1, strf. 0, elas. 0, sicc. 3 colour: very light brown, turning slightly yellow on exposure to air structure: massive lim. sup. 0 over 20 mm, lim. inf. base of core humo. 0, calc. 0 As2, Ag1, Ga1 "Light brown silty, sandy clay"

<u>Table A.7.2</u> Linwood Moss, Site LM-14; section of core containing the basal boundary of the peat: results of the Troels-Smith analysis. Heights are above the base of the core.

Unit No.	Height (mm)	Troels-Smith analysis
5	450 to 200	nig. 4, strf. 0, elas. 0, sicc. 3 colour: medium brown, darkening on exposure to air structure: granular lim. sup. top of core, lim. inf. 1 over 10 mm humo. 2, calc. 0 Sh2, $Th^1$2, Dl+, Tb^2+ "Dark, moderately decomposed herb peat"
4	200 to 190	nig. 3, strf. 0, elas. 0, sicc. 3 colour: medium-dark brown structure: fine-grained granular lim. sup. 1 over 10 mm, lim. inf. 4 humo. 2, calc. 0 Sh2, $Th^1$2, Dl+, Ag+, As+, Ga+ "Brown, moderately decomposed herb peat with occasional wood fragments and inorganic grains"
3	190 to 150	nig. 1, strf. 1, elas. 0, sicc.3 colour: very light green-brown structure: granular lim. sup. 4, lim. inf. 0 over 25mm humo. 0, calc. 0 Ag2, As1, Ga1, Th^1+, Dh+ "Light coloured clayey, sandy silt with occasional herb fragments"
2	150 to 100	nig. 1 & 4, strf. 0, elas. 0, sicc. 3 colour: light grey-brown and some orange-brown structure: coarse-grained granular - inorganic sediment with large fragments of peat lim. sup. 0 over 25 mm, lim. inf. 0 over 10 mm humo. 0 (inorganic component) & 2 (organic component), calc. 0 Inorganic component: As1, Ag1, Ga1, Gg(maj)1, Th^1+, Dh+ Organic component: Sh2, $Th^1$2, Ag+, Dl+ "Light coloured, poorly sorted inorganic fine- to coarse-grained sediment with large fragments of moderately decomposed herb peat"
1	100 to 0	nig. 1, strf. 1, elas. 0, sicc. 3 colour: very light brown structure: granular lim. sup. 0 over 10 mm, lim. inf. base of core humo. 0, calc. 0 Ga2, As1, Ag1, Th^1+, Ga+ "Light coloured, clayey, silty fine sand"

Table A.12.1 The Great Bend, River Irvine: faunal list. For bed titles see Chapter 12.2. Key: see notes below the table.

	Basal gravel		Gravelly sand		Shelly sand	
	this study[1]	Bertie (1974)[2]	this study	Bertie (1974)	this study	Bertie (1974)
Bivalvia:						
Cardium sp.	-	p	-	p	-	-
Chlamys sp.	-	-	-	-	r	p
Donax vittatus (da Costa)	r	p	r	p	s	p
Dosinia exoleta (Linneaus)	c	p	c	-	-	-
Ensis sp.	s	-	c	-	c	-
Laevicardium crassum (Gmelin)	vc	p	-	-	-	-
Lutraria lutraria (Linneaus)	c	-	-	-	-	-
Montacuta ferruginosa (Montagu)	-	p	-	-	-	-
Mytilus edulis (Linneaus)	-	-	-	-	r	-
Ostrea edulis (Linneaus)	r	-	r	-	-	-
Parvicardium scabrum (Phillipi)	-	p	-	p	-	-
Spisula subtruncata (da Costa)	c	p	a	p	a	p
Venerupis rhomboides (Pennant)	vc	p	s	p	-	-
Venus (Chamelea) striatula (da Costa)	c	p	c	p	c	p
Venus aff. (Timoclea) ovata (Pennant)	-	-	-	p	-	-

Table A.12.1 (continued)

	Basal gravel		Gravelly sand		Shelly sand	
	this study[1]	Bertie (1974)[2]	this study	Bertie (1974)	this study	Bertie (1974)
Venus aff. (*Venus*) *verrucosa* (Linneaus)	-	p	-	-	-	-
Venus (*Clausinella*) *fasciata* (da Costa)	-	p	-	-	-	-
Gastropoda:						
Buccinium sp.	-	p	-	-	-	-
Clathrus sp.	-	p	-	-	-	-
Cypraea sp.	-	p	-	-	-	-
Gibbula magus (Linneaus)	c	p	s	p	s	p
Littorina sp.	-	p	r	p	c	-
Mangelia sp.	-	p	-	-	-	-
Natica alderi (Forbes)	s	p	c	p	c	p
Patella vulgata	-	p	-	-	r	-
Rissoa sp.	-	p	-	p	-	-
Echinoidea:						
Echinocyanus pusillus (O. F. Müller)	s	-	-	-	-	-

1 r = rare (1 to 5 specimens found); s = sparse (6 to 10 specimens found); c = common; vc = very common; a = abundant

2 p = present

Table A.12.2 The Great Bend, River Irvine; Lithothamnium analysis: Site 1, raw data. For discussion of the factors recorded, see Chapter 12.4. See notes at end of this table for abbreviations used.

Shape		Dimensions (mm)			Branching	Damage			Other Comments
Orig.	Rev'd	L	I	S		Break.	Abras.	Whole.	
D	D	20	17	12	II/III	1	1	W	
E	E	44	28	27	III	3	2	W	
E	E	25	19	15	III/IV	3	3	W	
E	E	25	11	12	II/III	2	2	P	
D	D	23	18	12	III/IV	3	3	W	almost massive
ED	E	23	14	9	III	3	4	W	
E	E	11	9	8	III	3	3	P	not recently broken
ED	D	17	15	10	II/III	3	2	?	
D	D	17	10	5	II/III	3	3	?	
ED	E	28	22	15	II/III	5	5	W	
ES	E	30	23	21	III/IV	3	4	W	massive with some fine branching
E	E	34	27	23	III/IV	4	4	W	damage overgrown by secondary Melobesia
ED	E	33	22	17	III/IV	3	5	W	very worn and bleached
E	E	19	13	13	III/IV	4	5	?	
D	D	21	17	11	II/III	3	3	W	
D	D	19	15	11	III/IV	3	5	W	very abraded - difficult to see degree of branching
D	D	14	13	7	III	?	4	?	extensive algal borings
D	D	14	10	4	II	3	3	P	
D	D	14	12	5	II	5	5	?	bored
D	D	15	11	6	II/III	3	5	P	
D	D	24	19	14	IV	?	5	W	becoming massive
E	E	24	17	16	IV	?	5	W	secondary Melobesia
E	E	30	18	16	III	2	3	?W	most breaks are recent
ED	E	35	21	13	II/III	4	4	W	

Table A.12.2 (continued)

Shape		Dimensions (mm)			Branching	Damage			Other Comments
Orig.	Rev'd	L	I	S		Break.	Abras.	Whole.	
ED	E	18	12	10	III	5	4	?W	
D	D	17	16	8	II/III	4	4	P	with serpulid tubes
D	D	17	17	6	II/III	5	4	?	
S	D	50	44	36	IV	4	5	W	secondary <u>Melobesia</u> present
E	E	41	26	25	IV	?	5	W	ditto plus serpulid tubes
E	E	19	11	9	II/III	2	3	P	main damage is recent
D	D	15	10	5	II/III	2	5	P	
D	D	28	20	12	III	4	4	?W	
D	D	13	10	5	II/III	3	3	P	
E	E	24	15	13	III/IV	5	5	W	
ED	E	22	13	11	III	5	4	?W	
ES	E	50	39	33	IV	5	5	W	secondary <u>Melobesia</u> present
E	E	36	24	19	IV	5	5	W	
D	D	19	14	9	II/III	3	3	P	
ED	E	15	10	10	II/III	2	2	P	
ED	D	17	14	8	III	2	2	P	
D	D	14	13	5	II/III	2	4	W	
D	D	12	12	4	II	5	3	P	
D	D	18	16	12	III	5	5	?W	
D	D	16	10	8	II	2	4	P	
E	E	17	12	10	III	3	3	?W	with algal borings
ES	E	16	13	13	III	2	4	P	
D	D	16	15	8	III	1	1	W	
D	D	13	10	5	II/III	5	2	P	
E	E	14	11	10	III/IV	5	4	?W	
E	E	19	9	7	III	4	4	P	

Abbreviations used for Table A.12.2 and A.12.3:

Shape: E = ellipsoidal, D = discoidal, S = spheroidal, and intermediate forms are denoted by ED etc.

Dimensions: L, I and S represent the three axes mutually perpendicular (see Chapter 12.4)

Branching: II to IV denotes increasing complexity (see Chapters12.4)

Damage: 1 to 5 denotes increasing severity of damage, and degree of wholeness (W, ?W, P, ?P and ?) are as explained in Chapter 12.4

<u>Table A.12.3</u> The Great Bend, River Irvine; <u>Lithothamnium</u> analysis: site 2, raw data. See Table A.12.2 for explanation of abbreviations used.

Shape		Dimensions (mm)			Branching	Damage			Other Comments
Orig.	Rev'd	L	I	S		Break.	Abras.	Whole.	
DS	E	37	32	29	IV	3	2	W	
E	D	43	39	27	IV	1	2	W	
D	D	42	32	19	III/IV	5	4	?W	
D	D	28	25	10	III	2	2	?W	
D	D	31	29	24	III/IV	3	2	W	some recent damage
D	D	33	33	21	IV	1	1	W	some recent damage
S	E	25	22	22	II/III	2	1	W	
D	D	40	39	23	IV	2	5	W	almost massive
E	E	35	20	18	III	5	5	W	
D	D	31	25	16	IV	5	5	W	almost massive
E	E	37	21	16	IV	5	4	W	much recent damage
D	E	36	30	27	III/IV	5	2	W	some recent damage
D	D	28	24	18	III/IV	?	5	W	
ED	D	23	22	16	II/III	2	1	W	
E	D	25	20	13	II/III	2	3	W	
ED	D	27	24	14	III	2	2	W	
ED	D	29	20	10	II/III	4	5	W	
E	D	27	19	9	II/III	5	5	?P	
ED	D	22	17	9	II/III	3	2	W	
D	D	18	16	12	II/III	2	1	?W	
D	D	22	18	9	II/III	3	1	?P	
E	E	31	16	15	III/IV	5	5	W	
E	E	19	14	14	II/III	2	1	W	
E	E	20	13	12	II/III	2	1	W	
E	E	26	14	10	III/IV	3	2	W	almost massive
ED	D	32	22	13	III	5	5	?W	very worn
D	E	17	16	13	IV	5	5	W	

Table A.12.3 (continued)

Shape		Dimensions (mm)			Branching	Damage			Other Comments
Orig.	Rev'd	L	I	S		Break.	Abras.	Whole.	
ED	D	25	16	7	II	?	5	?P	
S	D	18	18	14	II/III	1	1	P	
E	D	21	18	14	IV	2	3	?W	
D	D	17	16	9	III	5	4	P	
D	D	19	15	8	III	3	5	P	
D	D	25	20	14	III/IV	2	5	?W	secondary Melobesia
D	D	24	16	7	III	4	4	W	
S	D	12	12	10	III/IV	?	5	?W	
ED	D	15	12	7	IV	3	5	?	
ED	D	17	11	6	III/IV	3	5	?W	
E	D	19	14	10	III	4	5	?	
E	E	10	11	9	III/IV	3	5	?	with serpulid tubes
E	E	14	10	10	II	3	5	P	

Table A.13.1 Shewalton Moss: results of the auger survey

Site	Surface (m A.O.D.)	Base (m A.O.D.)	Peat thickness (m)	Comments, including basal sediment, if recovered
2	13.45	10.75	2.70	base reached
3	14.50	11.40	3.10	base reached
4	12.84	8.94	3.90	sand
5	16.20	12.40	3.80	base reached
6	14.52	9.82	4.70	base reached
7a	14.43	13.93	0.50	100 mm clay, ?related to nearby stream
7b	14.29	11.69	2.60	50 mm sand
8	15.43	9.37	6.06	100 mm blue-brown silty sand
9	15.57	9.41	6.16	100 mm blue sandy clay
10	14.68	9.33	5.35	150 mm light yellow-brown silty clay + occasional sand
11	14.56	10.66	3.90	base reached
12	14.00	9.70	4.30	base reached
13	13.18	10.73	2.45	sand
14	15.43	9.03	6.40	150 mm blue medium sand
15	unknown	?below 9.00	over 4.95	trial core in deep hollow; base not reached
16	15.80	11.10	4.70	base reached
17	18.39	12.89	5.50	100 mm white-brown medium sand
18	18.48	17.08	1.40	100 mm yellow-orange medium sand
19	17.73	13.03	4.70	base reached
20	15.71	9.01	6.70	100 mm white medium sand
21	15.41	8.33	7.08	base reached
22	15.15	8.45	6.70	fine sand
23	14.62	8.32	6.30	50 mm silty clay + occasional sand and fine gravel
24	14.05	7.95	6.10	50 mm blue silty clay
25	13.17	7.97	5.20	200 mm blue silty clay
26	12.48	7.83	4.65	100 mm blue silty clay
27	12.72	8.93	3.85	100 mm yellow-grey medium to coarse sand
28	13.04	9.39	3.65	100 mm blue silty clay over 10 mm blue sandy clay
29	13.28	9.68	3.60	150 mm blue silty clay, very plastic, coarser downwards to well-weathered rock fragments
30	15.92	7.72	8.20	100 mm blue silty clay
31	15.68	7.33	8.35	sand
32	15.89	7.49	8.40	sand
33	unmeasured c.14.5	?below 8.50	over 6.00	trial core near 48 ft spot height; base not reached

Table A.13.2 Shewalton Moss; electrical resistivity survey raw data. Arrays arranged approximately east-west. Abbreviations used: a = separation distance between electrodes; R = measured resistivity; ρ_a = apparent resistivity, calculated from the formulae given in Chapter 13.3; LP, E, W = Lee Partition, east and west sides of array. Most of the measurements are made using a Wenner array.

	a (m)	R (Ω)	ρ_a (Ω m)
Site 8			
	0.30	63.15	119.08
	0.60	32.70	123.33
	1.00	20.00	125.71
	2.00	9.04	113.58
	4.00	4.11	103.34
	8.00	1.74	87.50
	14.00	0.76	66.88
	20.00	0.44	54.69
	30.00	0.27	50.91
	40.00	0.21	52.80
Site 9			
	0.30	34.95	65.91
	0.60	19.80	74.67
	1.00	12.95	81.40
	1.00 LP,E	6.12	76.87
	1.00 LP,W	6.47	81.34
	2.00	7.69	96.67
	4.00	3.72	93.53
	6.00	2.18	82.03
	6.00 LP,E	1.13	85.23
	6.00 LP,W	1.05	79.20
	8.00	1.43	71.91
	12.00	0.78	58.83
	18.00	0.46	52.05
	18.00 LP,E	0.24	53.18
	18.00 LP,W	0.23	52.05
	22.00	0.37	51.66
	26.00	0.32	51.80
	30.00	0.28	52.80
	40.00	0.23	56.57
	40.00 LP,E	0.12	57.83
	40.00 LP,W	0.12	57.83

Table A.13.2 (continued)

	a (m)	R (Ω)	ρ_a (Ω m)
Site 10			
	0.30	38.90	73.35
	0.60	24.65	92.97
	1.00	17.00	106.86
	2.00	7.96	100.07
	4.00	4.18	104.97
	8.00	1.67	83.98
	14.00	0.76	66.44
	20.00	0.46	57.20
	30.00	0.28	52.80
	40.00	0.21	52.80
Site 11			
	0.30	33.20	62.61
	0.60	21.00	79.20
	1.00	14.30	89.89
	2.00	7.32	91.96
	4.00	3.33	83.60
	8.00	1.46	73.17
	14.00	0.70	61.91
	20.00	0.38	48.15
	30.00	0.24	45.63
	40.00	0.19	46.77
Site 12			
	0.30	30.35	57.23
	0.60	21.05	79.39
	1.00	14.60	91.77
	2.00	5.62	70.65
	4.00	2.94	73.92
	8.00	1.41	70.90
	14.00	0.71	62.22
	20.00	0.42	52.42
	30.00	0.23	43.37
	40.00	0.18	45.01

<u>Table A.13.3</u> Shewalton Moss; electrical resistivity survey: the derivation of limits for values of sediment porosity, pore-water content and water salinity in layers 1 and 2. Adapted from Bridges (1970, pp.8 & 13), Parasnis (1979, p.129-30), and D. W. Powell (pers. comm.). All values given are approximations.

Archie's Law: $\rho = \rho_o f^{-m} s^{-n}$

where: ρ_o = resistivity of the water contained in the sediment

f = porosity (volume fraction pores)

m = variable power, equal to 1.3 for loose Tertiary sediments; $m = 1.3$ is used here

s = fraction of pore space filled with water, assumed to be >30%

n = variable power, close to 2 for $s > 30\%$; $n = 2$ is used here

Values for layers 1 and 2 are suffixed $_1$ and $_2$ respectively

<u>Table A.13.3a</u> Sediment porosity and pore-water content

Assumptions:
(1) Layer 2 is equally or more compressed than layer 1, i.e. $f_1/f_2 \geqslant 1$
(2) Layer 1 is equally or less saturated than layer 2, i.e. $s_1/s_2 \leqslant 1$
(3) Salinity or clay content values of the water are constant throughout both layers, i.e. the water conductivity is constant

From Archie's Law:

$$\frac{\rho_2}{\rho_1} = \left(\frac{f_1}{f_2}\right)^m \left(\frac{s_1}{s_2}\right)^n = \underline{c}.\ 2.25$$ (from average values for 4 sites; Table 13.3)

assume $s_1/s_2 = 1$, then $f_1/f_2 = \underline{c}.\ 1.9$

As s_1/s_2 decreases, f_1/f_2 increases, i.e. layer is at least twice as porous as layer 2.

Table A.13.3b Pore-water salinity

Assumptions: (1) f_1/f_2 = c. 2; $f_1 = 0.5$

(2) s_1/s_2 is slightly less than 1; $s_2 = 1$

(3) $\rho_2 = 120$ (approximate average for 4 sites; Table 13.3)

For the lower layer:

$120 = \rho_o\ 0.25^{-1.3} \Rightarrow \rho_o = 20\ \Omega m$; equivalent to c. 0.13% NaCl in solution

For the upper layer:

$55 = \rho_o\ 0.5^{-1.3} \Rightarrow \rho_o = 22\ \Omega m$; equivalent to c. 0.13% NaCl in solution

Table A.13.3c Salinity differences in layers 1 and 2

Assumptions: (1) $s_1/s_2 = 0.5$

(2) $f_1/f_2 = 2$

(3) $\rho_o \propto 1/\sigma_o$, and $\sigma_o \propto$ salinity; where σ_o = conductivity

$$\frac{\rho_2}{\rho_1} = \frac{\sigma_{o1}}{\sigma_{o2}}\ 2^{1.3} 0.5^{2} \Rightarrow \frac{\sigma_1}{\sigma_2} = 1.2$$

Therefore the salinities of layers 1 and 2 are approximately equal.

Table A.13.5 Shewalton Moss; SM-81-II, section of core for which pollen analysis was undertaken: results of Troels-Smith analysis. Heights are given above the base of the core.

Unit No.	Height (m)	Troels-Smith analysis
3	0.55 to 0.39	nig. 4, strf. 0, elas. 1, sicc. 2-3 colour: medium brown darkening to black on exposure to air structure: fine-grained granular lim. sup. top of core, lim. inf. 0 over 15 mm humo. 2-3 $Th^2$2, Sh1, TbSphagni^{2}1, anth.+, rami+, Tb^2+, Dl+, Dh+ "Medium-brown herb peat with *Sphagnum* and various other detrital components"
2	0.39 to 0.12	nig. 4, strf. 0, elas. 1-2, sicc. 3 colour: medium to light brown, darkening to black on exposure to air structure: fine- to medium-grained granular lim. sup. 0 over 15 mm, lim. inf. 0 over 15 mm humo. 2 TbSphagni^{1}2, Sh1, $Tb^1$1, Th^2+ "Light-brown *Sphagnum* peat"
1	0.12 to 0	nig. 4, strf. 0, elas. 1-2, sicc. 3 colour: medium to light brown, darkening to black on exposure to air structure: fine granular lim. sup. 0 over 15 mm, lim. inf. base of core humo. 2-3 Sh1, $Th^2$2, Tb^2+, Dl+, Dh+ "Light-brown, moderately decomposed peat with occasional wood and herb detritus"

Table A.14.1 Dundonald Burn; DB-81: results of the Troels-Smith analysis. Heights are above the base of Unit T.S.1.

Unit No.	Height (m)	Troels-Smith analysis
7	0.66 to unmeasured level	nig. 1, strf. 0, elas. 0, sicc. 3 colour: orange-yellow brown structure: granular lim. sup. top of core, lim. inf. 4, level variable humo. 0, calc. 0 Ga2, As1, Ag1, Gg(maj)+, Gg+, Dh+ "Orange sand with occasional herb detritus"
6	0.62 to 0.66	nig. 2, strf. 0, elas. 0, sicc. 3 colour: dark, greyish-brown structure: granular lim. sup. 4, lim. inf. 4, both variable in level humo. 2 Th^{2}2, Sh1, Dl1, Tb^1+, Dh+, Ag+, Gg+, [anth. 1] "Herb peat with occasional silt and fine gravel"
5	0.47 to 0.62	nig. 3, strf. 1, elas. 0, sicc. 3 colour: medium brown, darkening on exposure to air structure: fine-grained granular lim. sup. 4, lim. inf. 2 over 2 mm, both variable in level humo. 3 Sh1-2, Dl1, Th^{2}1, Ag+-1, Dg+, [anth. +-2] "Bedded organic detritus containing some sand"
4	0.33 to 0.47	nig. 4, strf. 2, elas. 0, sicc. 3 colour: dark brown, darkening to black on exposure to air structure: fine- and medium-grained granular lim. sup. 2 over 2 mm, lim. inf. 0 over 10 mm, both variable in level humo. 3 Sh2, Dl1, Th^{2}1, Dh+, Ga+, Ag+, [anth. 1-2] "Dark, bedded organic detritus"
3	0.30 to 0.33	nig. 2-4, strf. 3-4, elas. 0, sicc. 3 colour: dark grey and dark brown, the latter darkening on exposure to air structure: very fine-grained granular lim. sup. 0 over 10 mm, lim. inf. 0 over 15 mm, both variable in level humo. 0 & 3, calc. 0 Sh1, As1, T(h?)^{3}1, Dl1, Dh+, Ag+ "Finely-horizontally-bedded clay grading upwards into organic matter"

Table A.14.1 (continued)

Unit No.	Height (m)	Troels-Smith analysis
2	0.05 to 0.30	nig. 1, strf. 1, elas. 0, sicc. 3 colour: variable, mostly green- to blue-grey structure: very fine- to very coarse-grained granular lim. sup. 0 over 15 mm, lim. inf. base of core humo. 0, calc. 0 As1, Ag1, Ga1, Gg1, Gg(maj)+, Dl+, Dh+ "Grey clay with weathered boulders"
1	0 to 0.05	"Hard iron-cemented gravel"

Table A.17.1 Valley of the River Irvine: extracted data from commercial bore logs from sites at which marine clay may be present.

(1) NS 3695 3780: several boreholes in valley bottom containing laminated sand gravel and clay (possibly river deposits). From c. 11 m A.O.D. to c. 4 m A.O.D.

(2) NS 3705 3790: a bore log contains the following entry:

14.75 m A.O.D.: "loose coarse to fine brown SAND with some fine gravel and bands of soft, brown laminated silty clay"

10.75 m A.O.D.: "firm dark grey laminated silty CLAY with partings of fine grey sand"

to at least 9.75 m A.O.D.

(3) NS 3715 3785: a bore log contains the following entry:

16.5 m A.O.D.: "firm to stiff mottled brown laminated silty CLAY with partings of fine sand and silt and containing vertical fissuring"

15.625 m A.O.D.: "stiff dark grey laminated silty CLAY with partings of sand and silt"

to at least 13.75 m A.O.D.

(4) NS 379 375: three bore logs contain the following entries:

(4.1) 26.0 m to at least 23.9 m A.O.D.: "firm to stiff brown laminated silty CLAY with partings of fine sand and silty containing some gravel. Top of stratum slightly mottled"

(4.2) 25.3 to 23.3 m A.O.D., on top of till: "soft to firm laminated sandy clayey SILT with partings of fine brown sand. Slight traces of rootlets"

(4.3) Ditto, between 24.9 and 23.5 m A.O.D. overlying till.

(5) NS 3845 3740: a bore log contains the following entry:

28.0 m A.O.D.: "firm to stiff mottled grey brown laminated silty clay"

27.35 m A.O.D.: "firm to stiff dark grey laminated silty clay"

26.85 m A.O.D.: boulder clay (7.5 m thick), over laminated clays and boulder clays.

Nearby, clay, not labelled as laminated, lies on top of till, overlying "alternating bands of stiff dark grey laminated silty clay"

Table A.17.1 (continued)

(6) NS 404 373: a bore log contains the following entry:

23.815 to 22.69 m A.O.D.: "firm to stiff mottled grey brown laminated silty CLAY with partings of fine sand and silt"

(7) NS 4055 37125: a bore log contains the following entry:

27.27 m A.O.D.: "mottled grey-brown laminated silty CLAY with vertical fissures and decayed vegetation tending to mottled sandy silty clay with gravel and containing remnant laminations near the bottom of the stratum - possibly fill material"

A P P E N D I X   4

FIGURES

APPENDIX 4

Figures: Introductory notes

All figures refered to in the text (Volume 1) and in Appendix 1 (Volume 2) are contained in this appendix. All the figures have been designed and drawn by the writer.

The maps are based on Ordnance Survey 1:10,000, 1:25,000 and 1:50,000 scale geological and topographical maps, and occasionally on the earlier edition, non-metric equivalents of these maps. Figure 10.1, in outline, is based on a map provided by Dr. W. G. Jardine.

Abbreviations in the figures follow usage described in the text or, occasionally, in the figure texts.

The figures showing sedimentary sections (Figures 10.2-10.12, etc.) are drawn to show only the in situ sediments. Slumped material and vegetation which obscures the in situ sediments are not shown.

The pollen and macrofossil diagrams, although being drawn to the same format, differ in detail and emphasis from each other, for example, with regard to the total sums used or the groupings of taxa. This depends on the results of the analysis. All pollen diagrams show relative results.

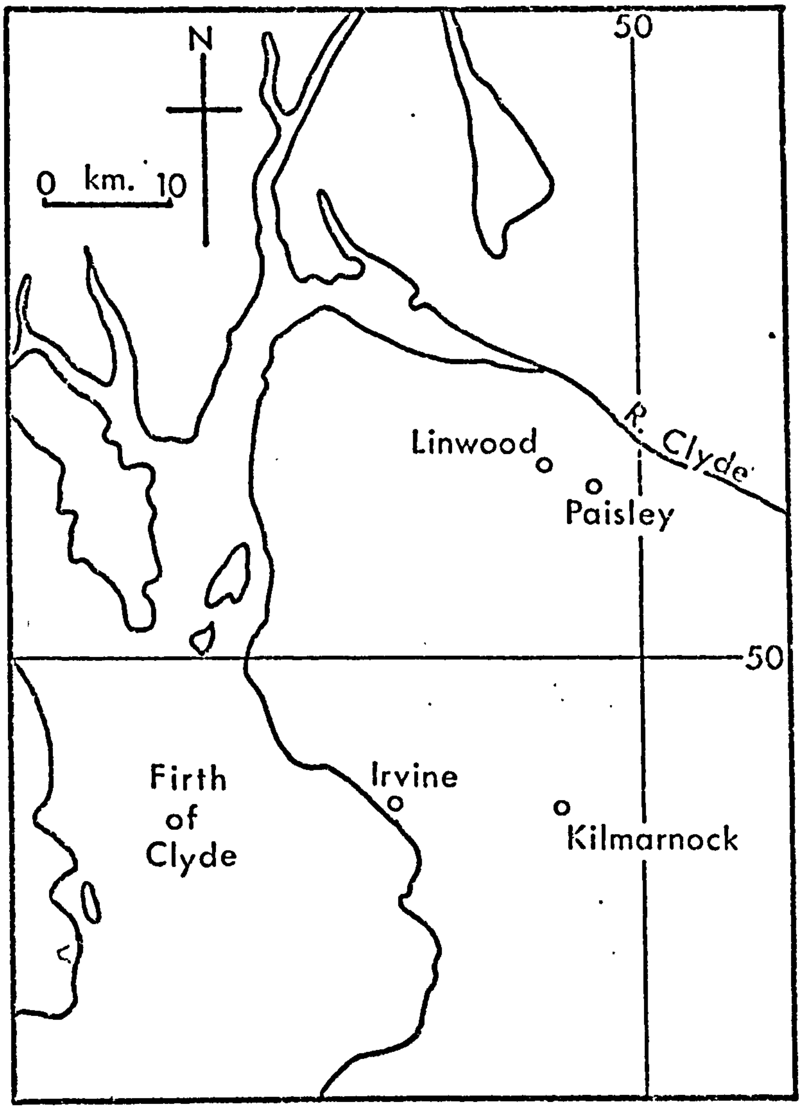


Figure 1.1 General location map. Map of western central Scotland, showing the locations of the two main areas, around Linwood and Irvine, studied in this work.

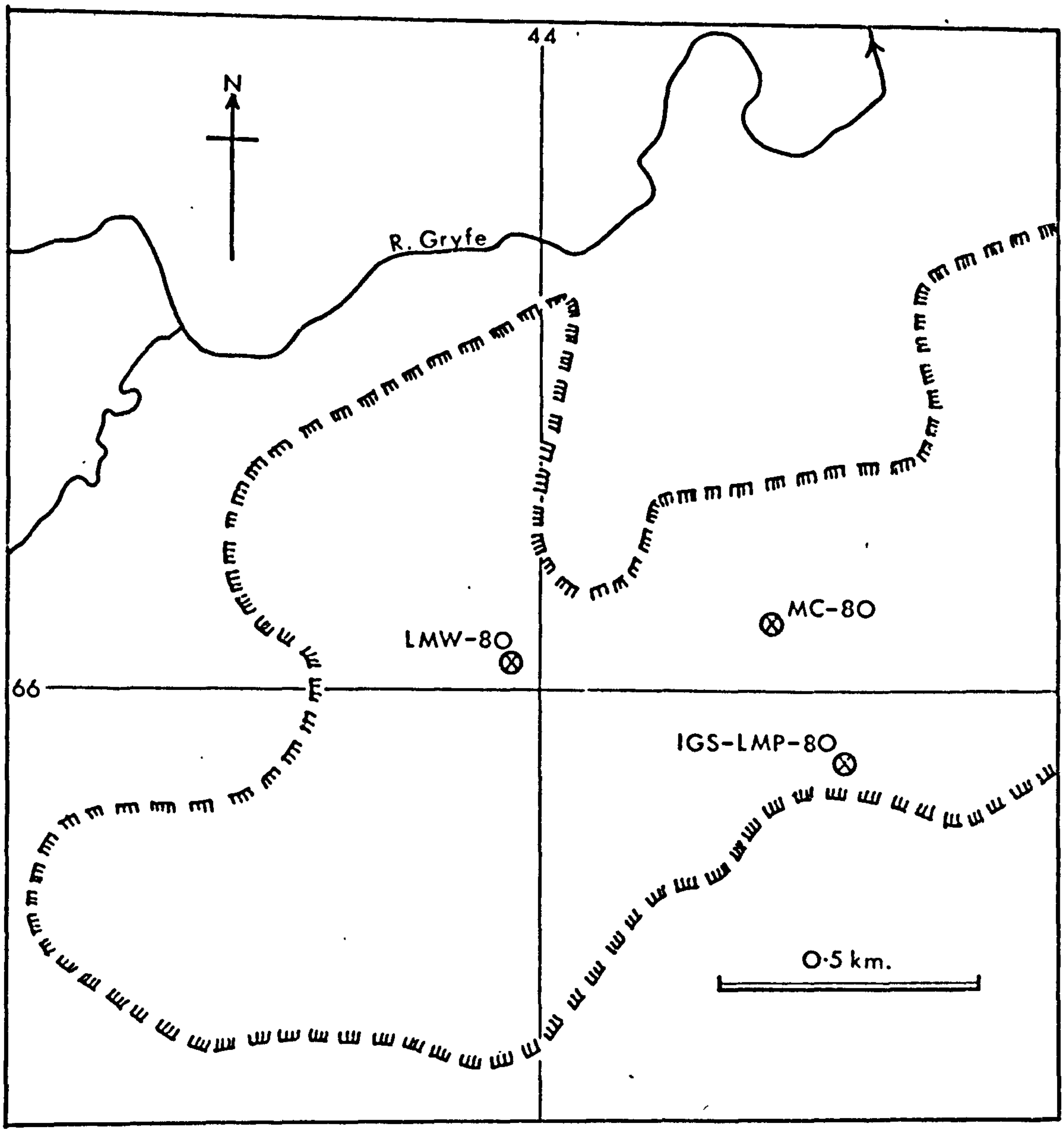


Figure 2.1 Linwood Moss, locations of core sites. The core sites are locations at which the cores used for pollen analysis were taken. The cores are Linwood Moss Wood, 1980 (LMW-80), Moss Cottage, 1980 (MC-80) and the I.G.S. Linwood Moss peat core (IGS-LMP-80). The outline of Linwood Moss is indicated by the hatched line. See Chapter 7.1 for discussion regarding the extent of Linwood Moss.

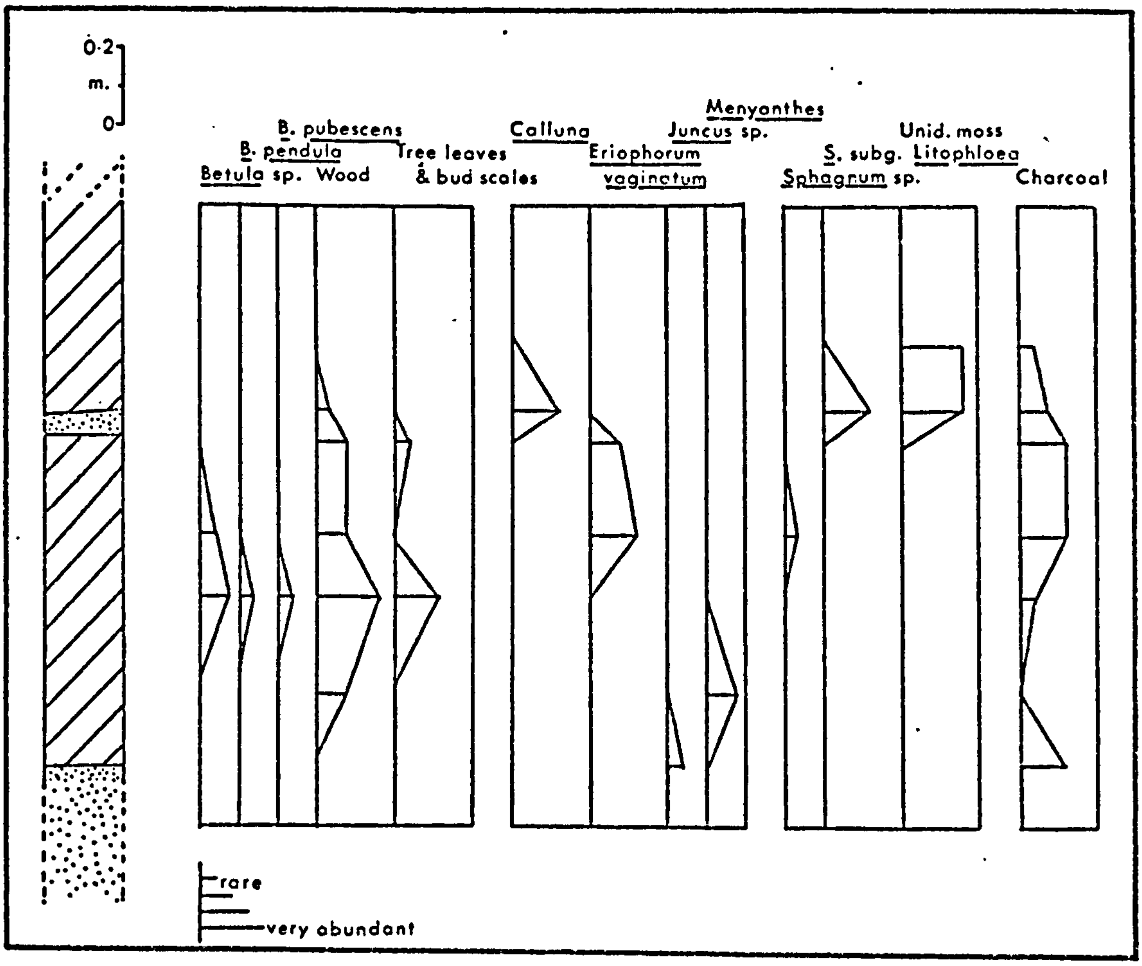


Figure 3.1 I.G.S. core from Linwood Moss; IGS-LMP-80; results of the analysis of plant macrofossils.

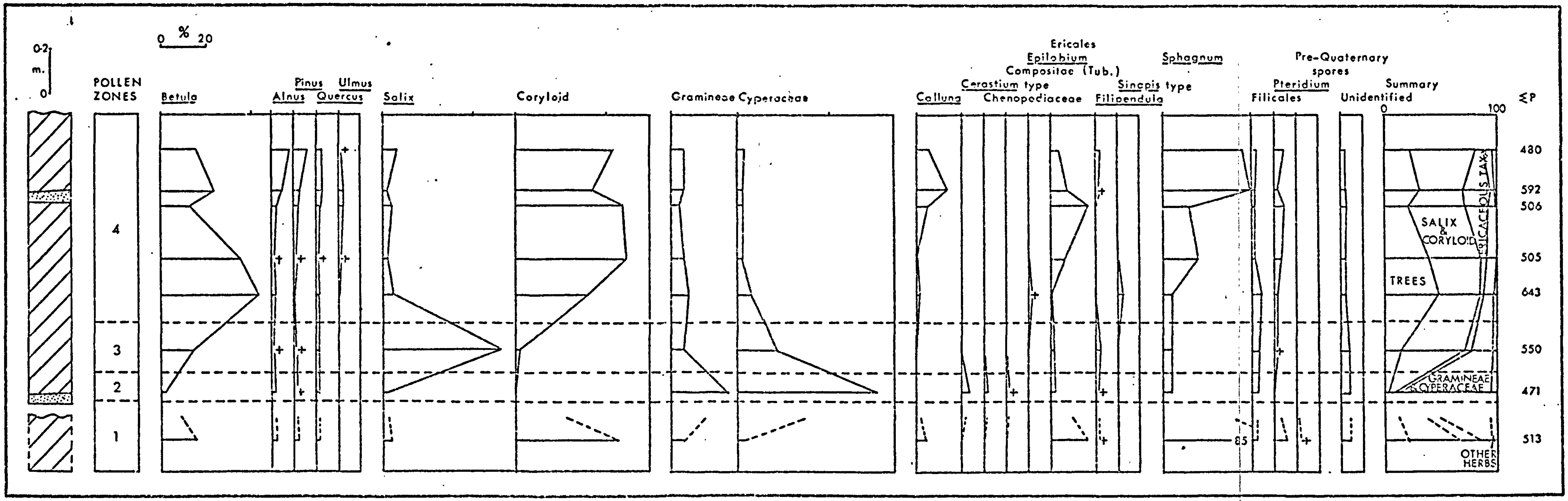


Figure 3.2 I.G.S. core from Linwood Moss; IGS-LMP-80: results of the pollen analysis. Values are percentages of total pollen.

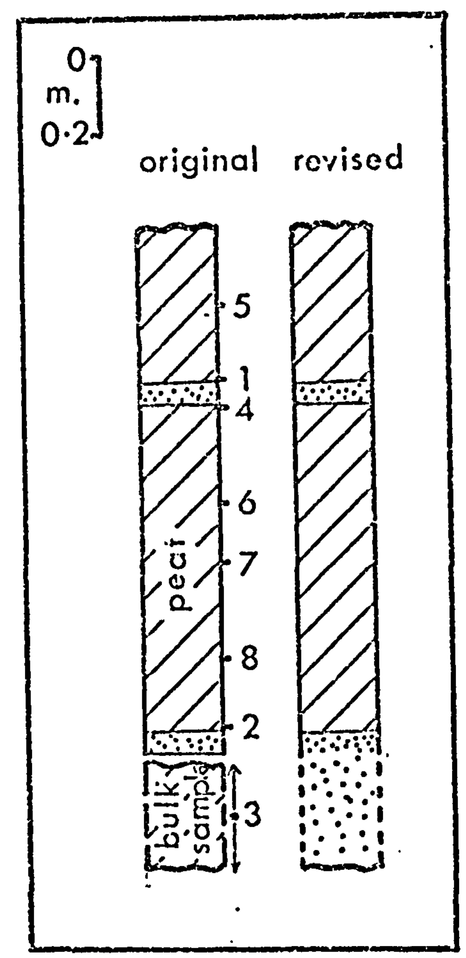


Figure 3.3 I.G.S. core from Linwood Moss; IGS-LMP-80: original and revised sediment successions. See Tables 2.2 and A.3.1 for further sediment details. Also shown are the sample positions for the pollen and macrofossil analyses.

Figures 3.2 & 3.3

Figure 4.1 Moss Cottage, Linwood Moss; MC-80: results of the pollen analysis. Values are percentages of total pollen.

Figure 4.1

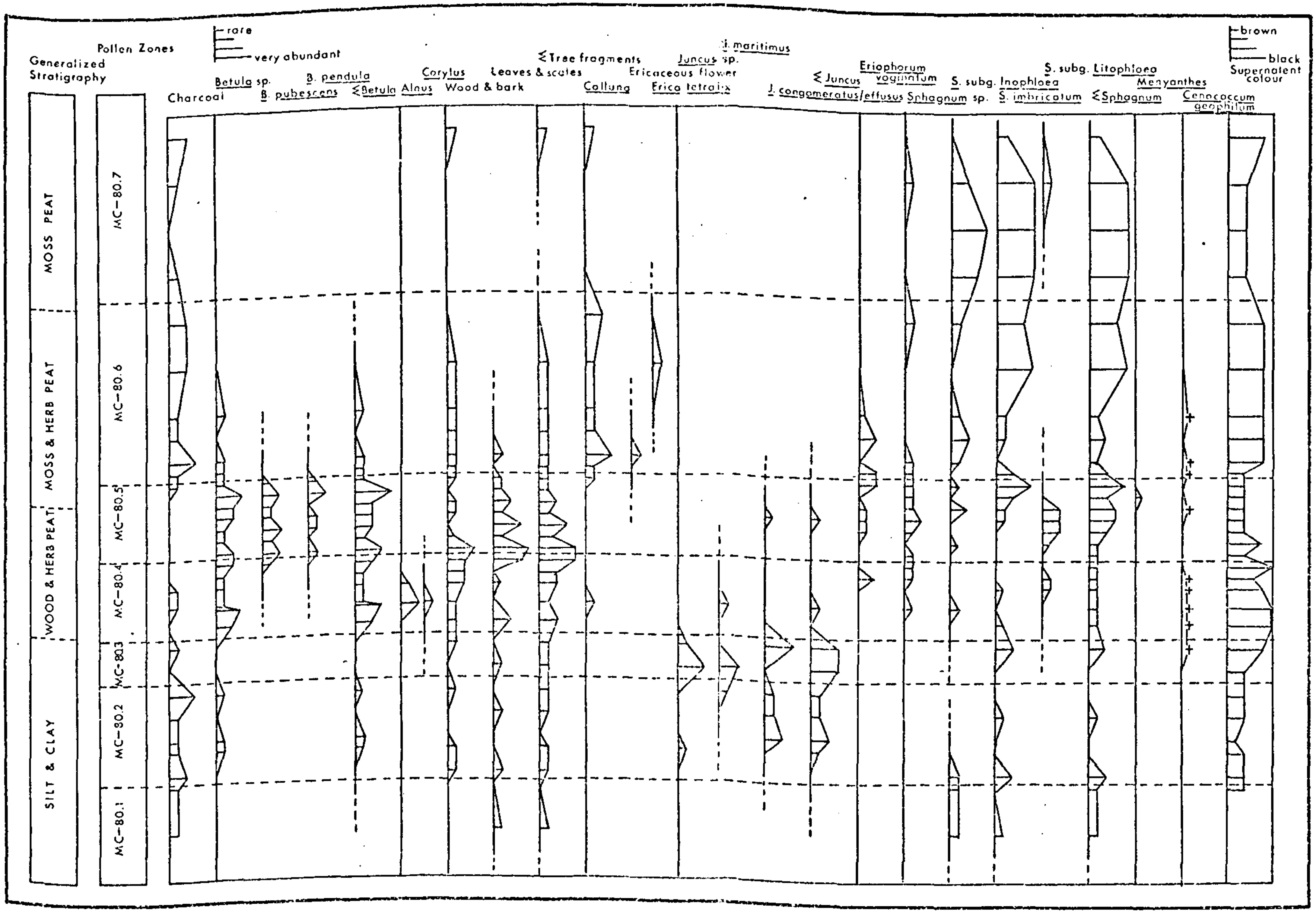


Figure 4.2 Moss Cottage, Linwood Moss; MC-80: results of the plant macrofossil analysis. Cenococcum geophilum is only noted as present (+) or absent. The supernatent colour represents degree of humification.

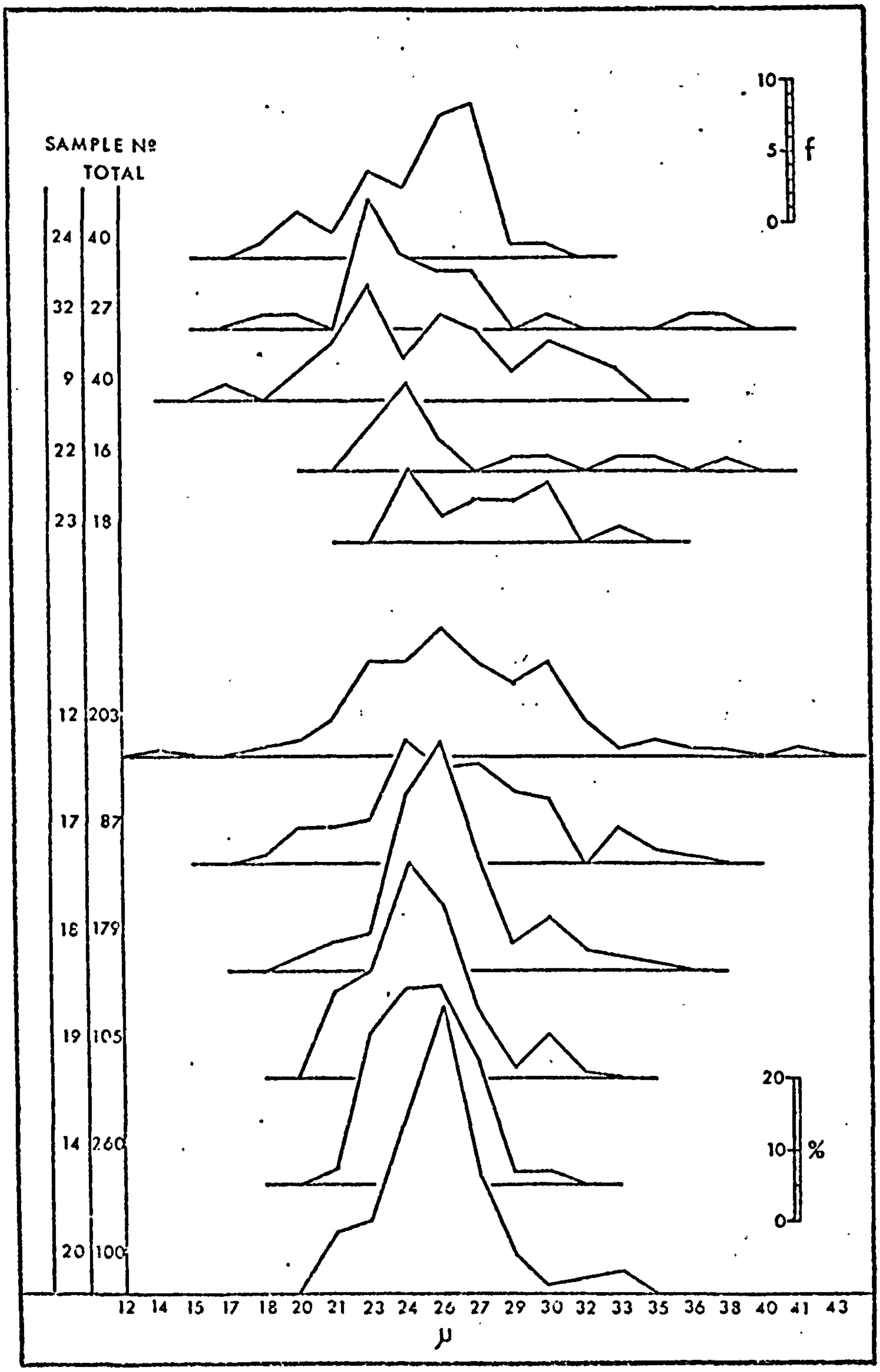
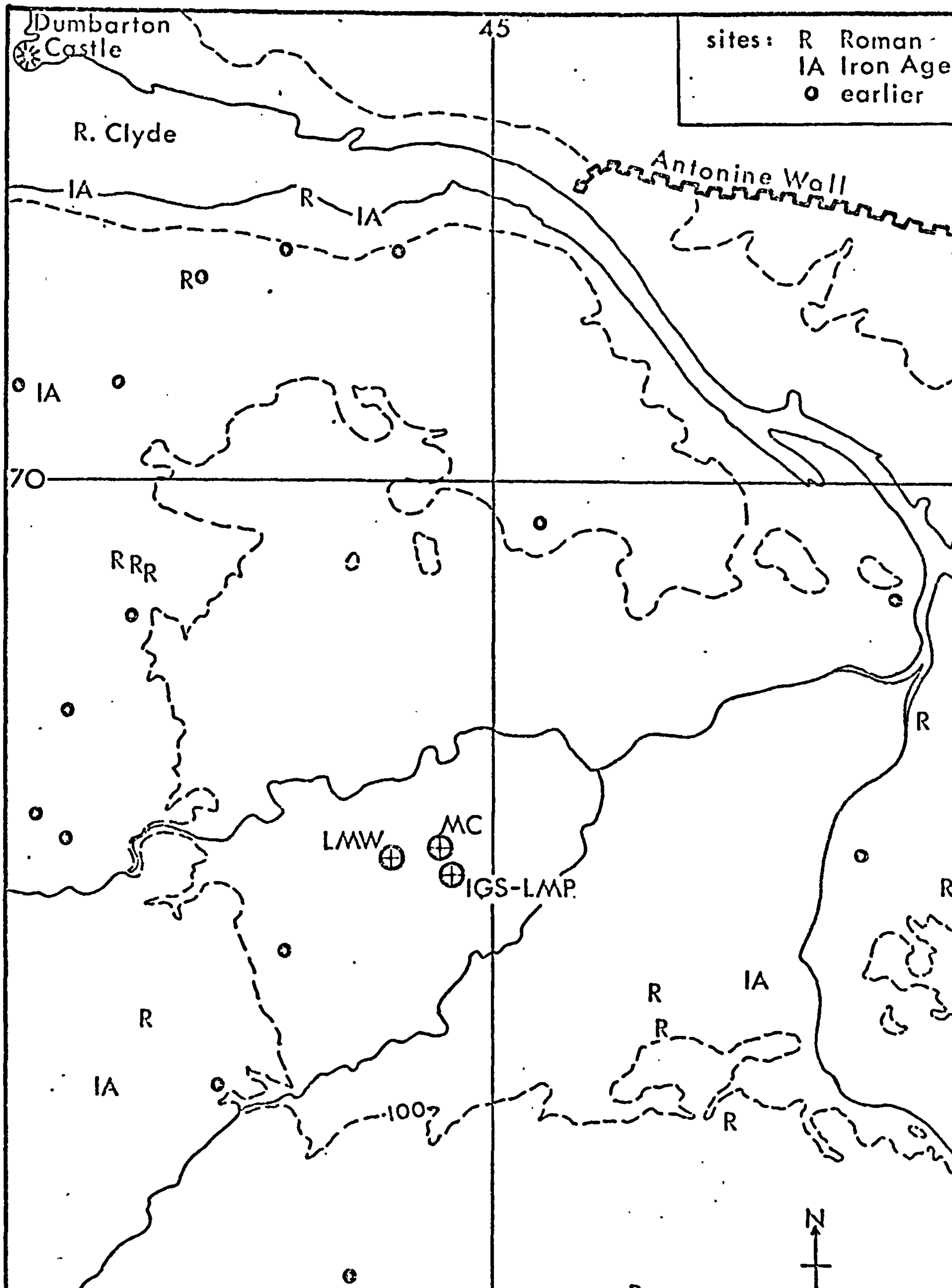


Figure 4.3 Moss Cottage, Linwood Moss; MC-80: Gramineae pollen grain size distributions. The measurements for 11 samples, presented in stratigraphical order, are of the maximum grain diameter. The results in the upper part of the figure (samples 23 to 24) are presented as frequencies (f), since low total counts were used. The results in the lower part (samples 20 to 12) are presented as percentages. The sizes (µm) are adapted from microscope graticule measurements and are rounded to the nearest 1 µm.



<u>Figure 4.4</u> Linwood Moss: archaeological sites in the surrounding area. North of the River Clyde only Dumbarton Castle and the Antonine Wall are shown. The 100 ft (32 m) contour is shown as a guide to land surface form and its altitude is of no significance.

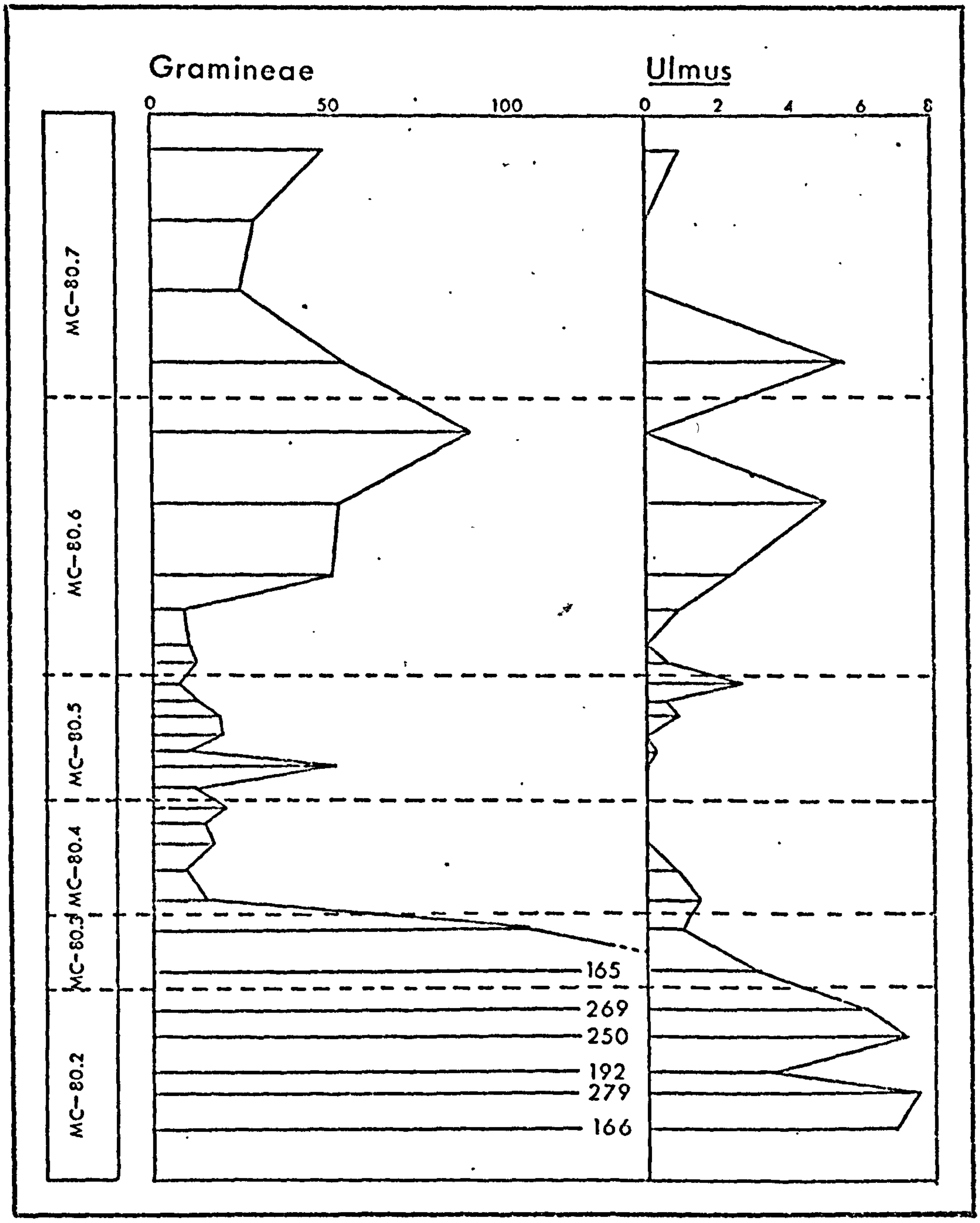


Figure 4.5 Moss Cottage, Linwood Moss; MC-80: Gramineae and *Ulmus* pollen values as percentages of A.P. Note the different scales for the two taxa.

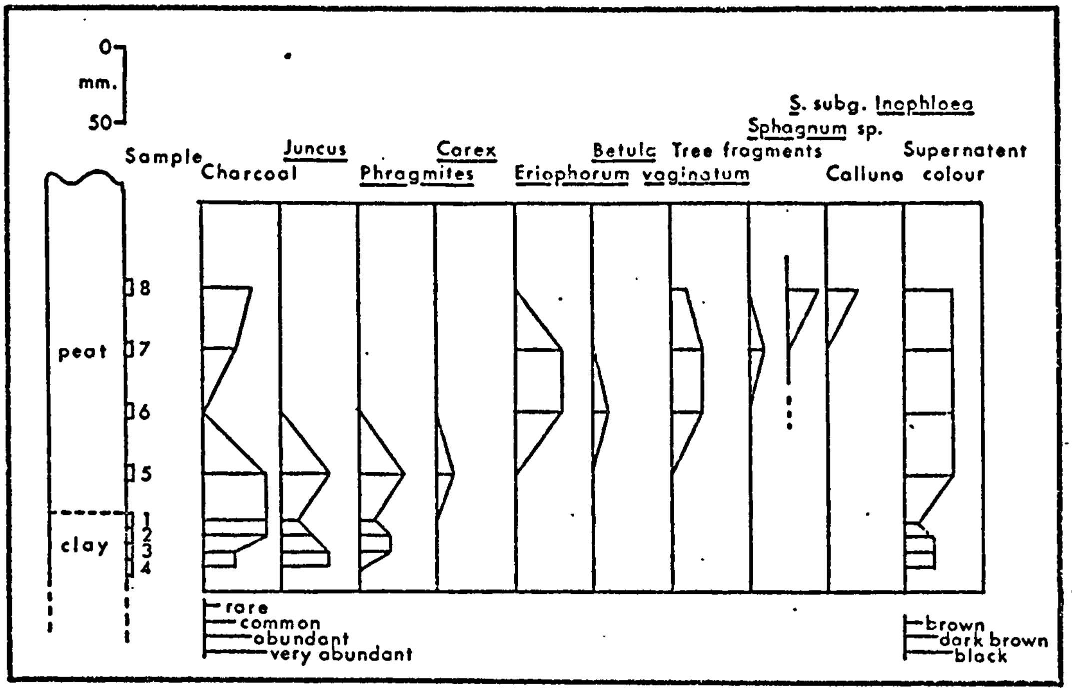


Figure 5.1 Flanders Moss; FM-80: results of the plant macrofossil analysis.

Figure 5.2 See next page.

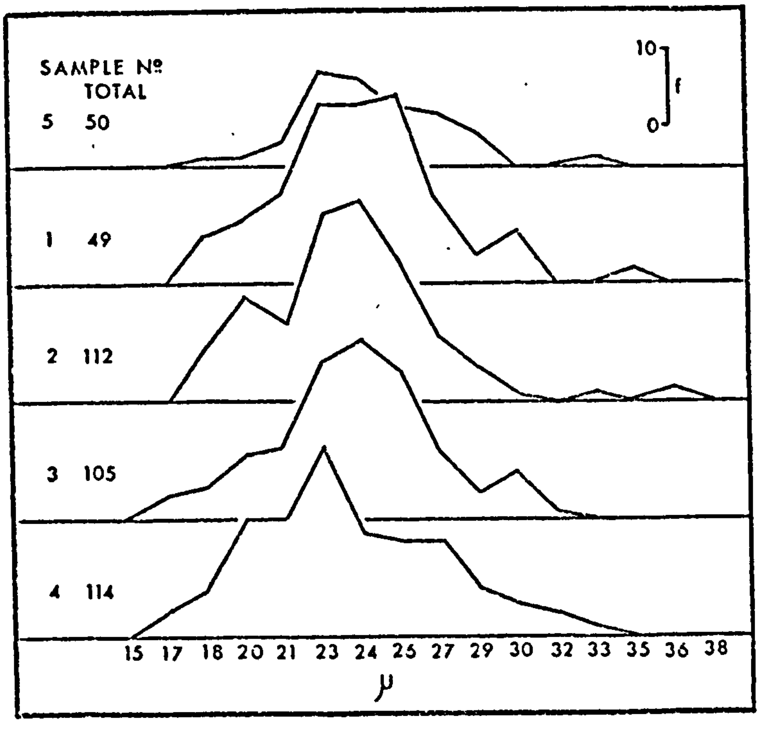


Figure 5.3 Flanders Moss; FM-80: Gramineae pollen grain size distributions.

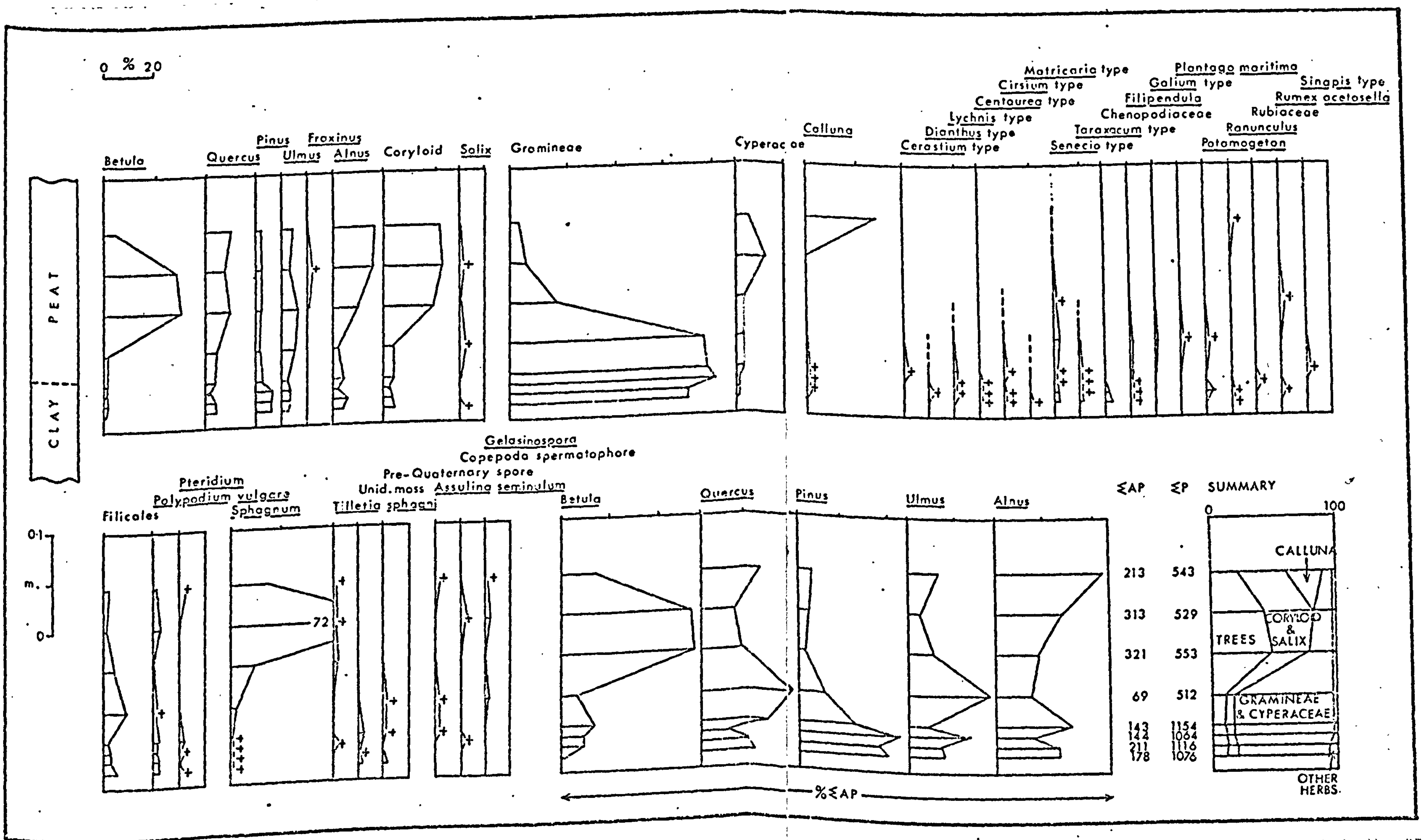


Figure 5.2 Flanders Moss; FM-80: results of the pollen analysis. Values are percentages of total pollen, except where indicated. The A.P. sum used is the sum of the taxa shown (i.e. Betula, Quercus, Pinus, Ulmus and Alnus).

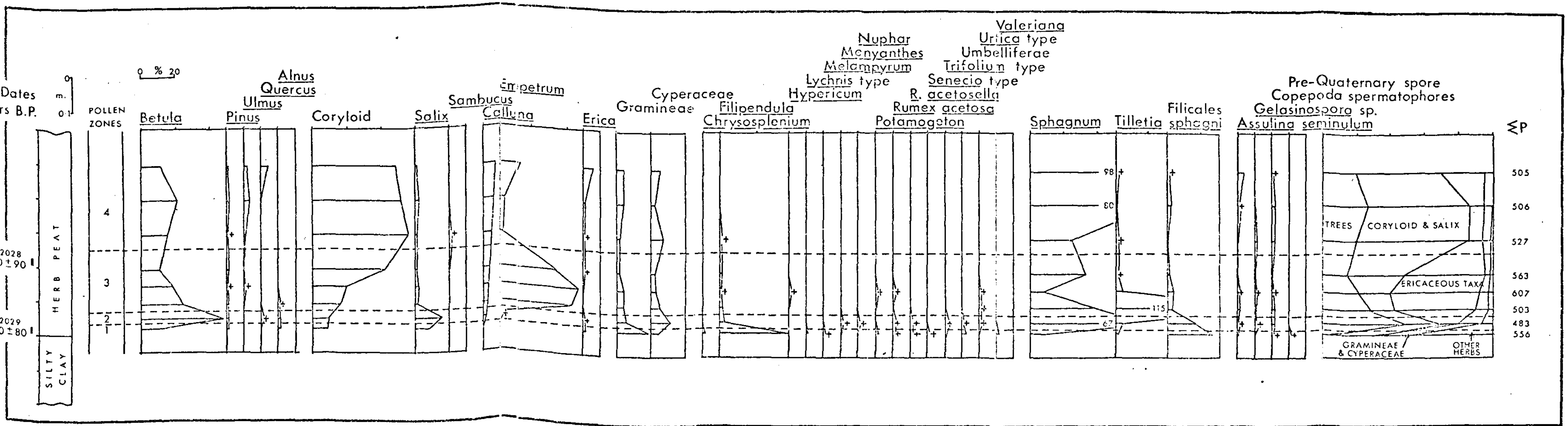


Figure 6.1 Linwood Moss Wood; LMW-80: results of the pollen analysis. Values are percentages of total pollen.

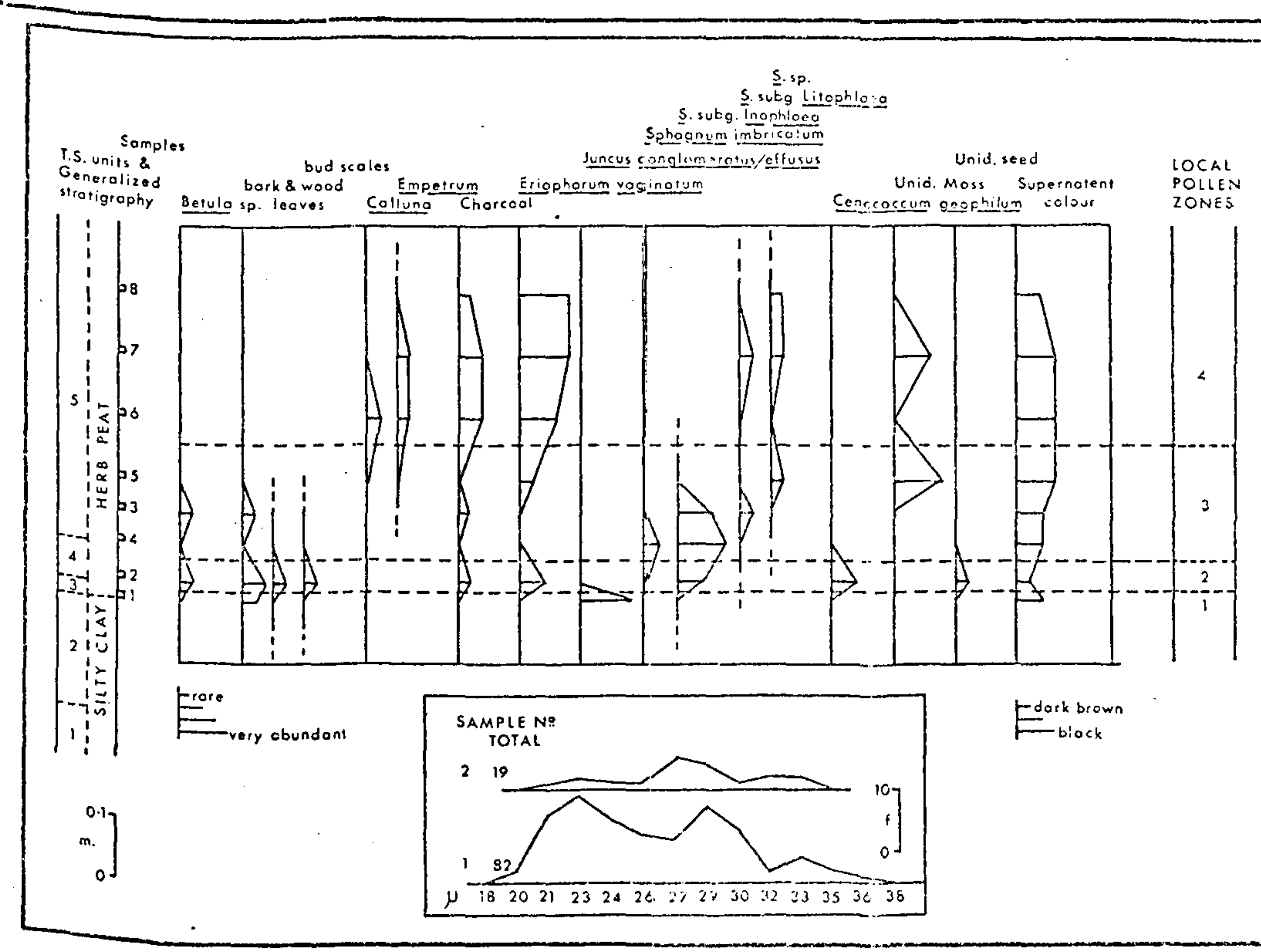


Figure 6.2 Linwood Moss Wood; LMW-80: results of the plant macrofossil analysis and Gramineae pollen grain size distributions.

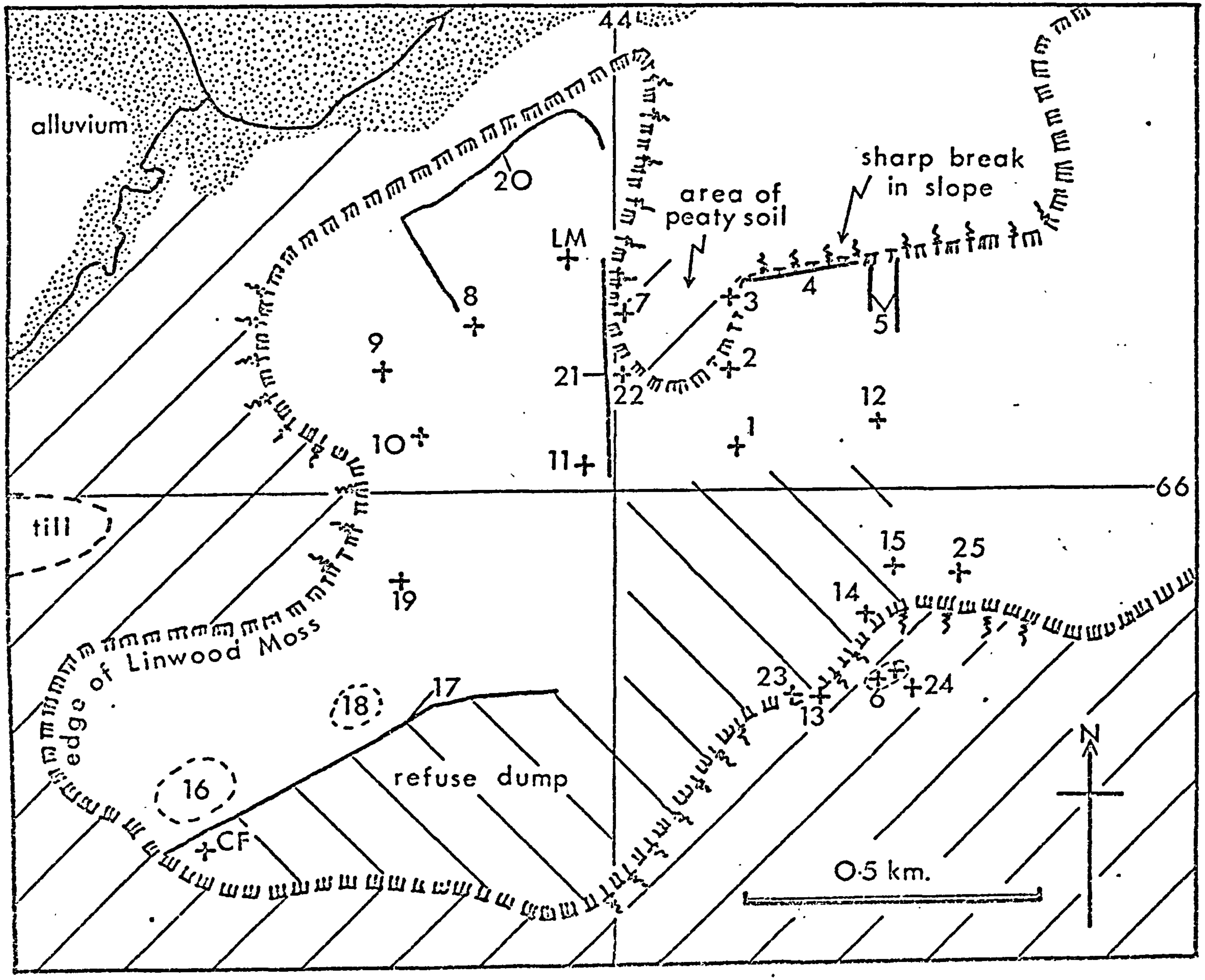
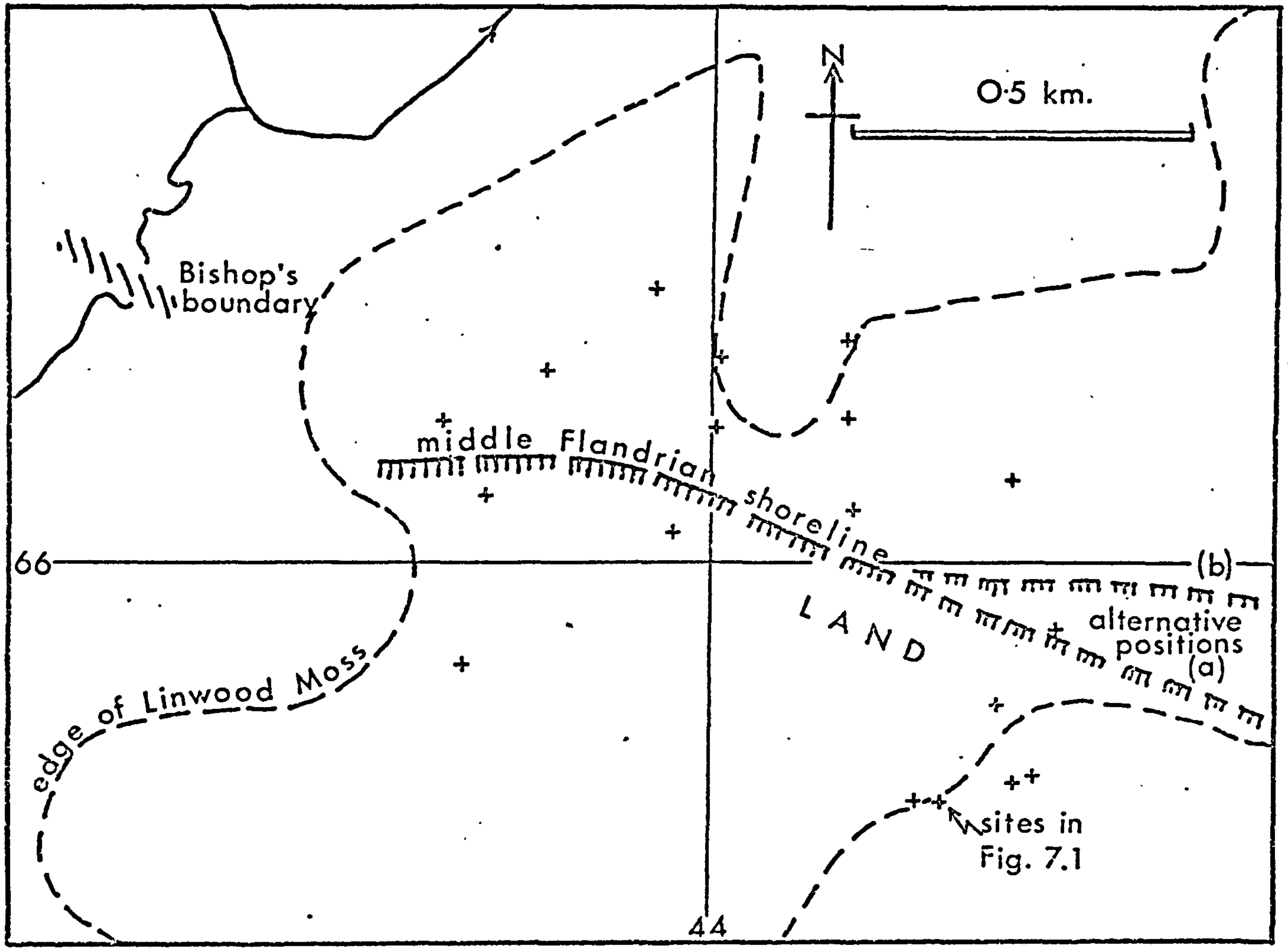


Figure 7.1

Linwood Moss: main extent of peat, and field survey sites. Outside the moss, areas with peaty soil (cross hatched) and clayey soil (no symbol), and the River Gryfe and its alluvium are shown. Within Linwood Moss, the extent of the refuse dump indicates where peat is inaccessible. Sites LM.1 to 25 are shown, as are the radiocarbon-date sites (Clippens Farm, CF, and Linwood Moss, LM). The hachures represent sharp breaks in slip.



<u>Figure 8.1</u> Linwood Moss: conjectural locations of the (buried) middle Flandrian shoreline. Alternative positions (a) and (b) are discussed in Chapter 8.4. "Bishop's boundary" is the boundary between the areas of surface or sub-peat outcrops of middle Flandrian marine sediments (to the north) and late Devensian marine sediments.

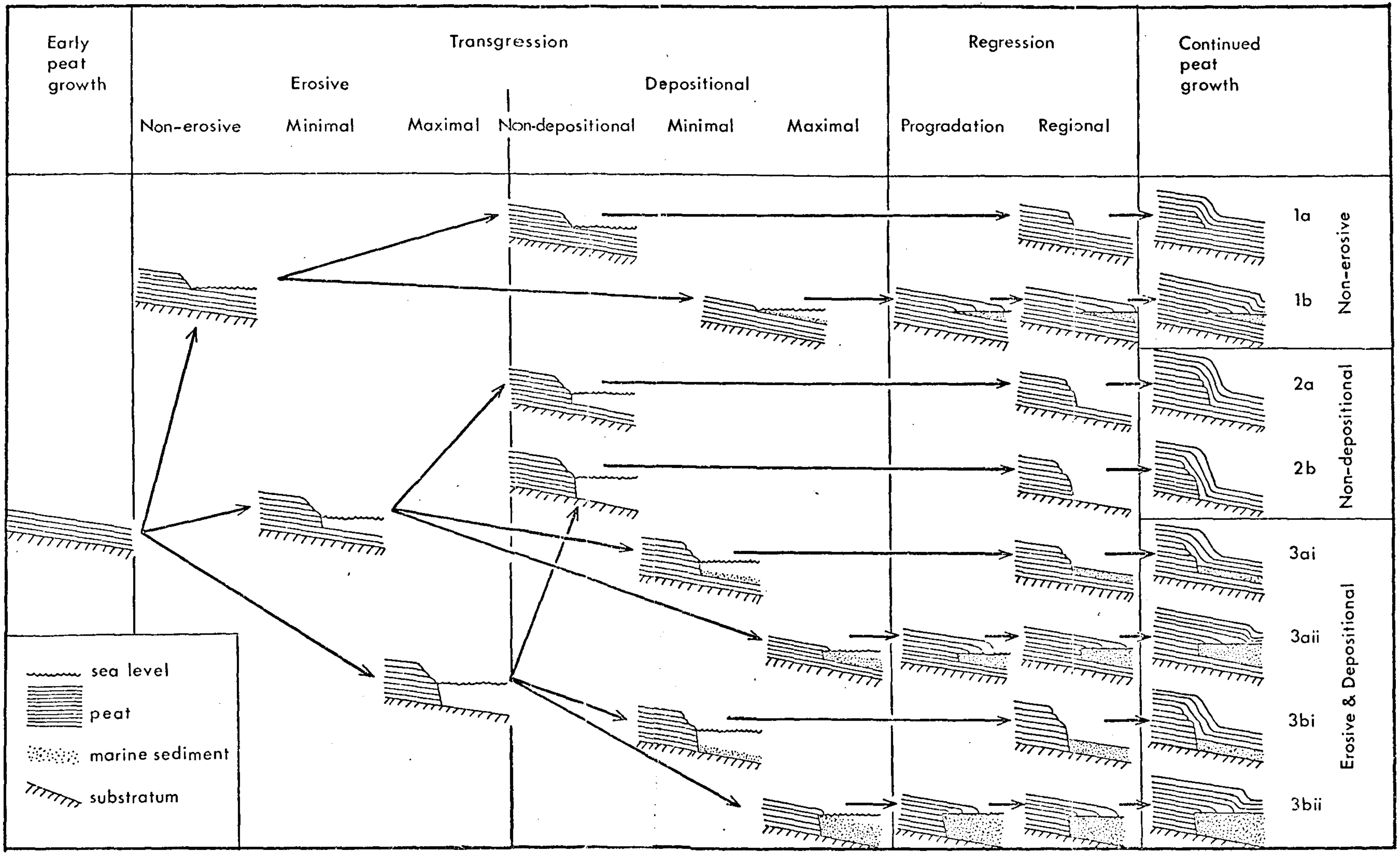


Figure 8.2 Theoretical model for the development of sediment successions during a transgressive and regressive event in an area of peat. The peat is represented by equal unit time lines (total 10). See Chapter 8.4 for discussion of the model.

Figure 8.2

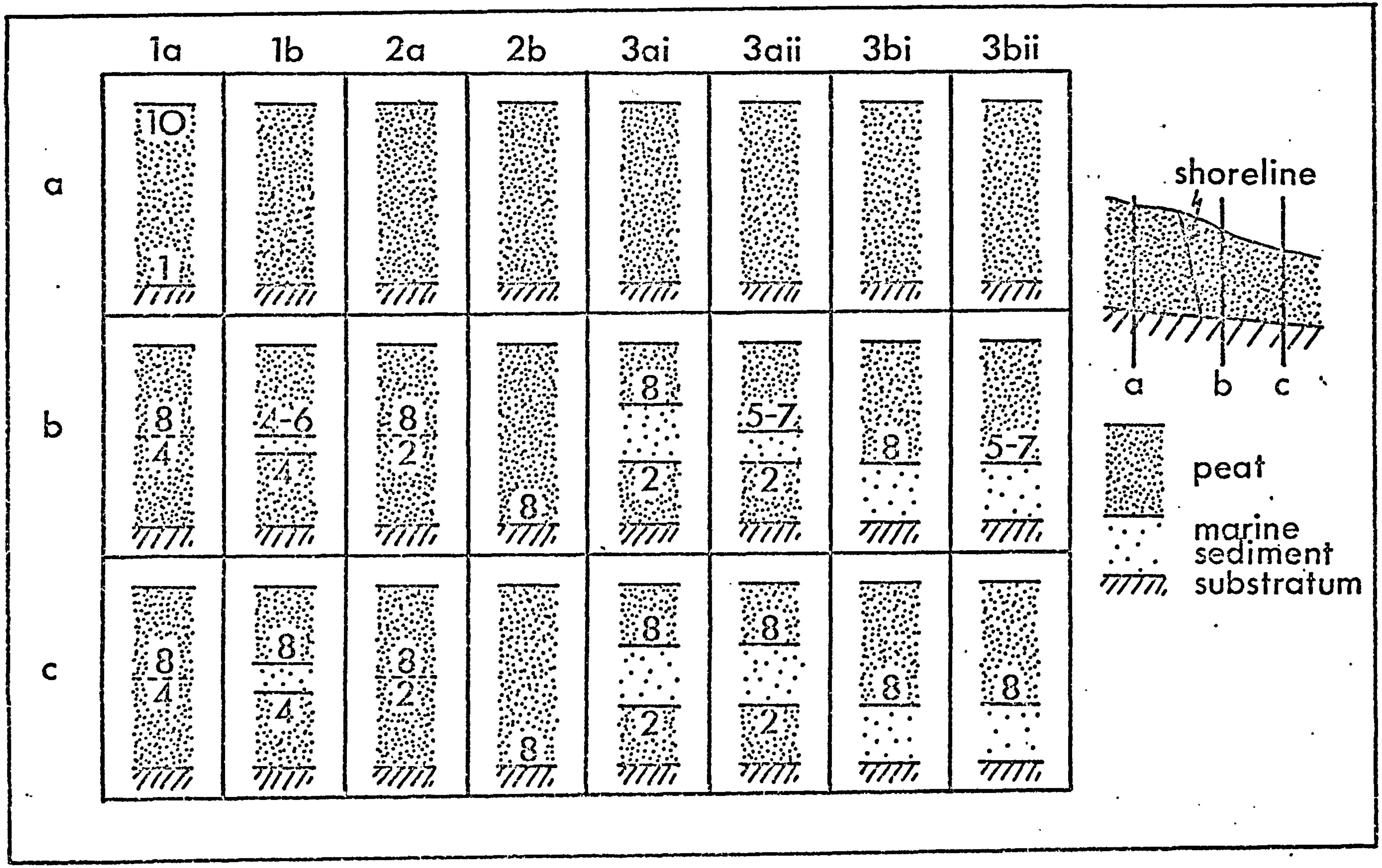


Figure 8.3 Resultant sections (not to scale) for the theoretic model. The expected sections for the outcomes of the model are shown for three different locations with respect to the shoreline position. See Chapter 8.4 for further discussion. The ages of the peat base(s) and top(s) are shown on a ten-point scale; unless otherwise stated, the base and top dates are 1 and 10 respectively (e.g. section a, outcome 1a). A broken line represents an unconformity.

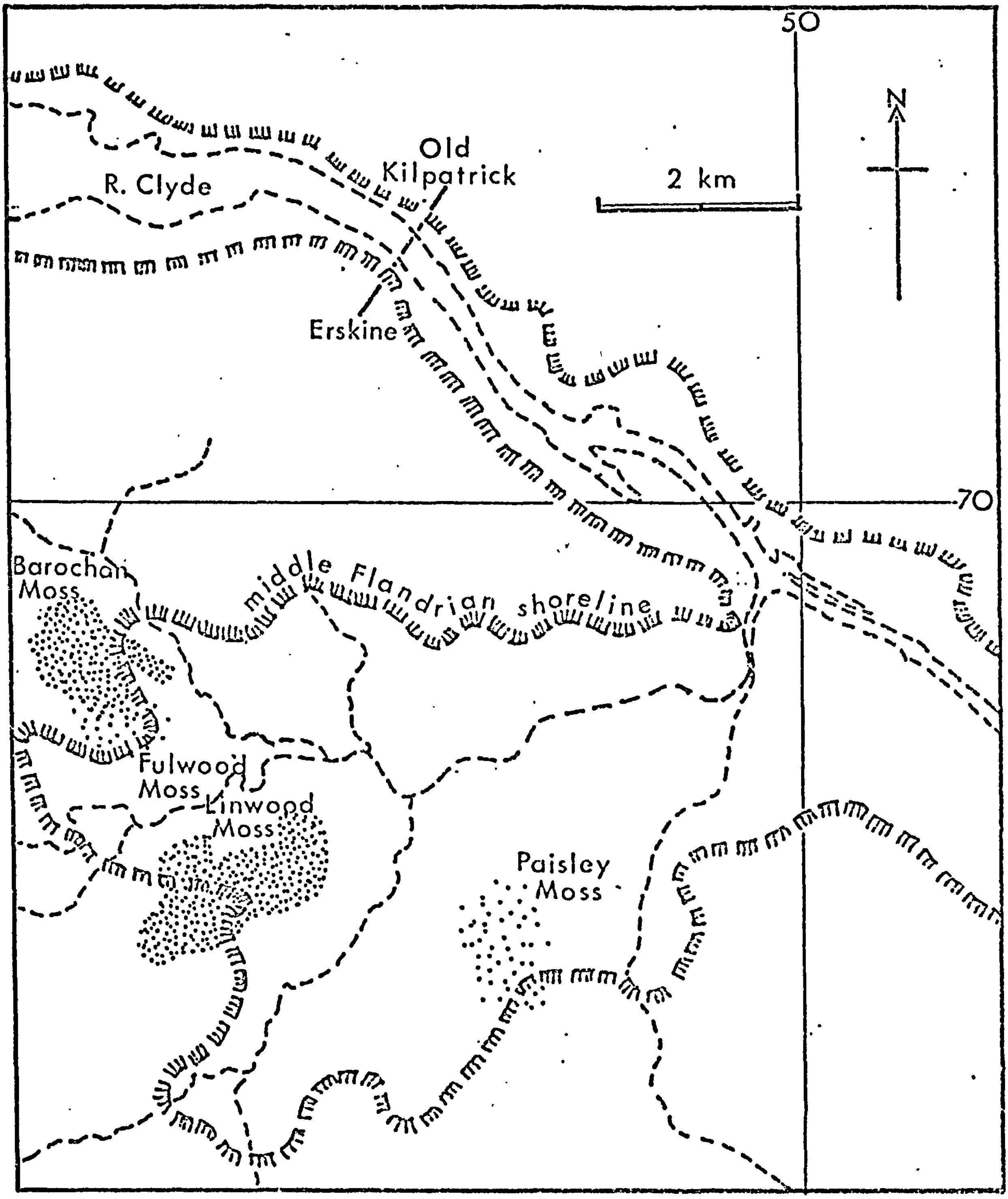


Figure 8.4 Linwood-Paisley Embayment: conjectural configuration of the middle Flandrian (high sea level) coastline. The positions of Linwood and Barochan Mosses are shown in dense stippling; the positions and extent of Fulwood and Paisley Mosses are less well known. The narrowest part of the restricted inlet to the embayment lies between Old Kilpatrick and Erskine. The present drainage pattern is shown by broken lines.

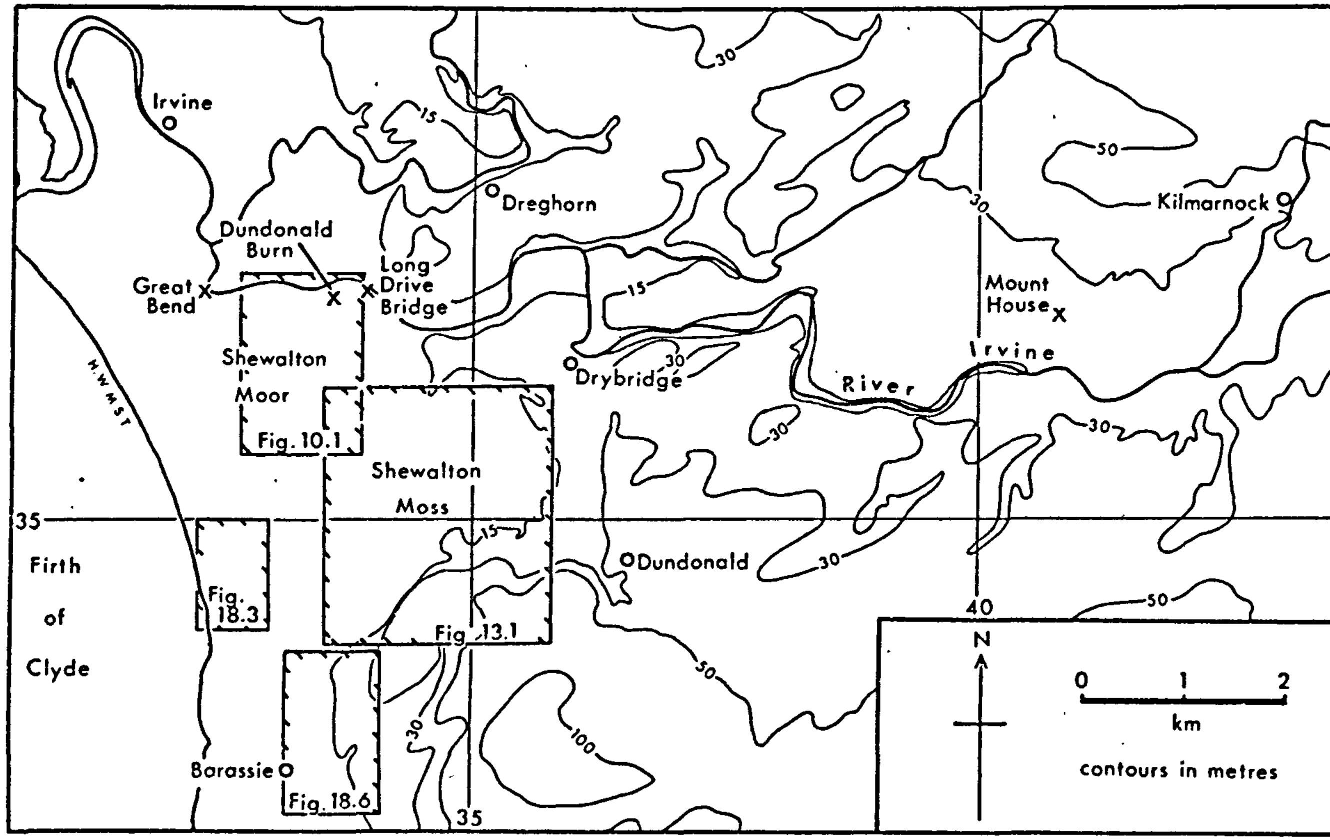


Figure 9.1 Location map for the Irvine-Kilmarnock area.

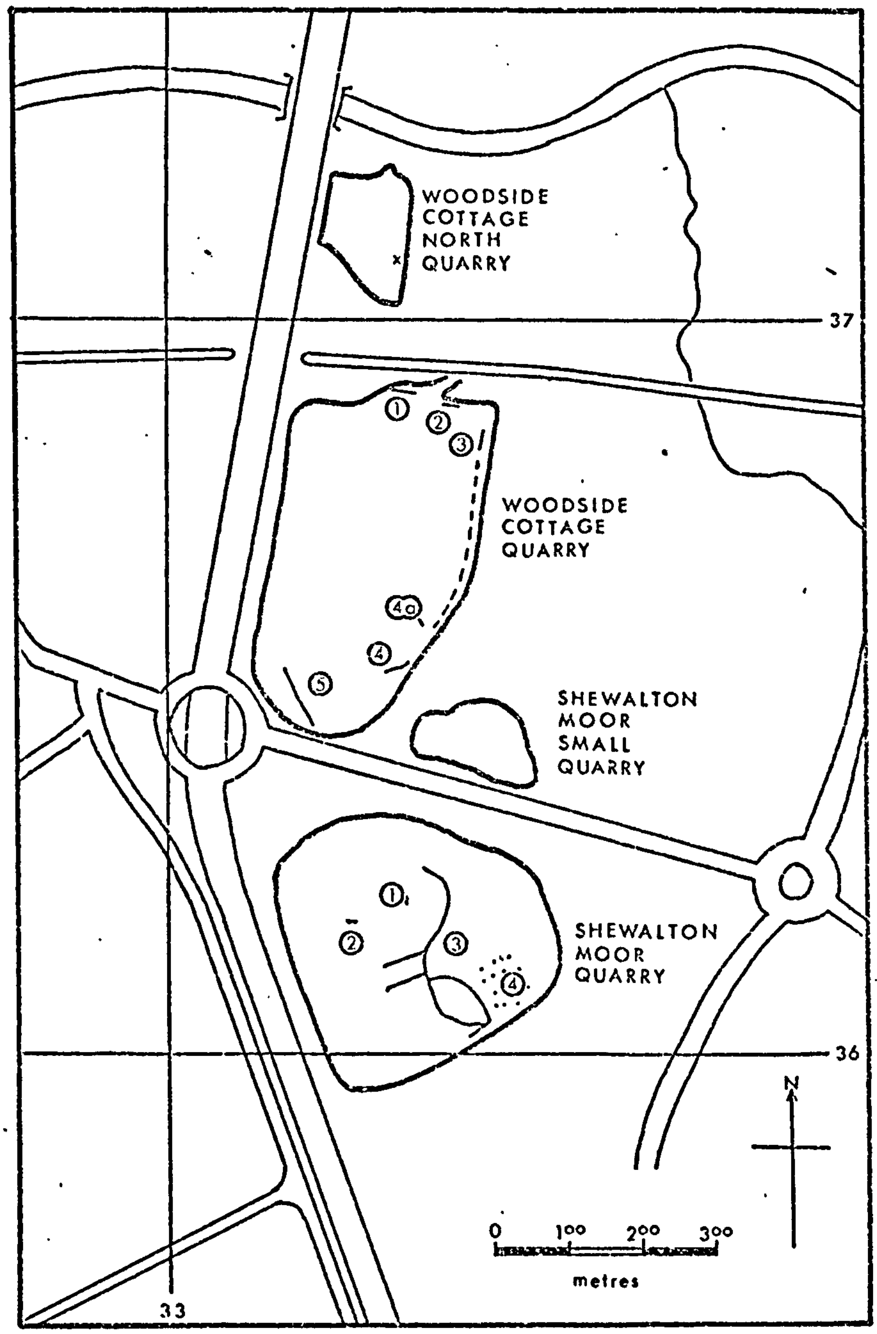
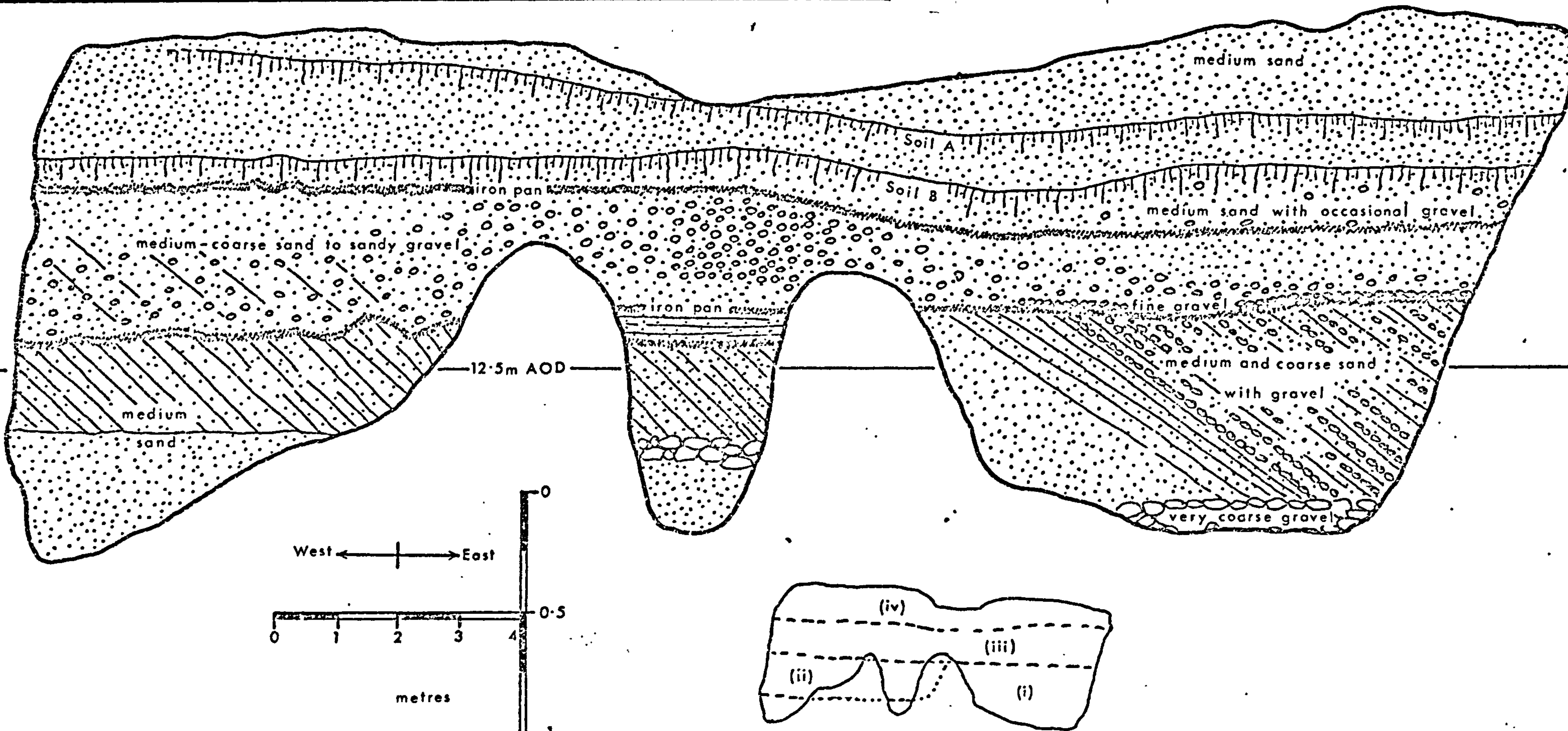


Figure 10.1 Shewalton Moor Quarries: location map. The locations and approximate boundaries of the sand quarries in the Shewalton area are shown, as are also the sites discussed in Chapter 10. The site locations in Shewalton Moor Small Quarry are shown on Figure 10.7.

Figure 10.2 Woodside Cottage Quarry, Site 1: section. Vertical exaggeration is x 4. The sketch at the bottom shows the approximate positions of the sedimentary units discussed in Chapter 10.4.



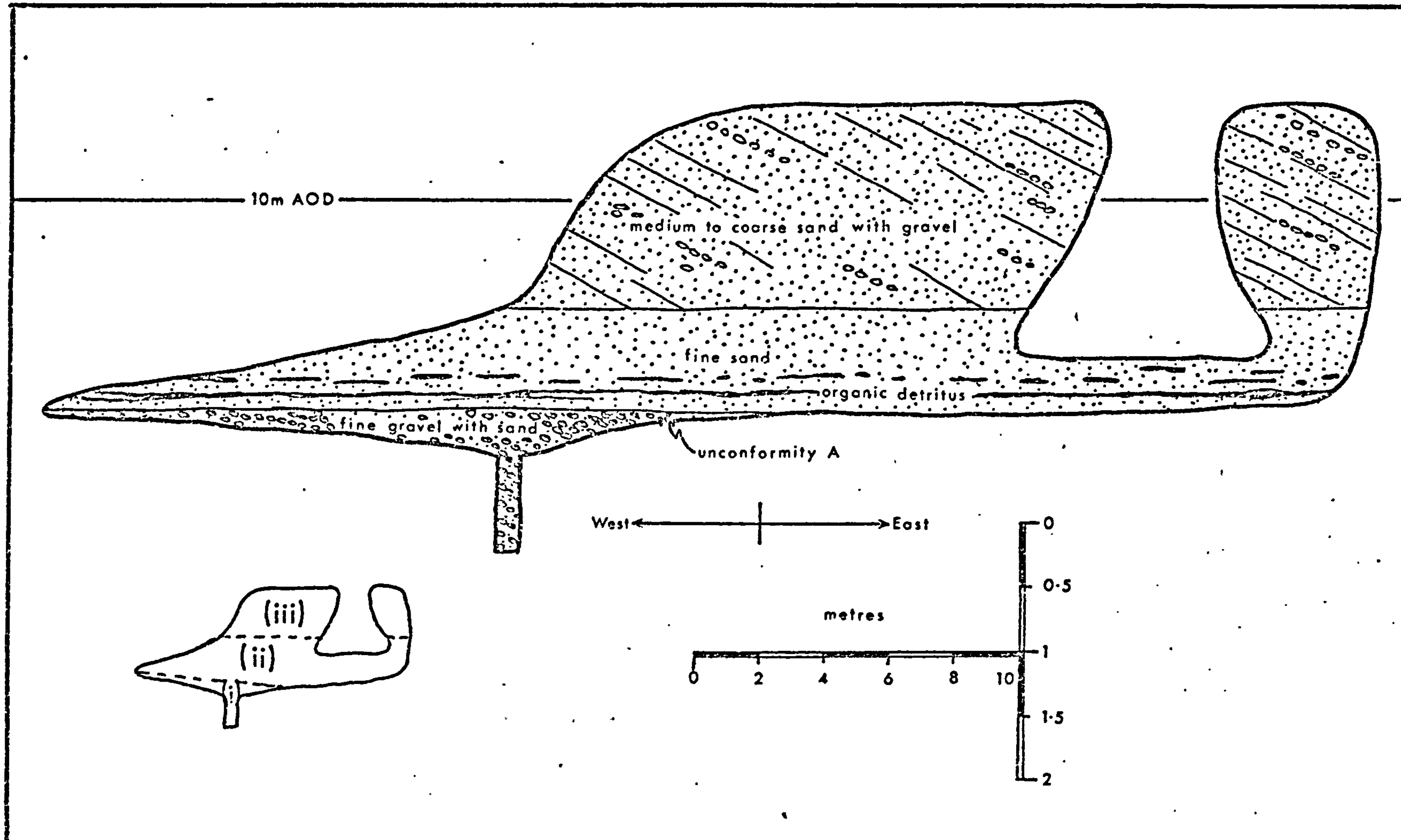


Figure 10.3 Woodside Cottage Quarry, Site 2: section. Vertical exaggeration is x 4. At the bottom the sketch shows the position of the sedimentary units discussed in Chapter 10.5.

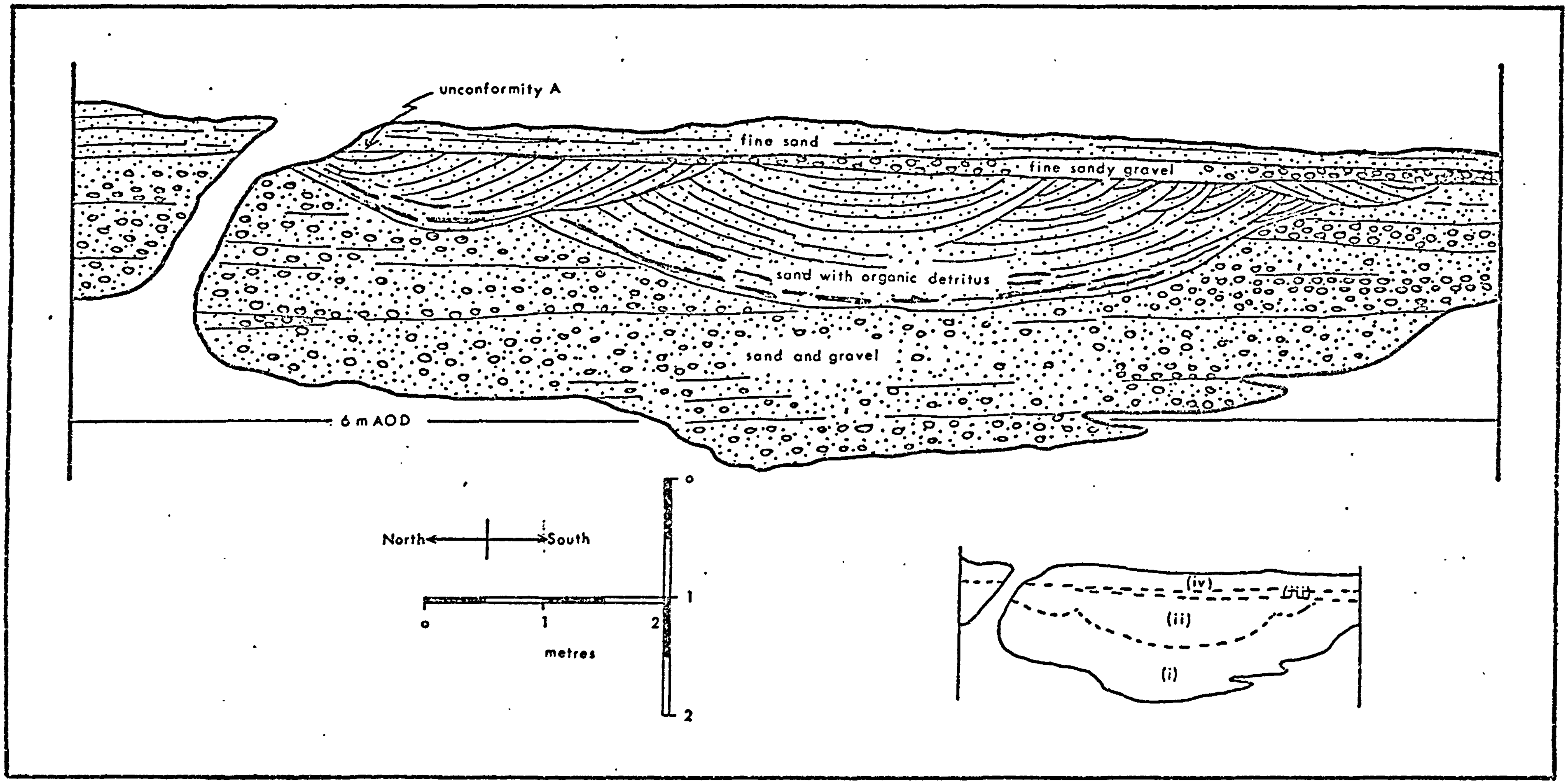


Figure 10.4 Woodside Cottage Quarry, Site 3: section. To the north and south, the horizontally bedded sand and gravel continues to be exposed. The sketch at the bottom shows the positions of the sedimentary units discussed in Chapter 10.6.

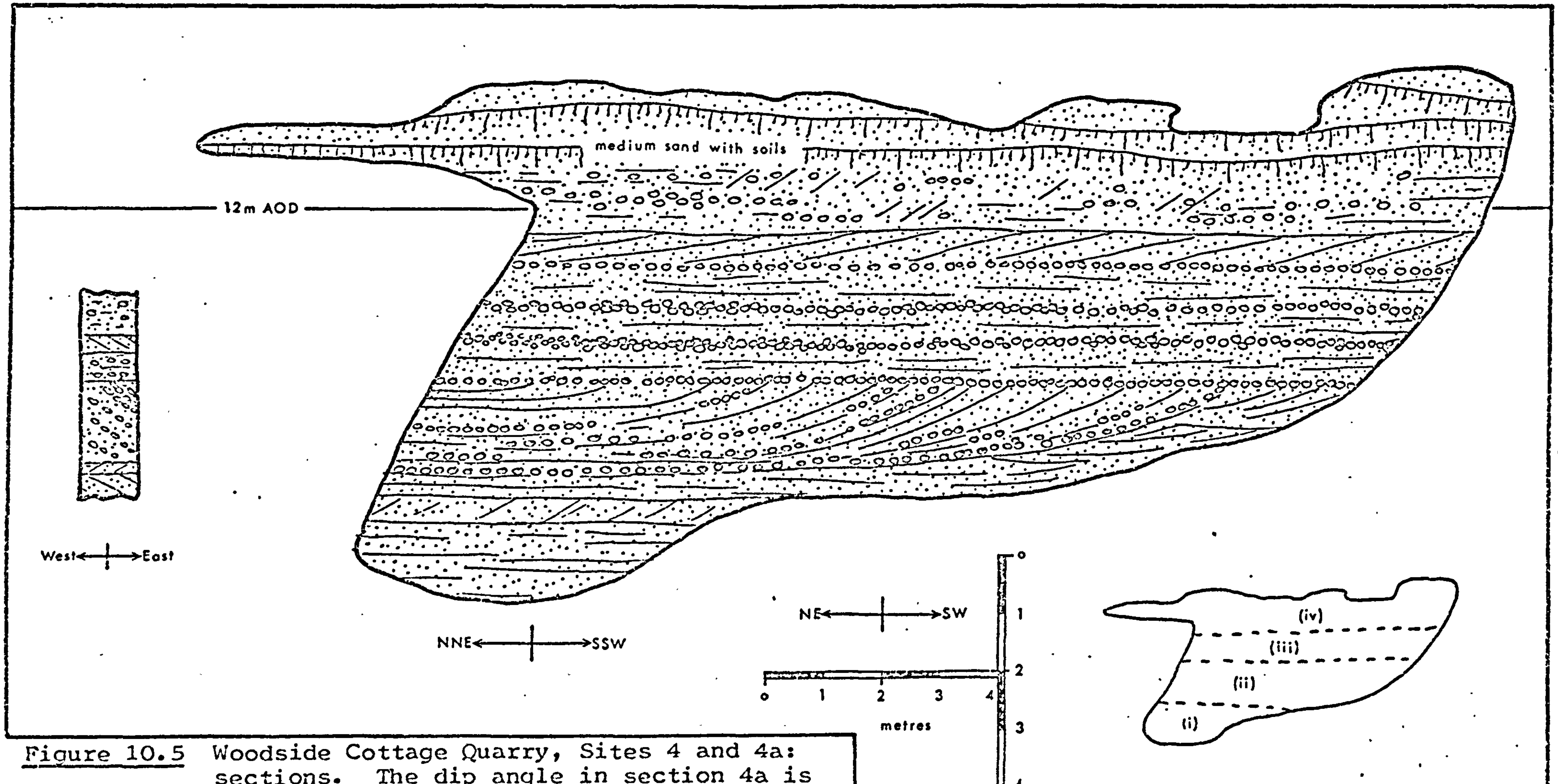


Figure 10.5 Woodside Cottage Quarry, Sites 4 and 4a: sections. The dip angle in section 4a is exaggerated. The sketch at the bottom shows the positions of the sedimentary units discussed in Chapter 10.7. Note the changing direction of section 4.

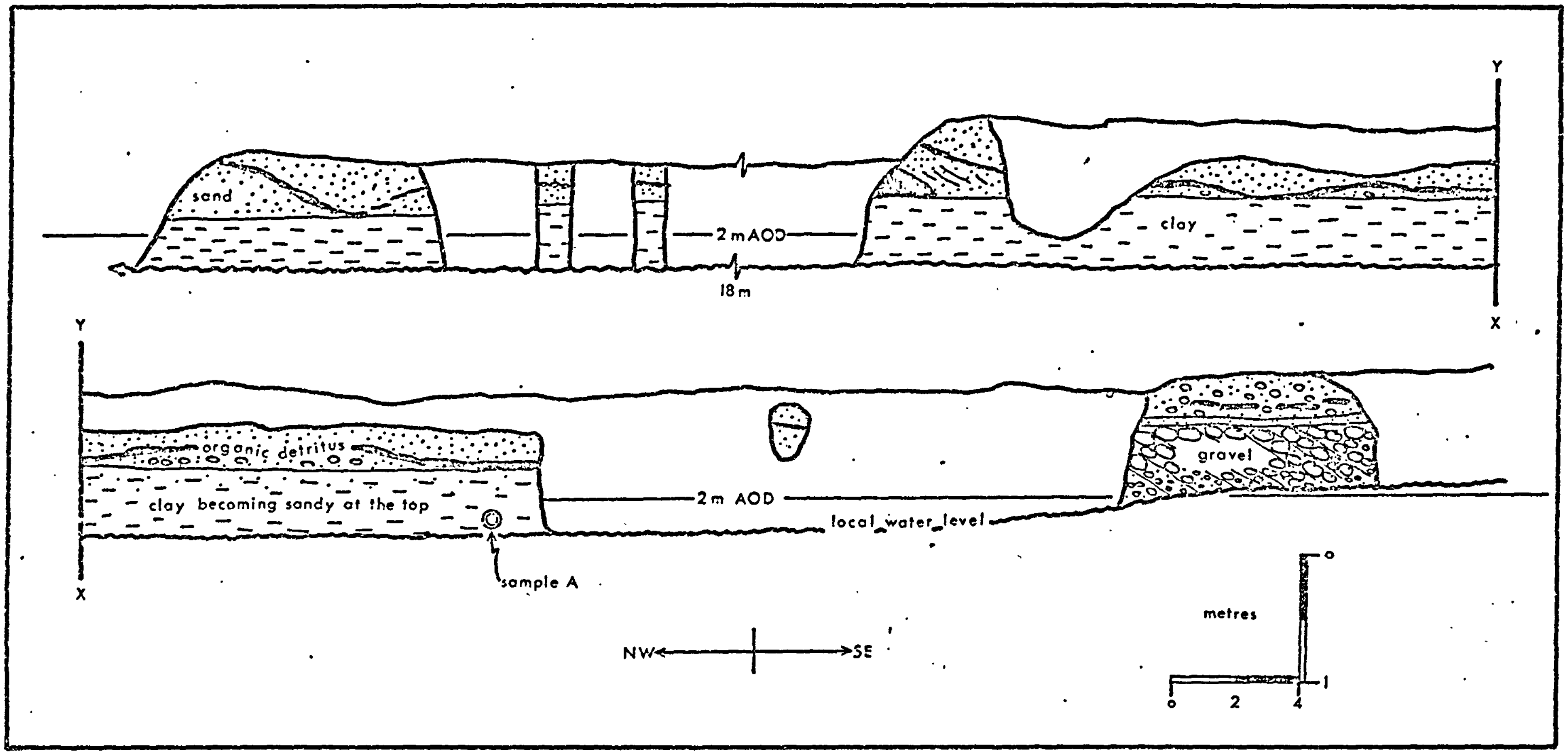


Figure 10.6 Woodside Cottage Quarry, Site 5: section. Vertical exaggeration is x 8. The south-easternmost part of the section (gravel) is drawn as if it is a south-west-facing section, although in reality it faces north-east.

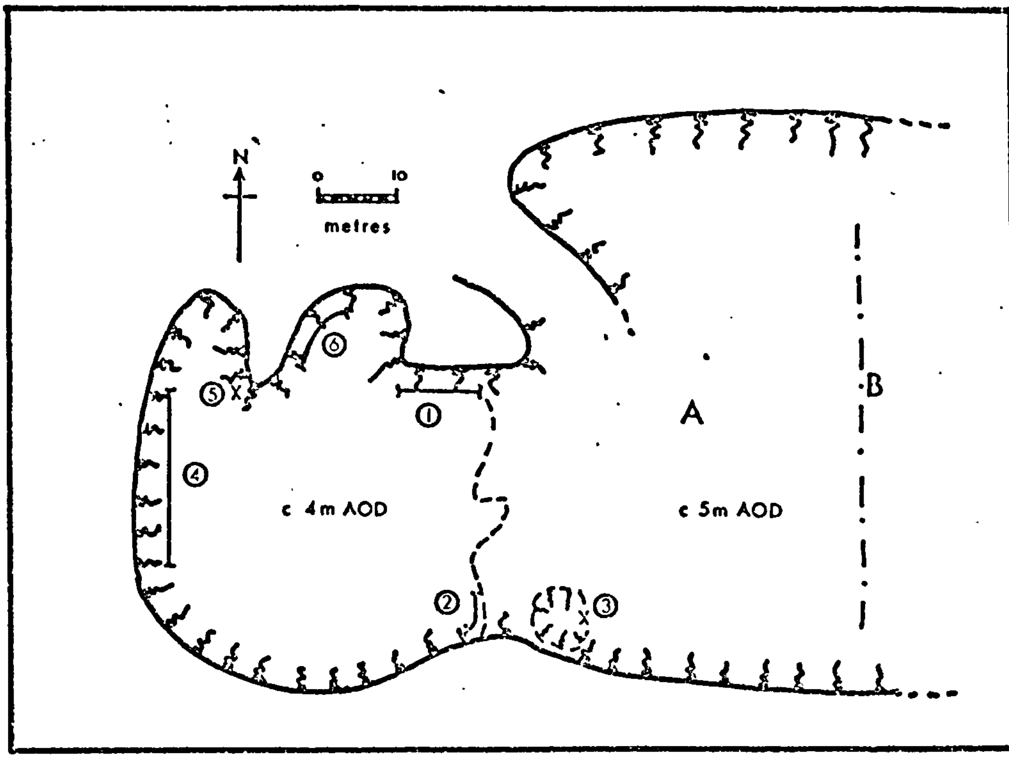


Figure 10.7 Shewalton Moor Small Quarry: section locations. The approximate levels of the quarry floor surfaces are shown. The surrounding land lies at c. 10-11 m A.O.D. In area A is a surface scatter of organic debris; B is the approximate easterly limit of the organic scatter.

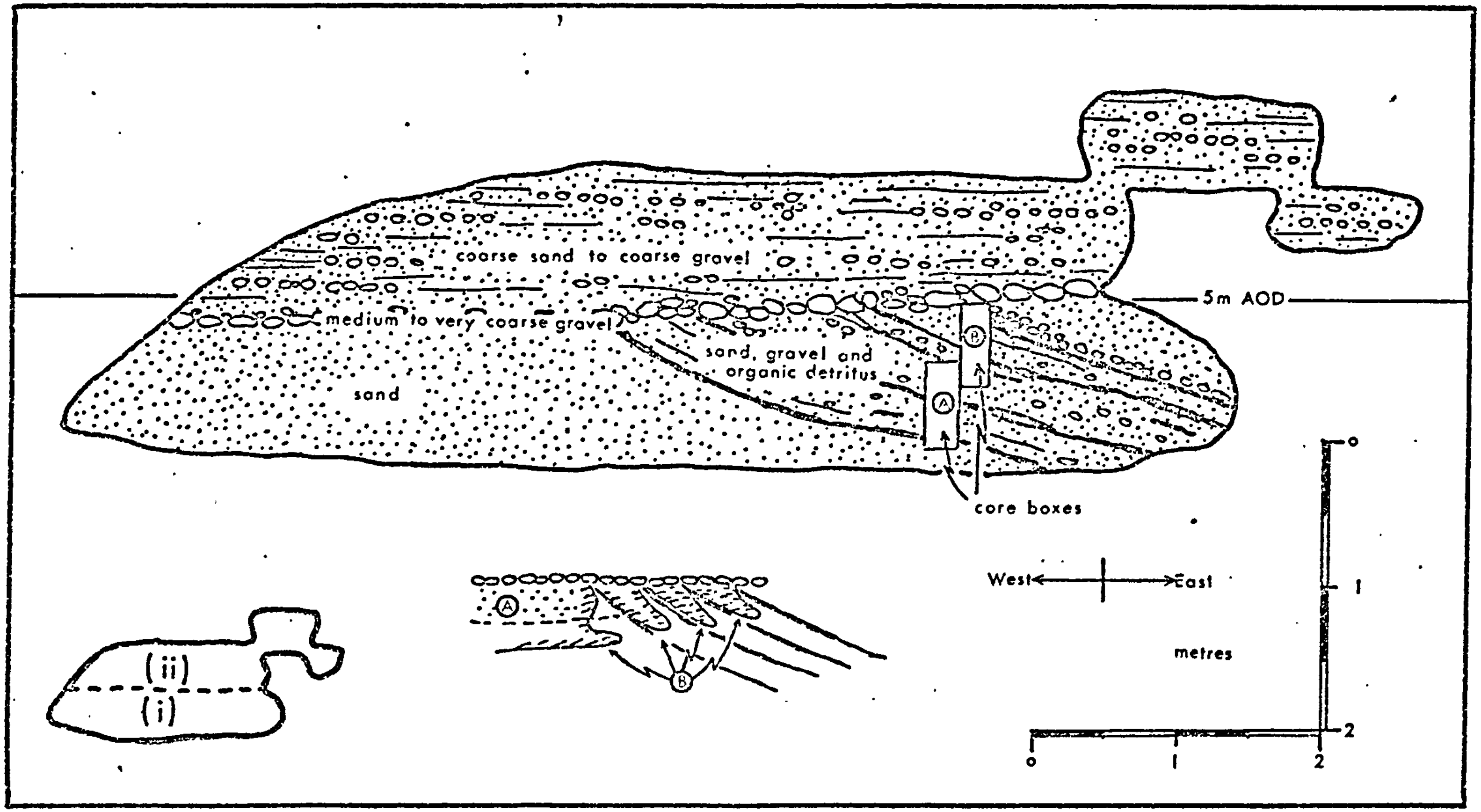


Figure 10.8 Shewalton Moor Small Quarry, Section 1. At the bottom, centre, a sketch of the central part of the section, showing the area of slight soil development (A) and the "lobes" of strong iron oxide staining (B). Bottom left is a sketch showing the positions of the sedimentary units discussed in Chapter 10.9.

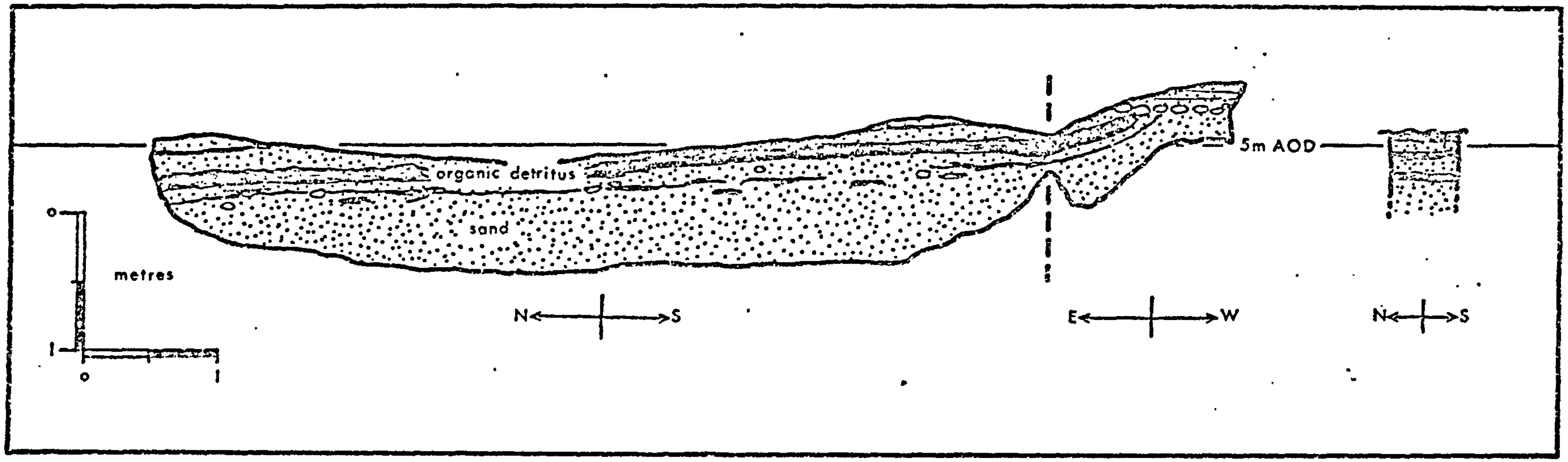


Figure 10.9 Shewalton Moor Small Quarry, Sections 2 (left) and 3 (right).

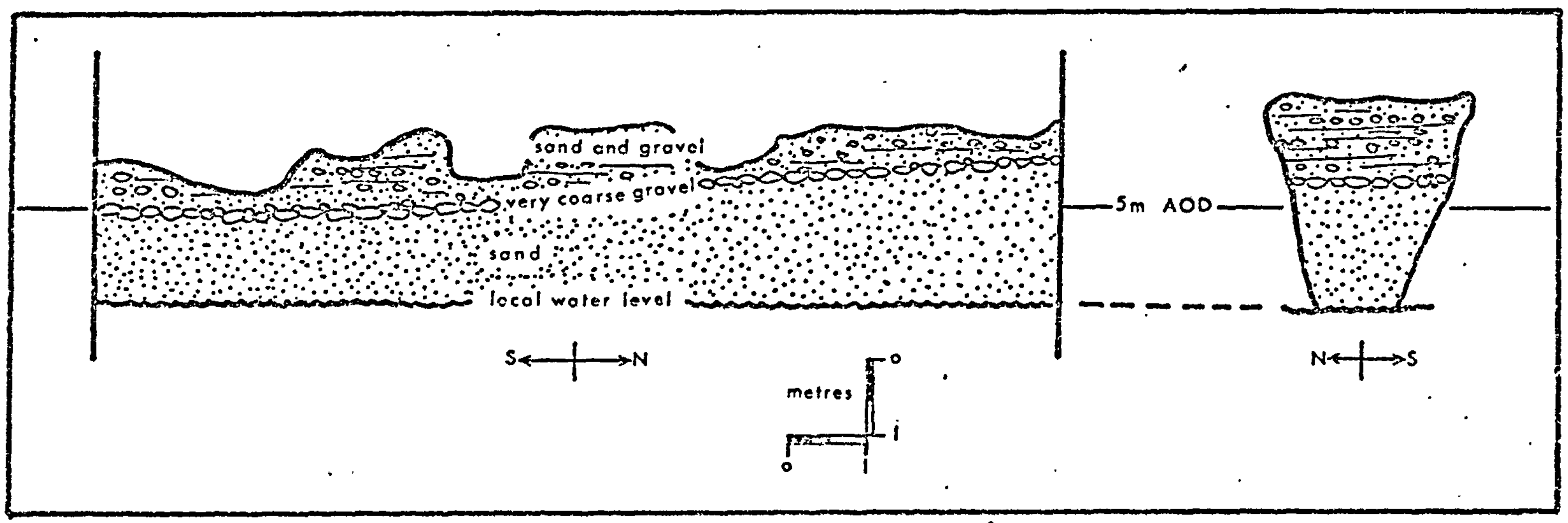


Figure 10.10 Shewalton Moor Small Quarry, Sections 4 (left) and 5 (right).

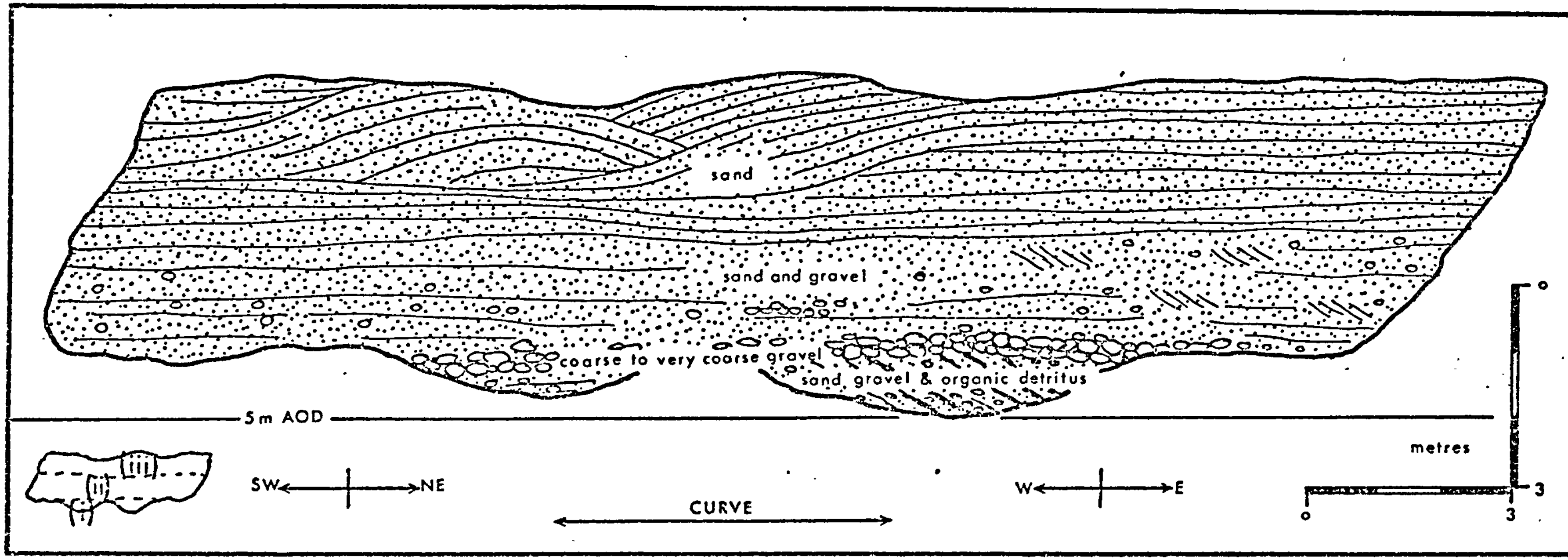


Figure 10.11 Shewalton Moor Small Quarry, Section 6. The large-scale cross bedding is represented diagrammatically. The sketch at the bottom (left) shows the positions of the sedimentary units discussed in Chapter 10.9.

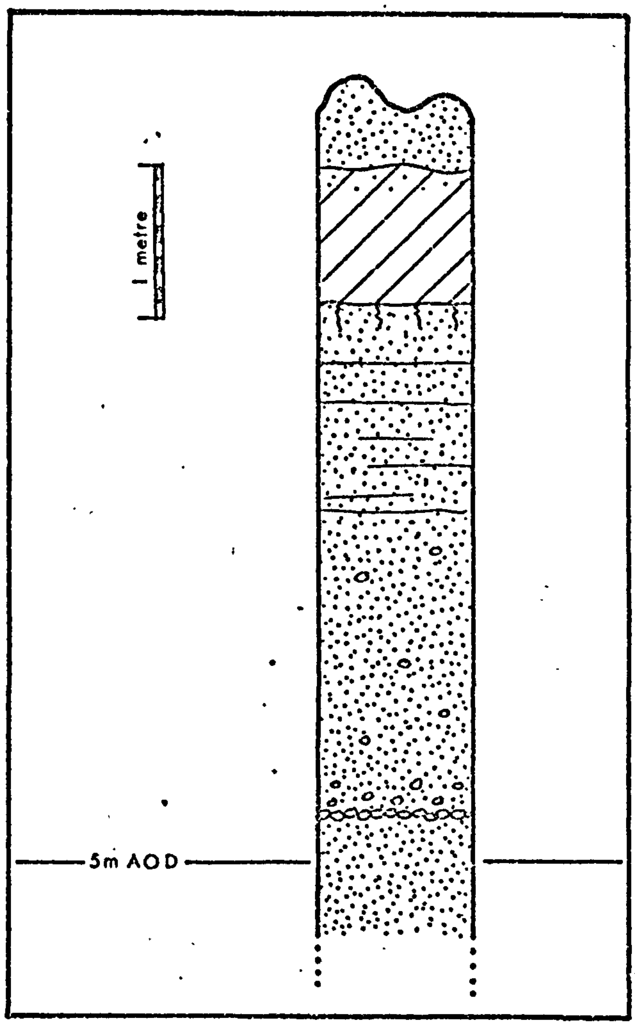


Figure 10.12 Shewalton Moor Quarry, Section 1. The section faces east. Sand is indicated by stippling, peat by cross hatching and the slight soil development delow the peat is shown by wavy lines.

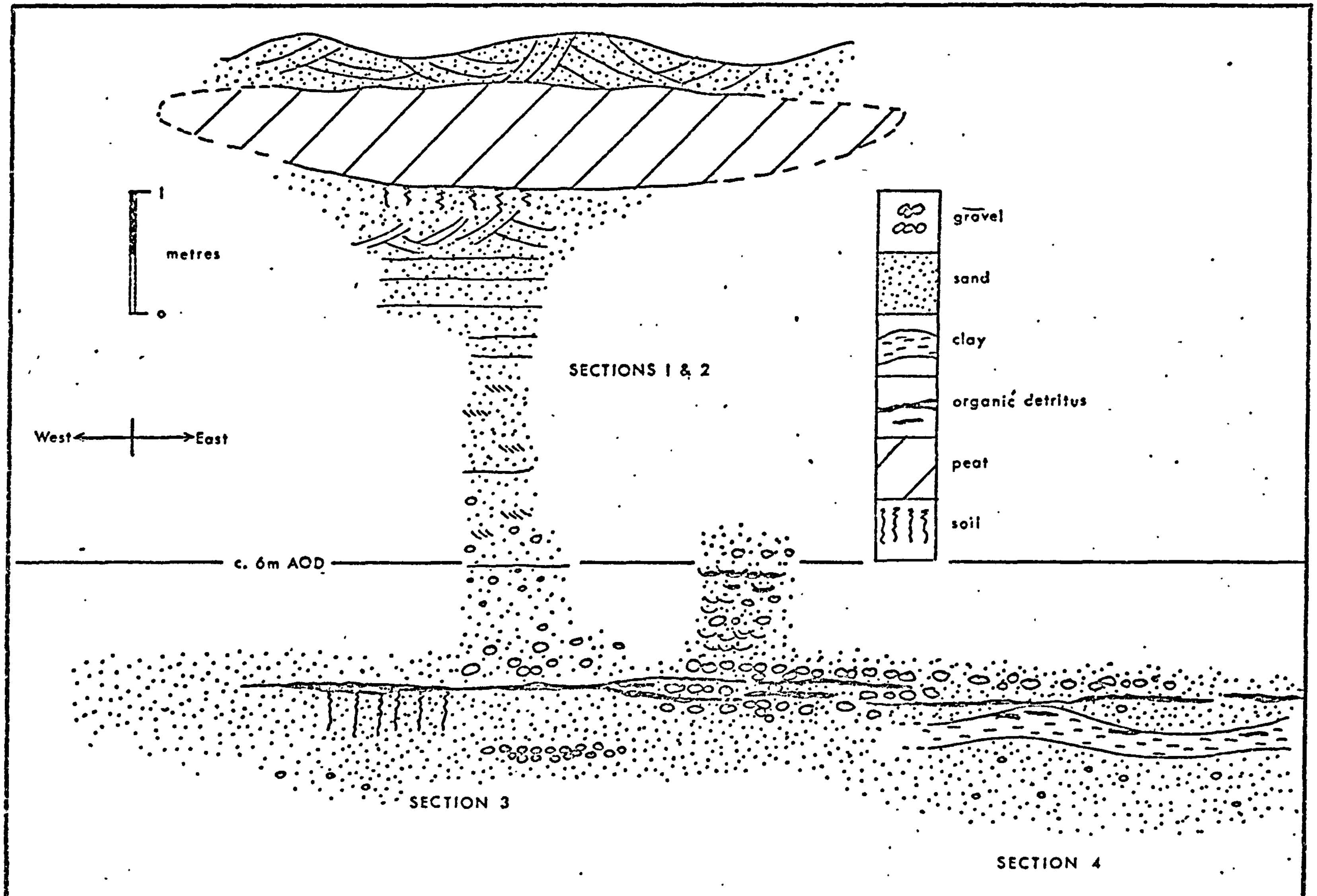


Figure 10.13 Shewalton Moor Quarry: summary sketch showing the main sedimentary features and their interrelationships. The section is c. 300 m long.

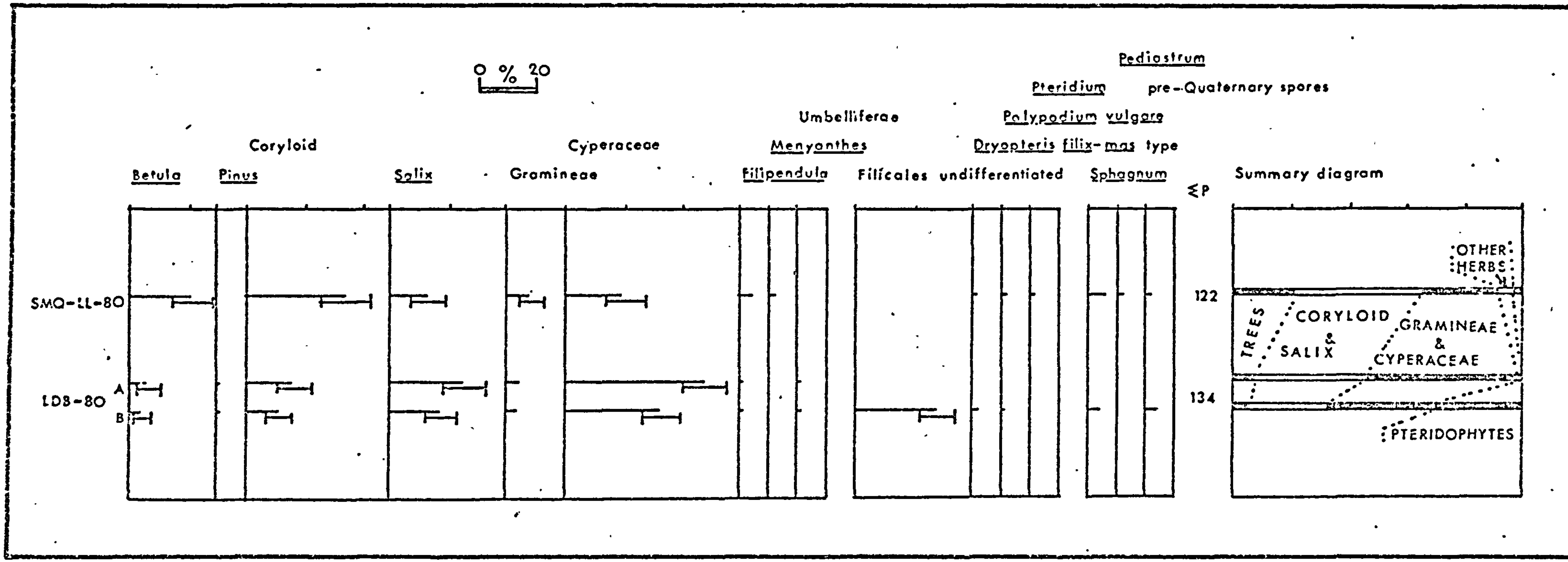


Figure 11.1 Shewalton Moor Quarry, basal organic detritus layer (SMQ-LL-80) and Long Drive Bridge (LDB-80): results of pollen analysis. The values are percentages of total pollen plus pteridophyte spores (SMQ-LL-80 and LDB-80, B) and of total pollen (LDB-80, A). Due to the low total counts used, error limits (Maher, 1972) are shown as bracketted bars.

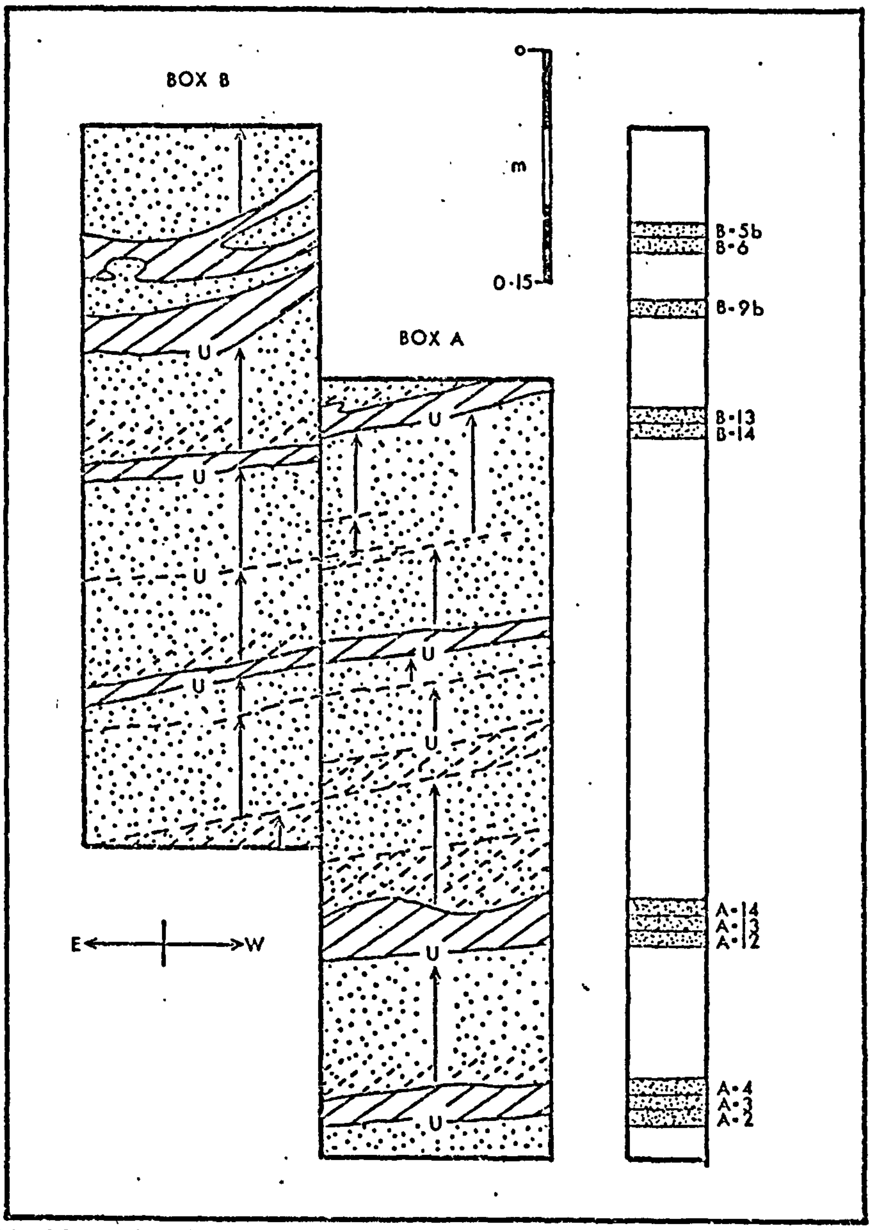


Figure 11.2 Shewalton Moor Small Quarry, Section 1: box core sections. Organic sediment is hatched, inorganic is stippled. Arrows indicate direction of sediment coarsening. U indicates an identifiable unconformity. The 10 mm thick pollen analysis samples are shown on the right. There is no vertical exaggeration for the box core sections.

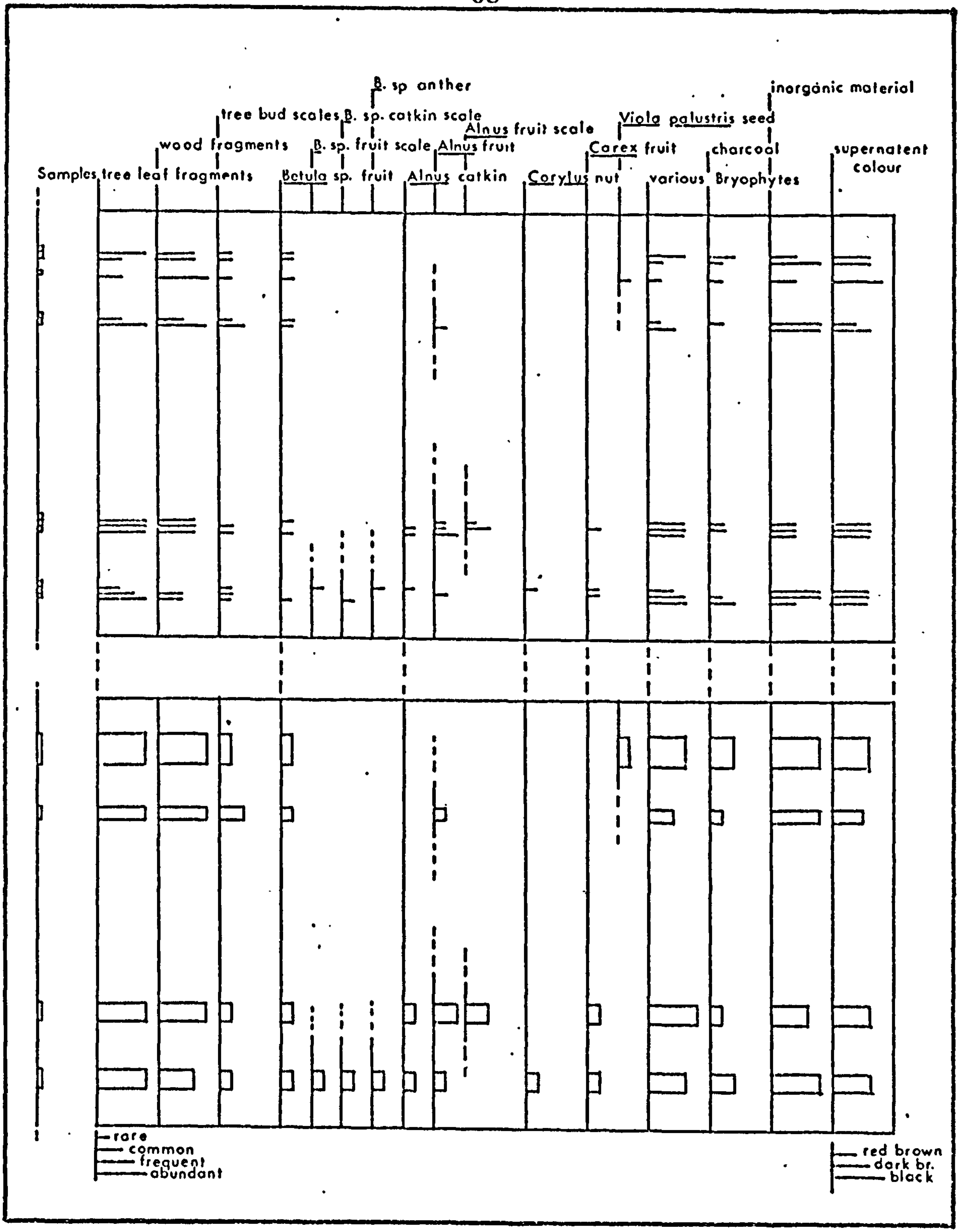


Figure 11.3 Shewalton Moor Small Quarry; results of the plant macrofossil analysis. Results for individual samples are shown in the upper part, and the compounded results for each organic layer are shown in the lower part.

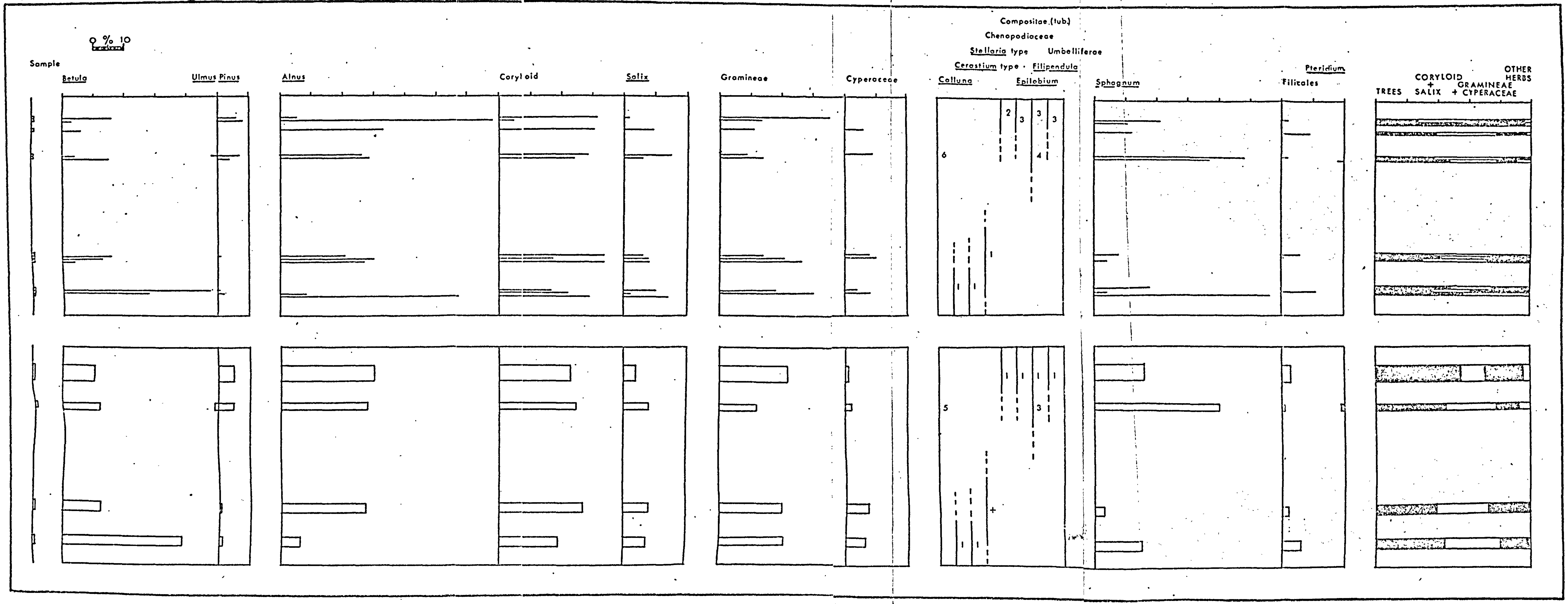


Figure 11.4 Shewalton Moor Small Quarry: results of the pollen analysis. Values are percentages of total pollen. The results are presented for each sample (upper part) and compounded for each organic layer (lower part); see Chapter 11.2 for further discussion.

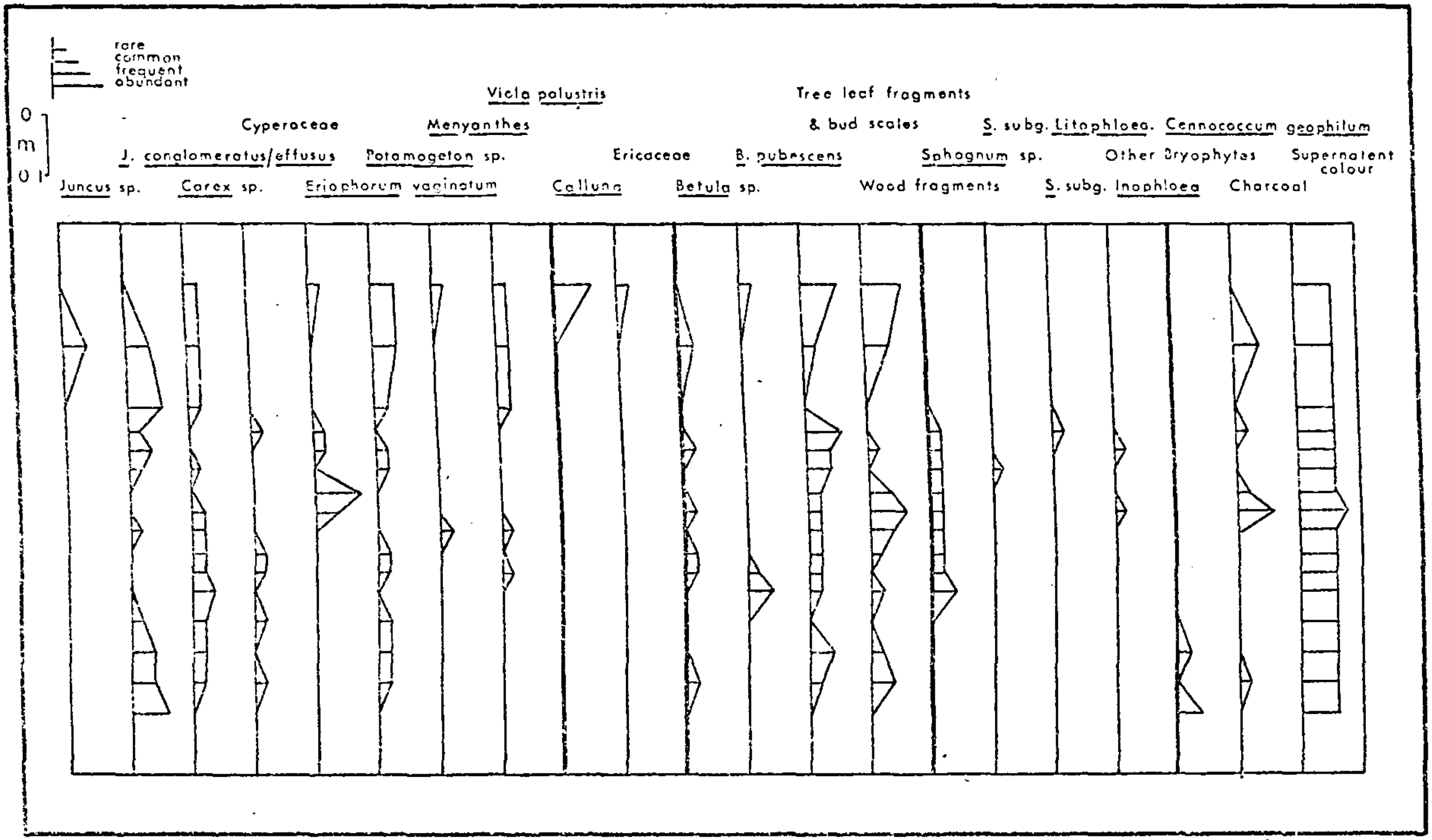


Figure 11.5 Shewalton Moor Quarry; SMQ-80: results of the plant macrofossil analysis. The supernatent colour is mostly very dark brown, with one record of black.

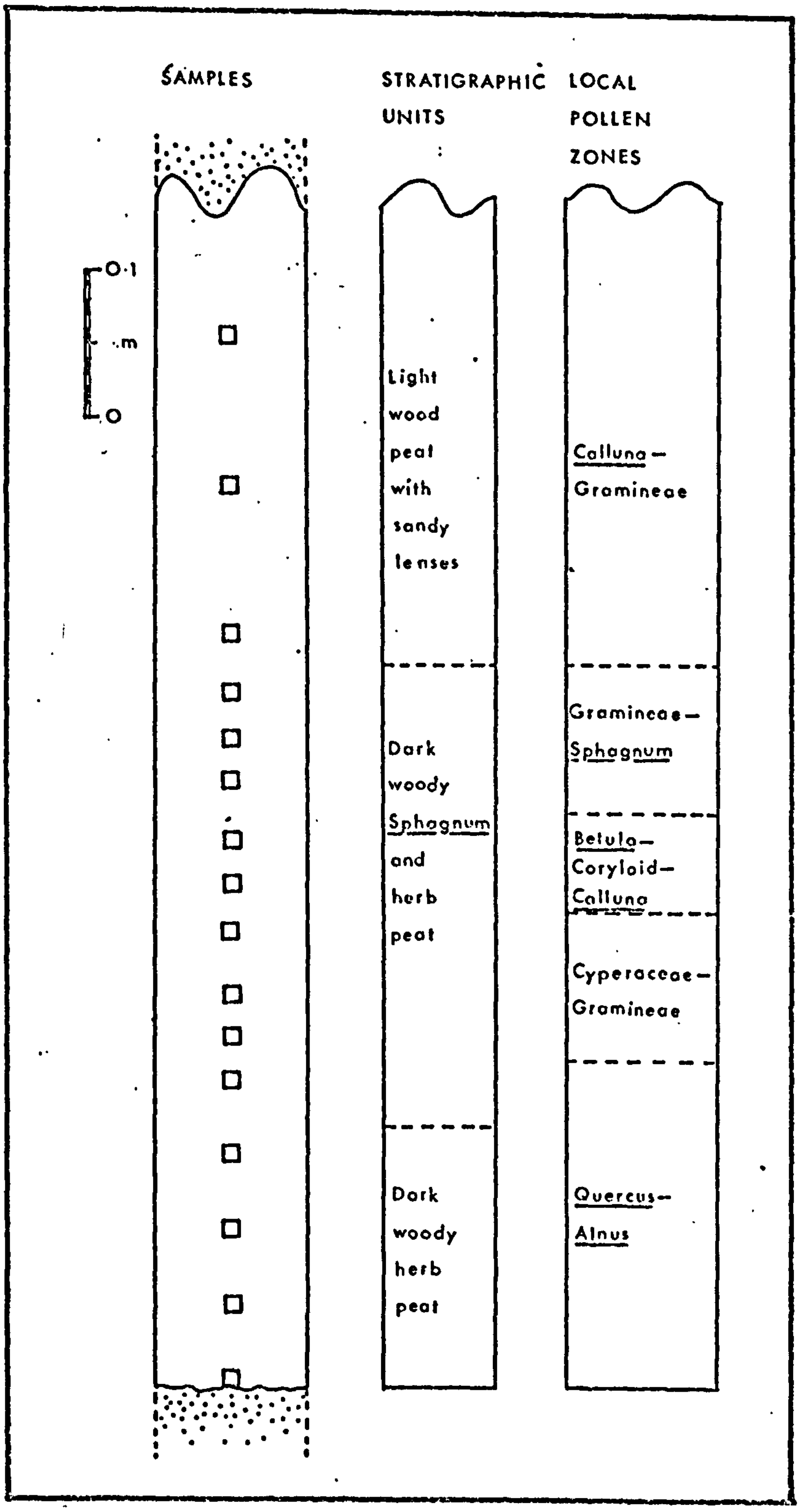


Figure 11.6 Shewalton Moor Quarry; SMQ-80: sample positions, peat and pollen stratigraphy.

Figure 11.7 Shewalton Moor Quarry; SMQ-80: results of the pollen analysis, presented as percentages of total pollen and pteridophyte spores. Total number of pollen taxa and herb taxa and total pollen counted are shown at the right hand side.

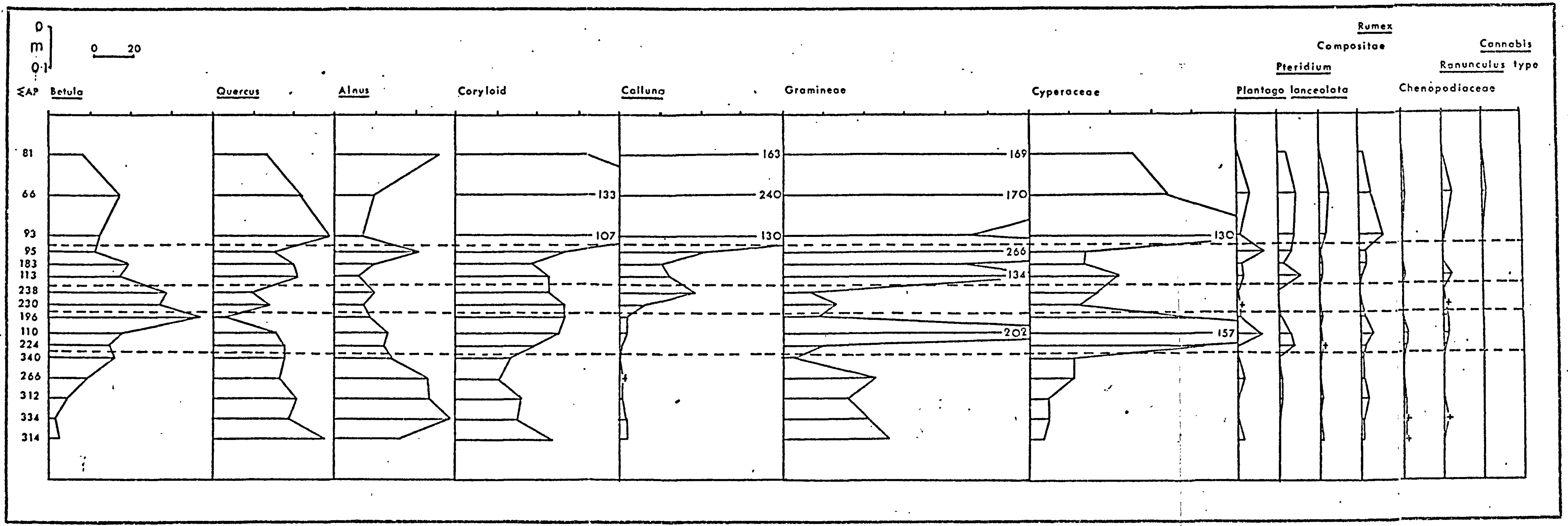


Figure 11.8 Shewalton Moor Quarry; SMQ-80: results of the pollen analysis, presented as percentages of total A.P. Curves for selected taxa only are shown. The curves for Compositae and *Rumex* represent all Compositae and *Rumex* taxa respectively.

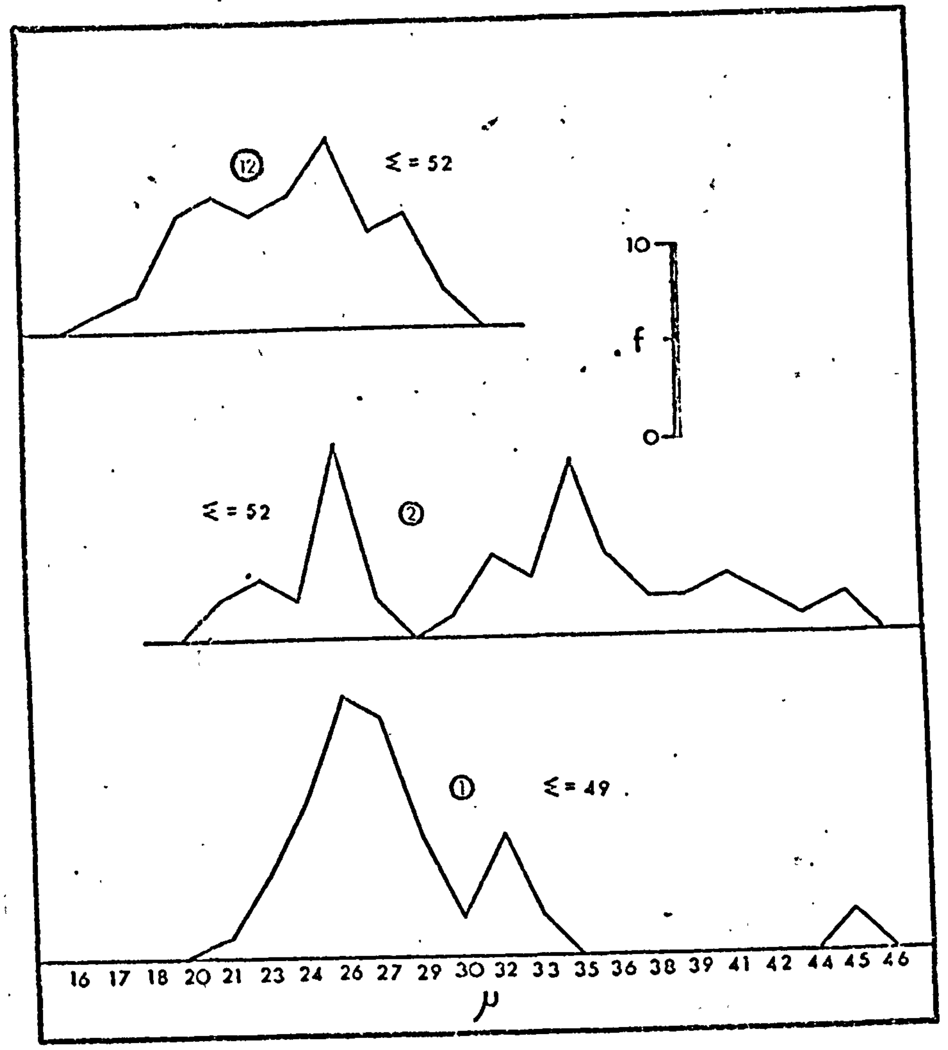


Figure 11.9 Shewalton Moor Quarry, SMQ-80: Gramineae pollen grain size distributions. The frequency (f) of grain sizes are shown for three samples. The sizes are converted to μm from the original microscope graticule measurements, and are rounded to the nearest μm.

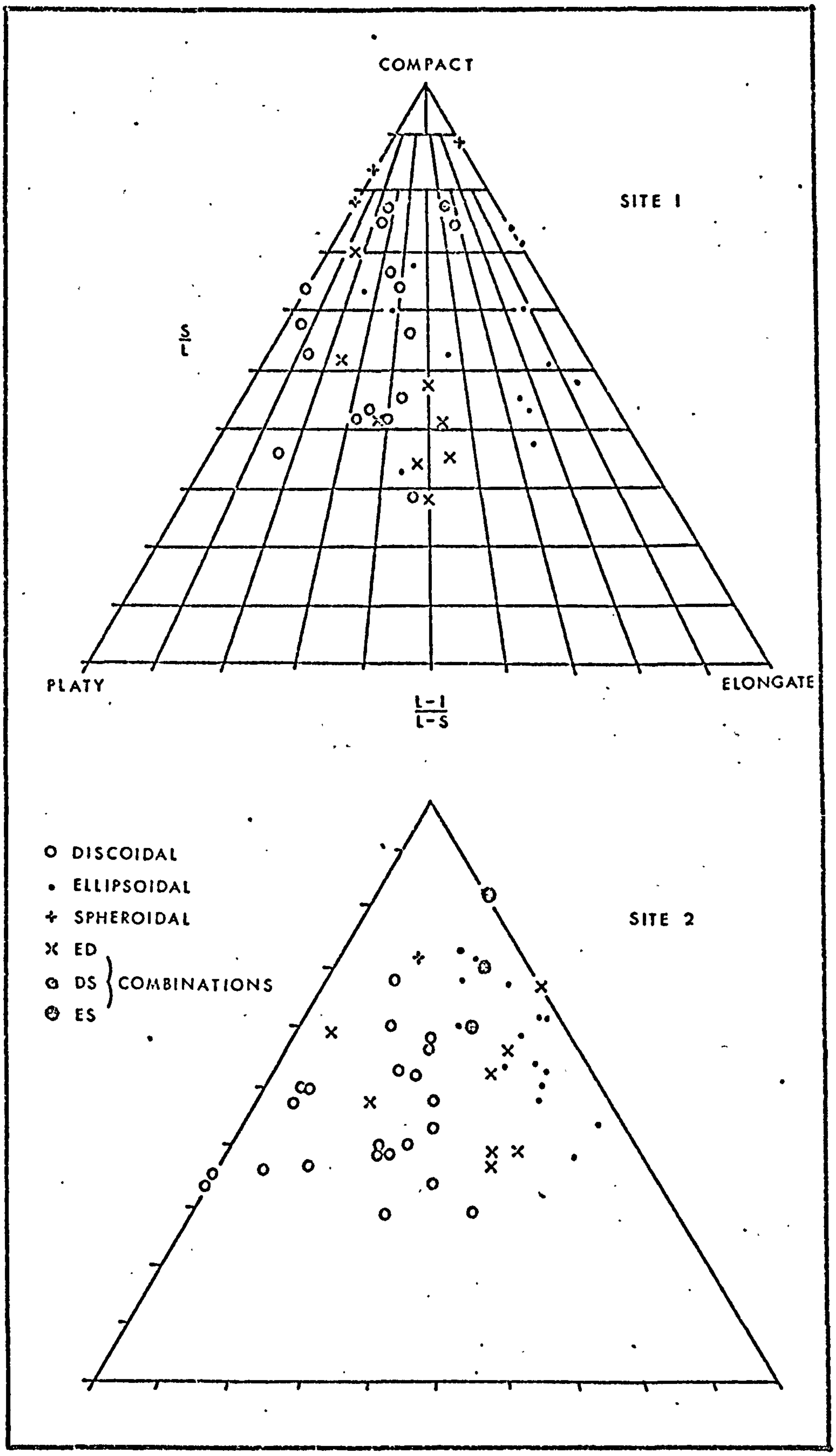
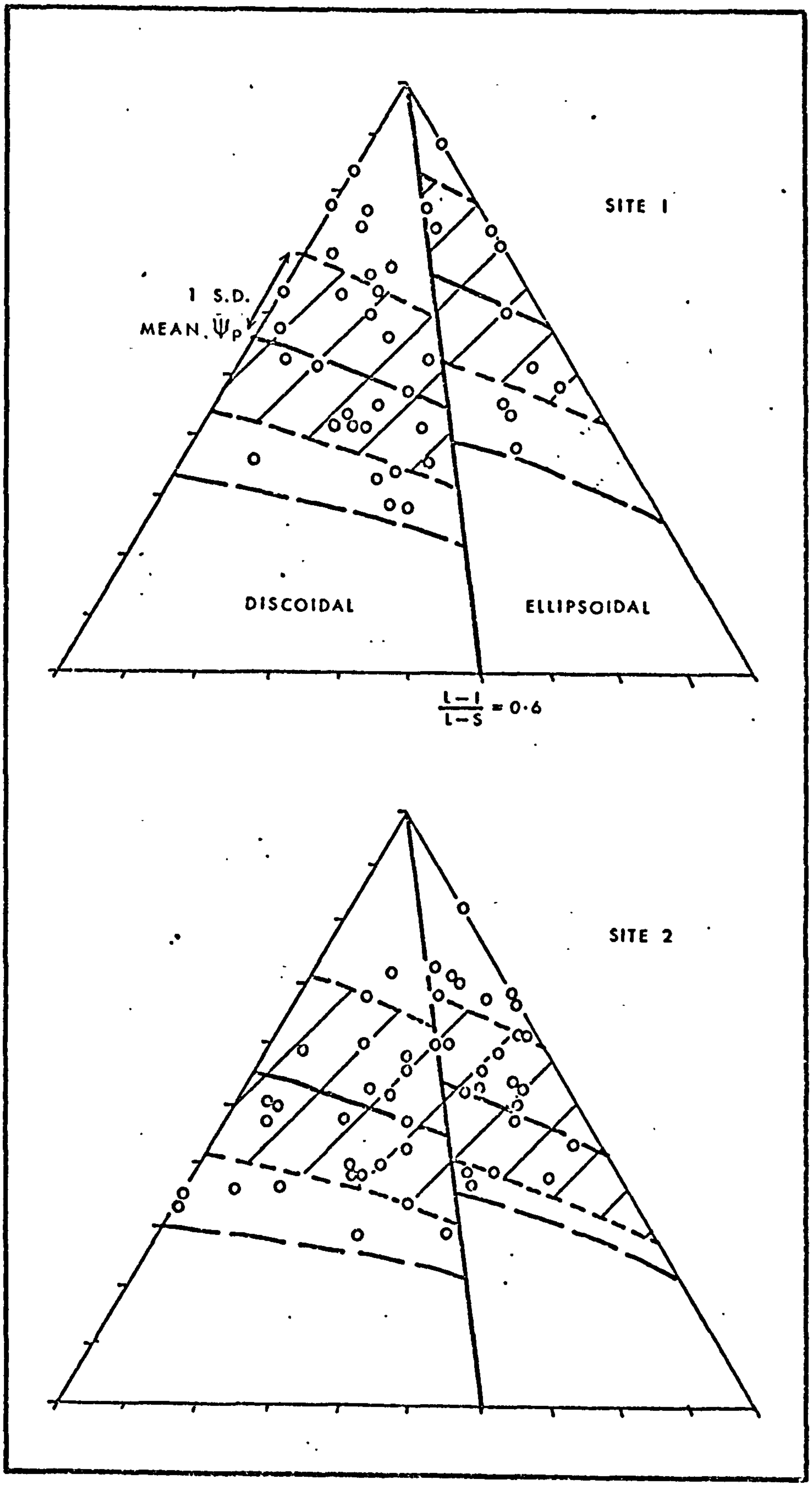


Figure 12.1 The Great Bend, River Irvine, sites 1 and 2; *Lithothamnium* analysis: Sneed & Folk diagrams plotting specimens according to shape as initially described.



<u>Figure 12.2</u> The Great Bend, River Irvine, sites 1 and 2; <u>Lithothamnium</u> analysis: limits and means for Ψ_p. For derivation of Ψ_p-lines, see Sneed & Folk, 1958.

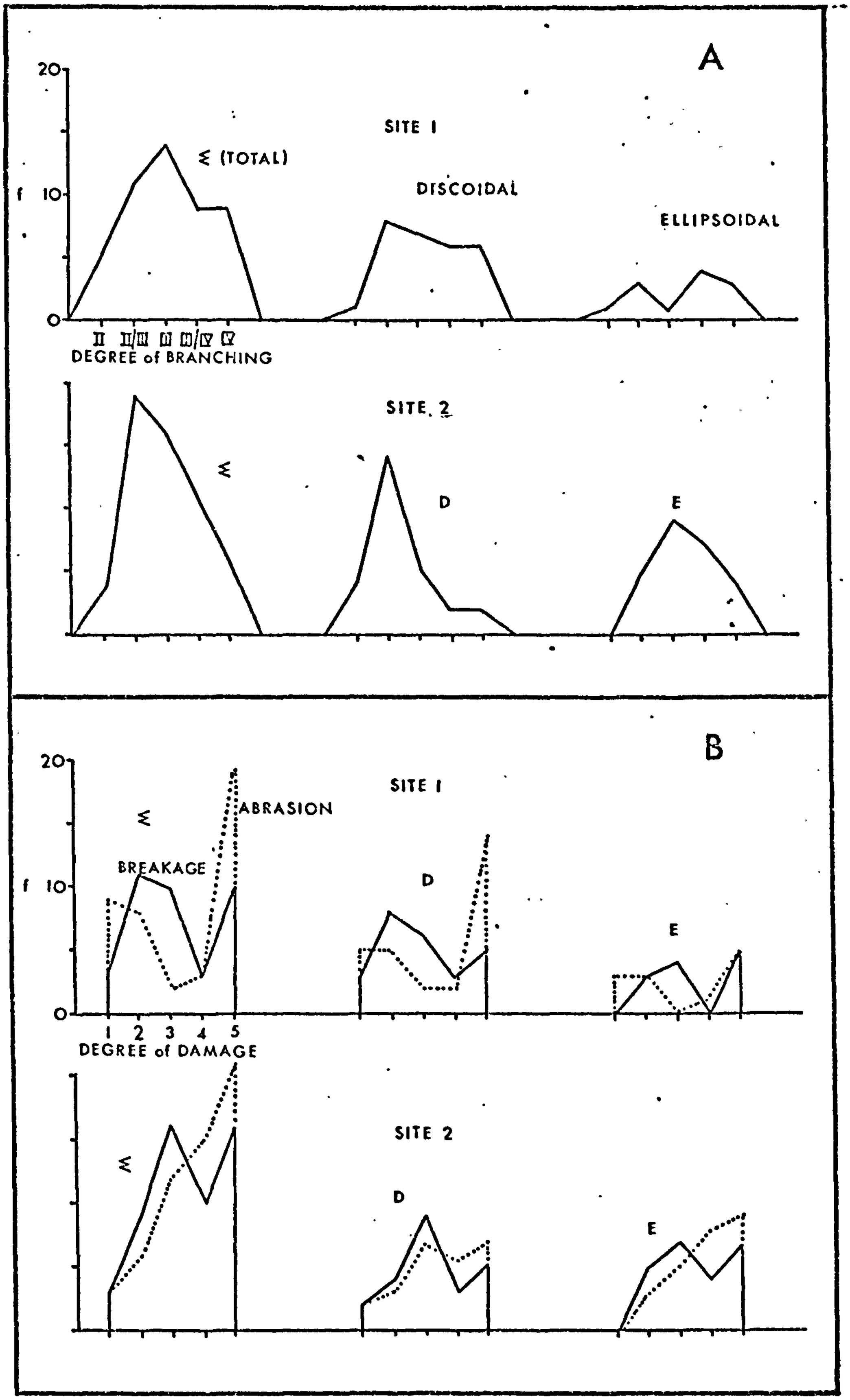


Figure 12.3 The Great Bend, River Irvine; Lithothamnium analysis: frequency graphs for (A) degree of branching and (B) degree of damage.

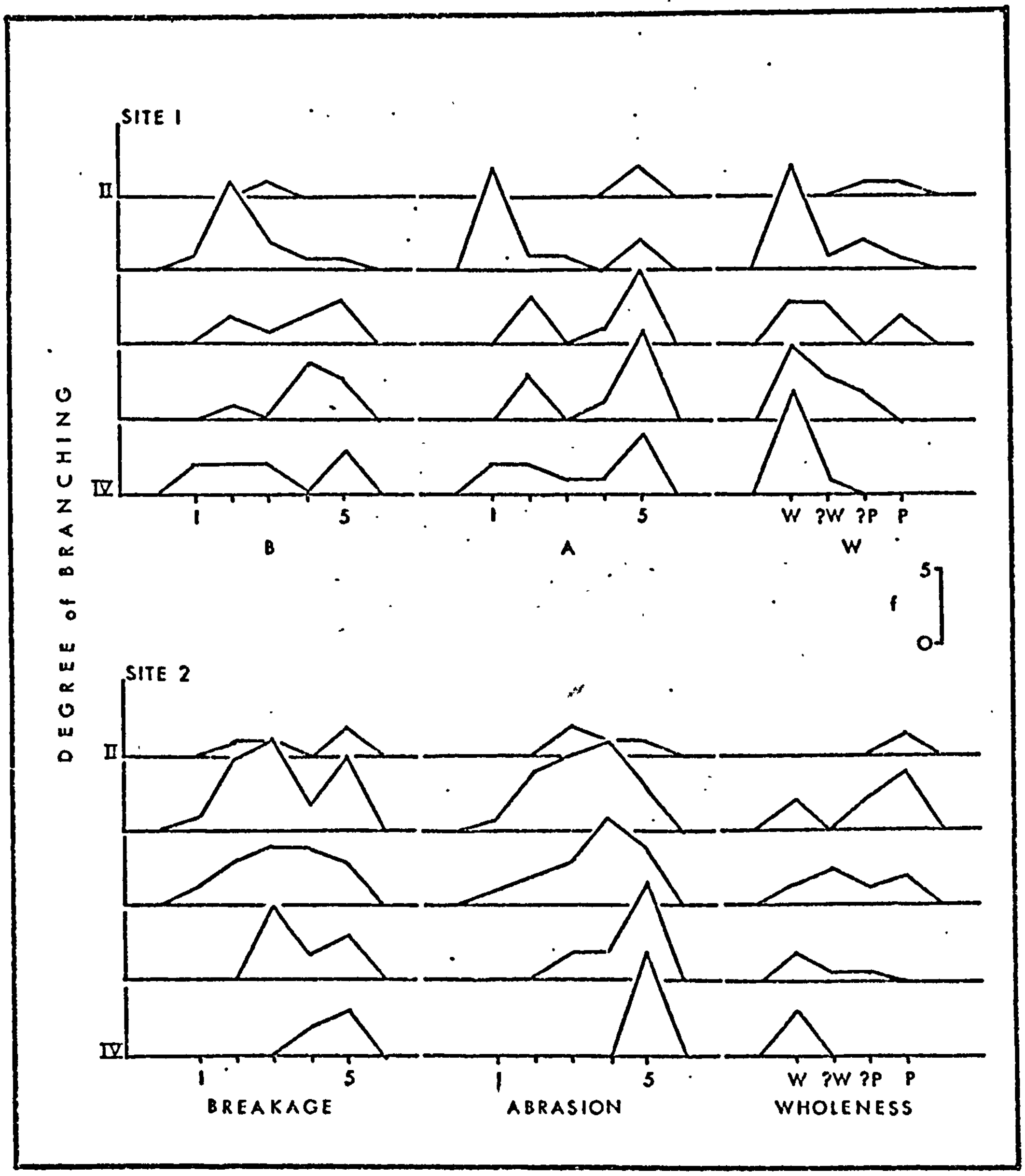


Figure 12.4 The Great Bend, River Irvine; *Lithothamnium* analysis: damage against branching.

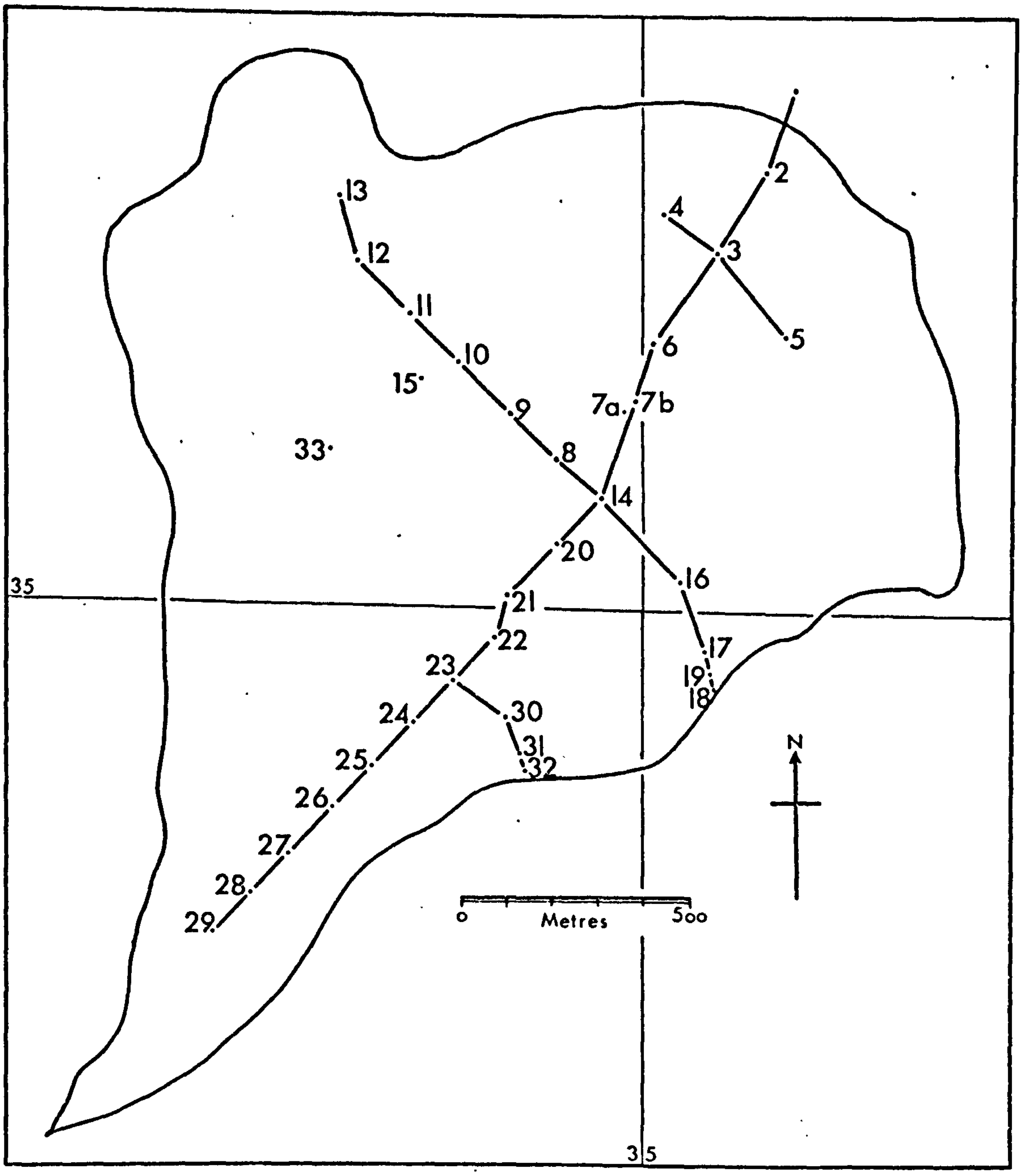


Figure 13.1 Shewalton Moss: outline map showing auger survey locations.

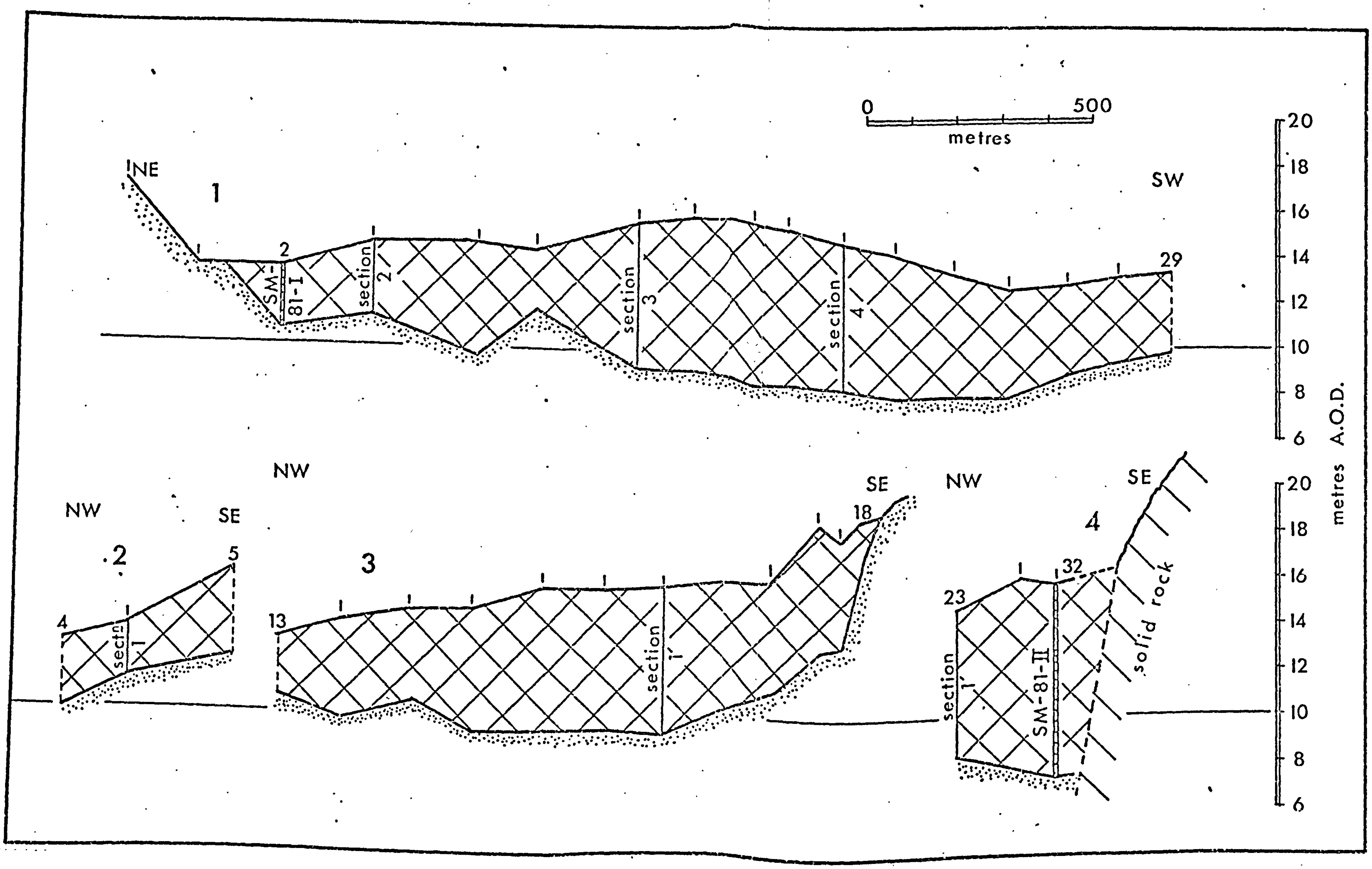


Figure 13.2 Shewalton Moss; auger survey: derived sections. Peat (cross hatching) overlies undifferentiated inorganic sediments (stippled). The positions of pollen cores SM-81-I and SM-81-II. Vertical exaggeration is x 50.

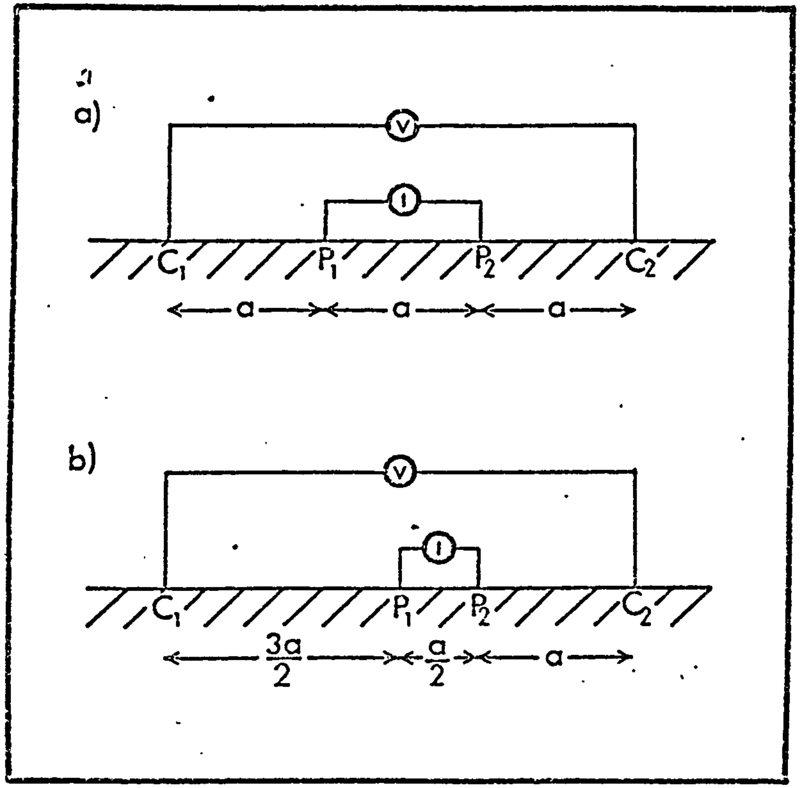


Figure 13.3 Electrical resistivity survey arrays for electrodes. (a) Wenner Array, and (b) Lee Partition, showing the array for measuring the right side. P_1 and P_2 are the potential electrodes, C_1 and C_2 are the current electrodes; I and V are the current input and voltage output; a is the separation distance in the Wenner Array.

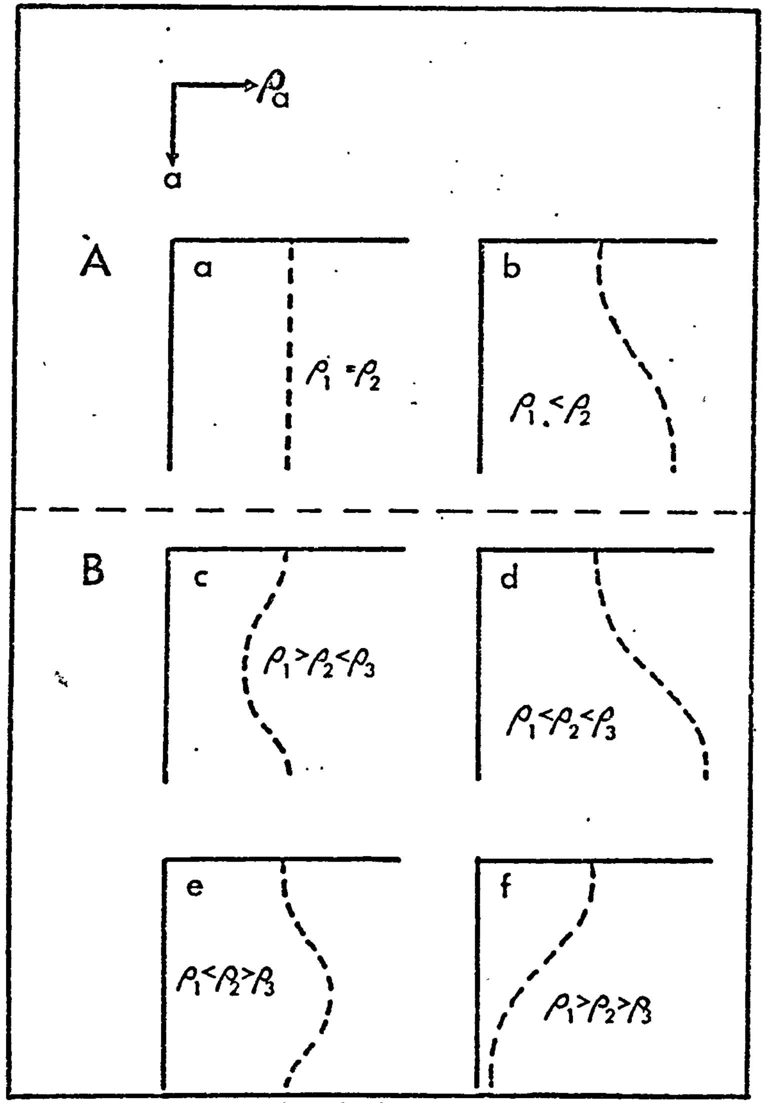


Figure 13.4 Sketch graphs of resistivity curves. Apparent resistivity (ρ_a) against electrode separation distance is shown for several situations in which sub-surface resistivity varies.

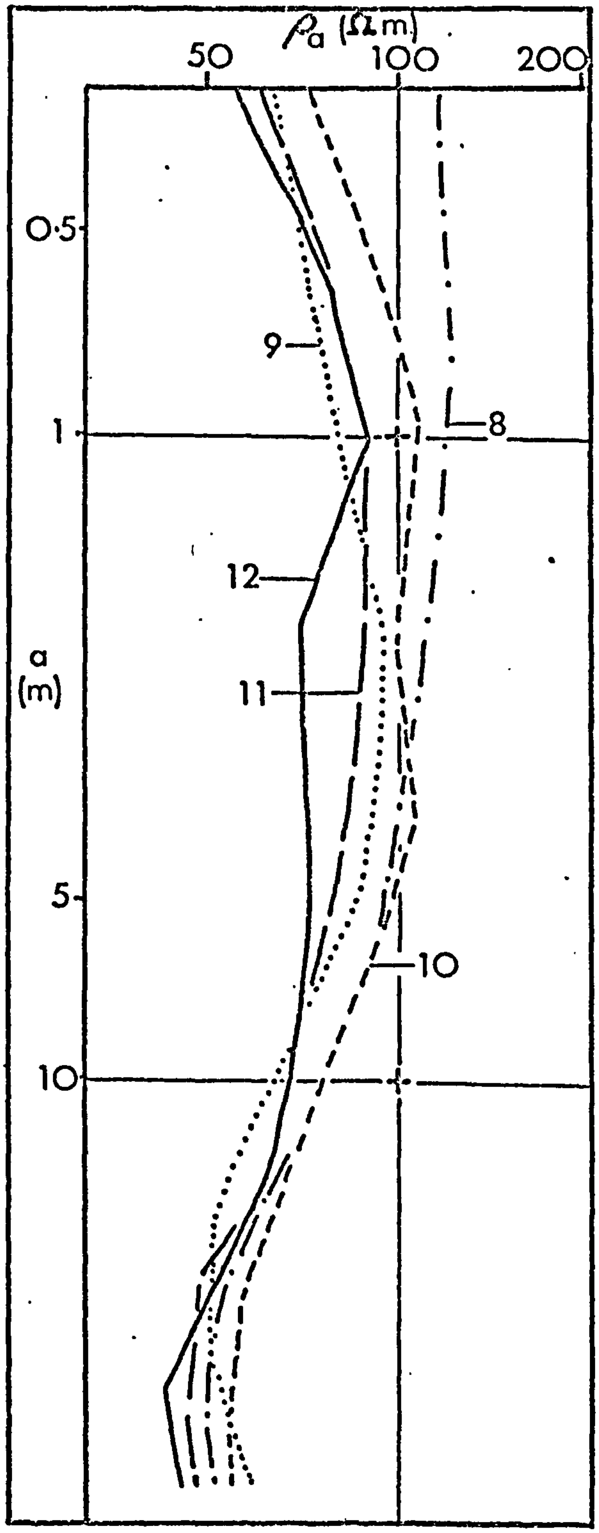


Figure 13.5 Shewalton Moss; electrical resistivity survey: plot of electrical resistivity field measurements. Note that both axes are drawn with logarithmic scales.

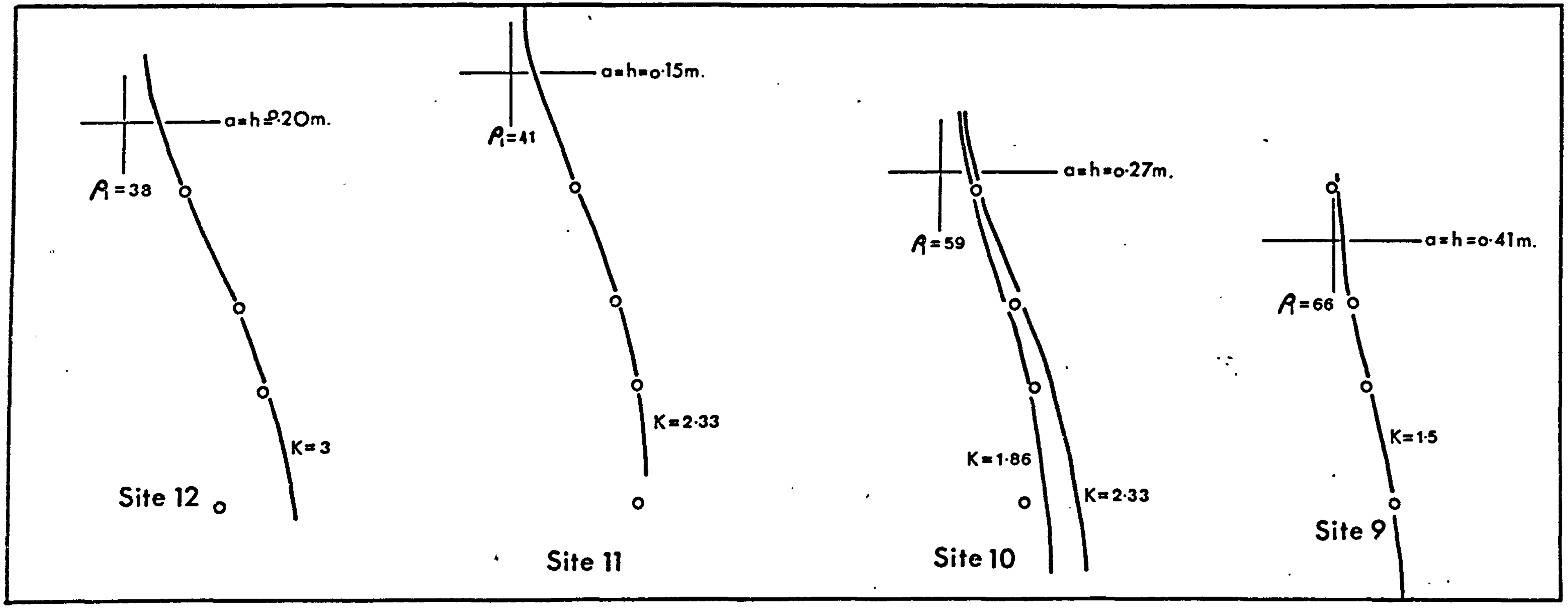


Figure 13.6 Shewalton Moss; electrical resistivity survey: two-layer curving matching for the upper parts of the field measurement curves (sites 9 to 12). The values are plotted on logarithmic scales as ρ_a (Ω m) (horizontal) against electrode separation (m) (vertical). The open circles are the measured values and the full lines are the best-fit theoretical two-layer curves.

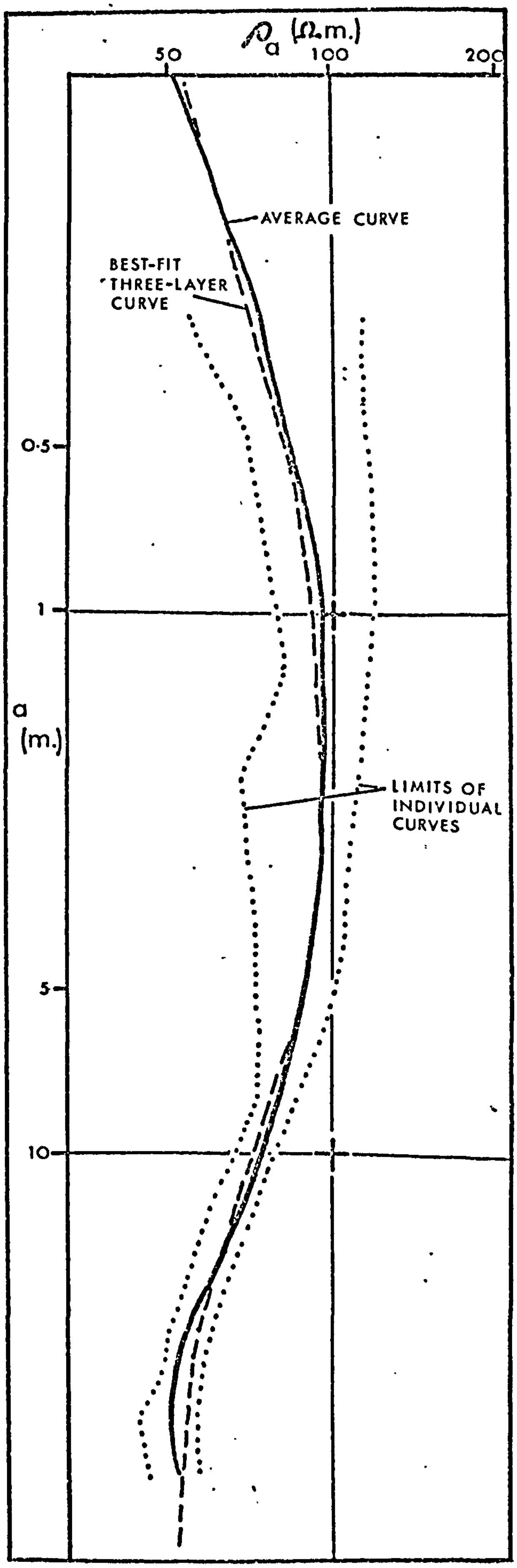


Figure 13.7 Shewalton Moss; electrical resistivity survey: average curve. The curve is drawn by eye from the distribution of curves from sites 8 to 12 (Fig. 13.5).

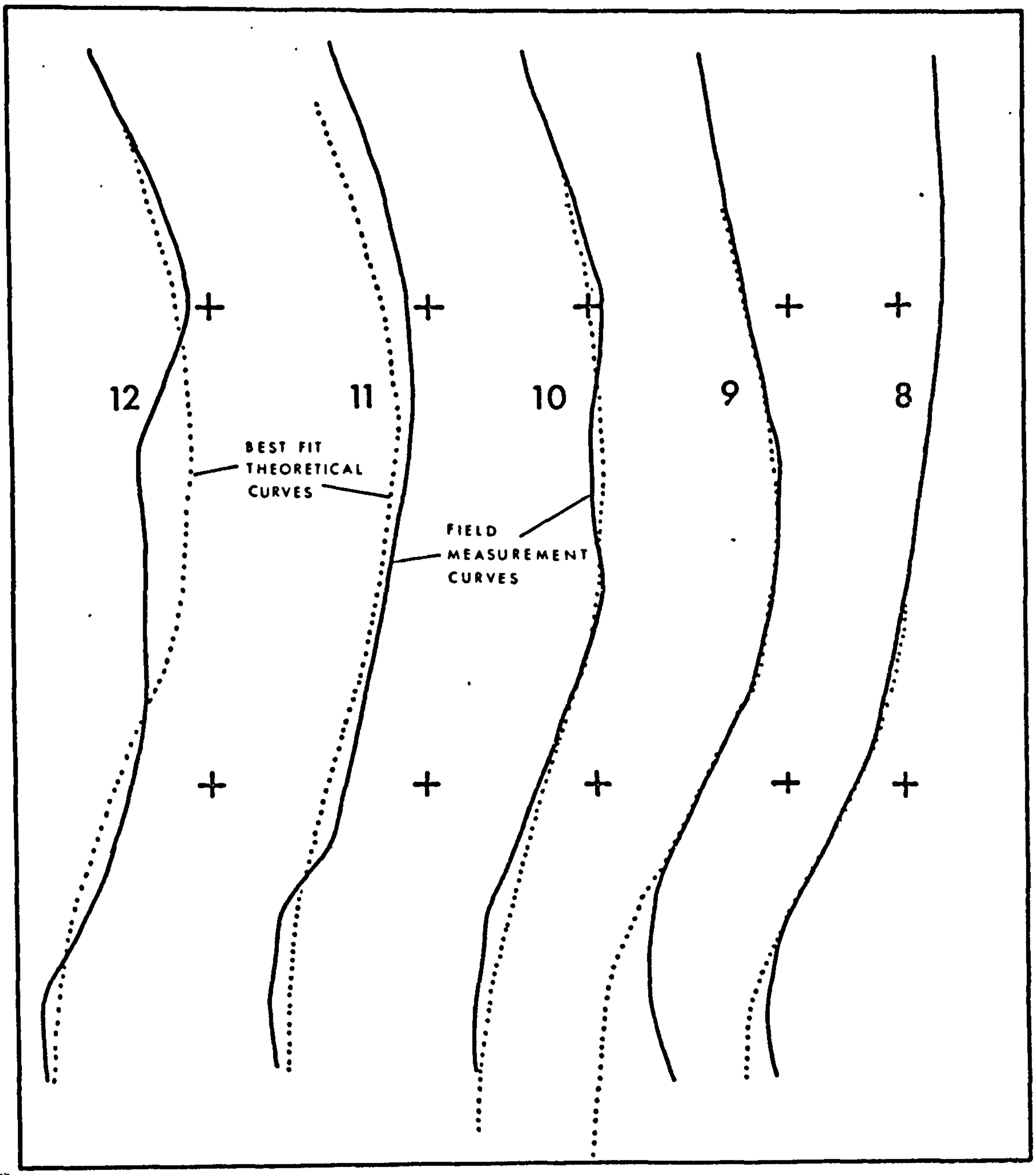


Figure 13.8 Shewalton Moss; electrical resistivity survey: field measurement and best-fit theoretical curves. At sites 9 to 12, computer-calculated three-layer curves are used, and at site 8, a standard two-layer curve is used. The curves are plotted as in Figures 13.5 and 13.7. The crosses represent the points (100 Ωm, 1 m) (top) and (100 Ωm, 10 m) (bottom). For results, see Table 13.3.

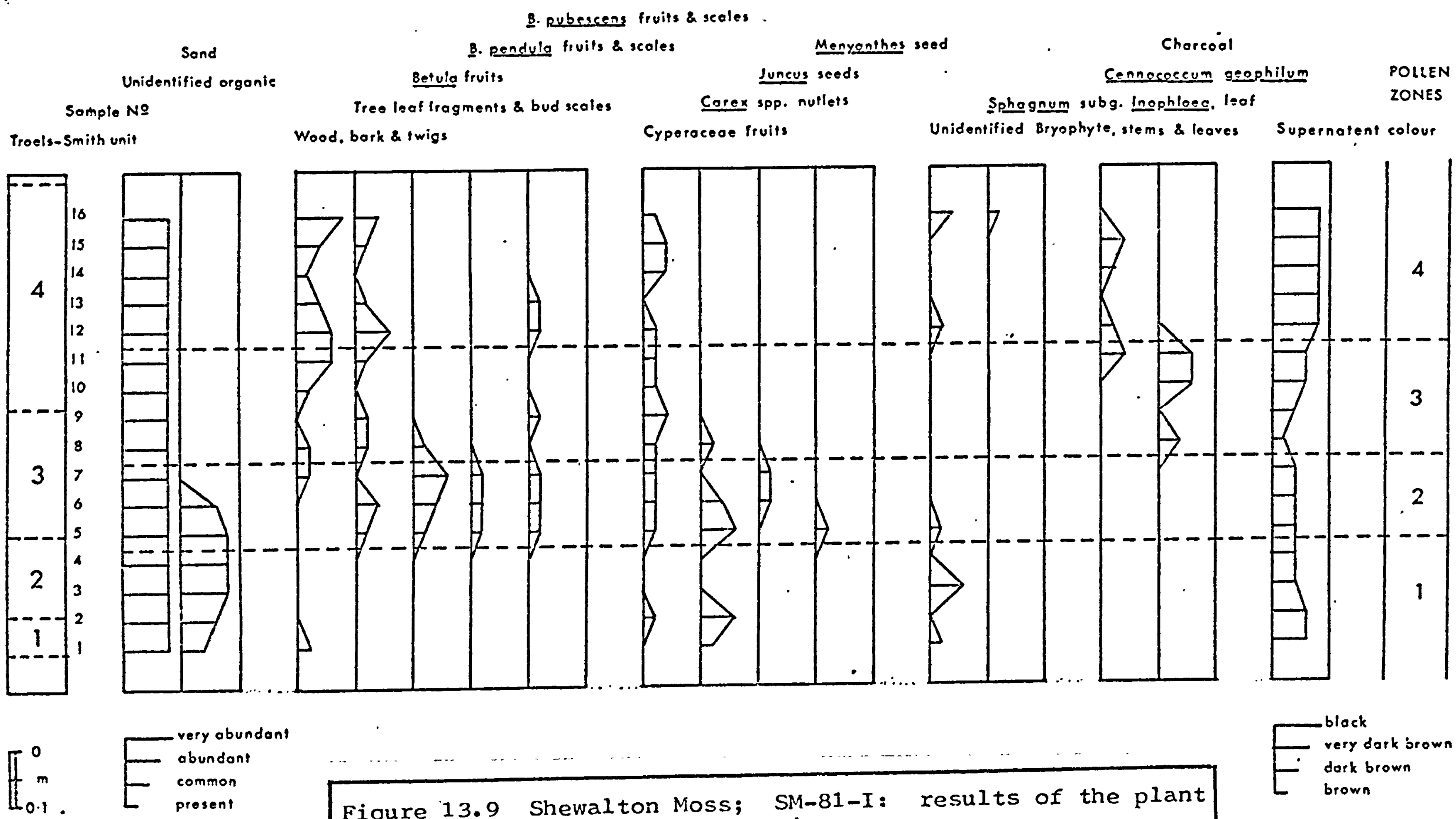


Figure 13.9 Shewalton Moss; SM-81-I: results of the plant macrofossil analysis.

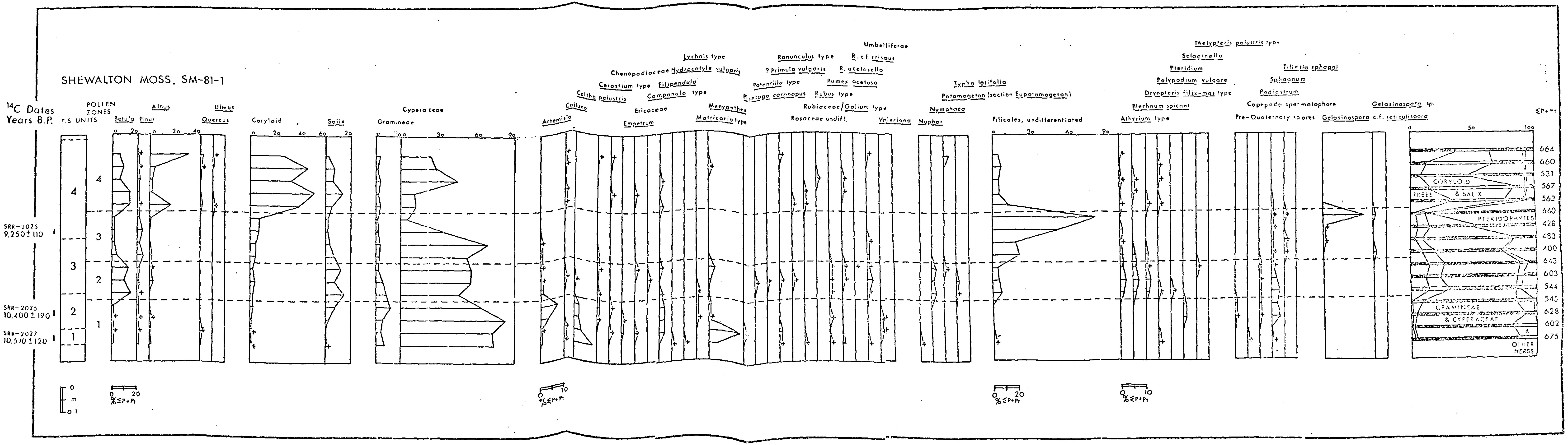


Figure 13.10 Shewalton Moss; SM-81-1: results of the pollen analysis, presented as percentages of total pollen plus pteridophyte spores.

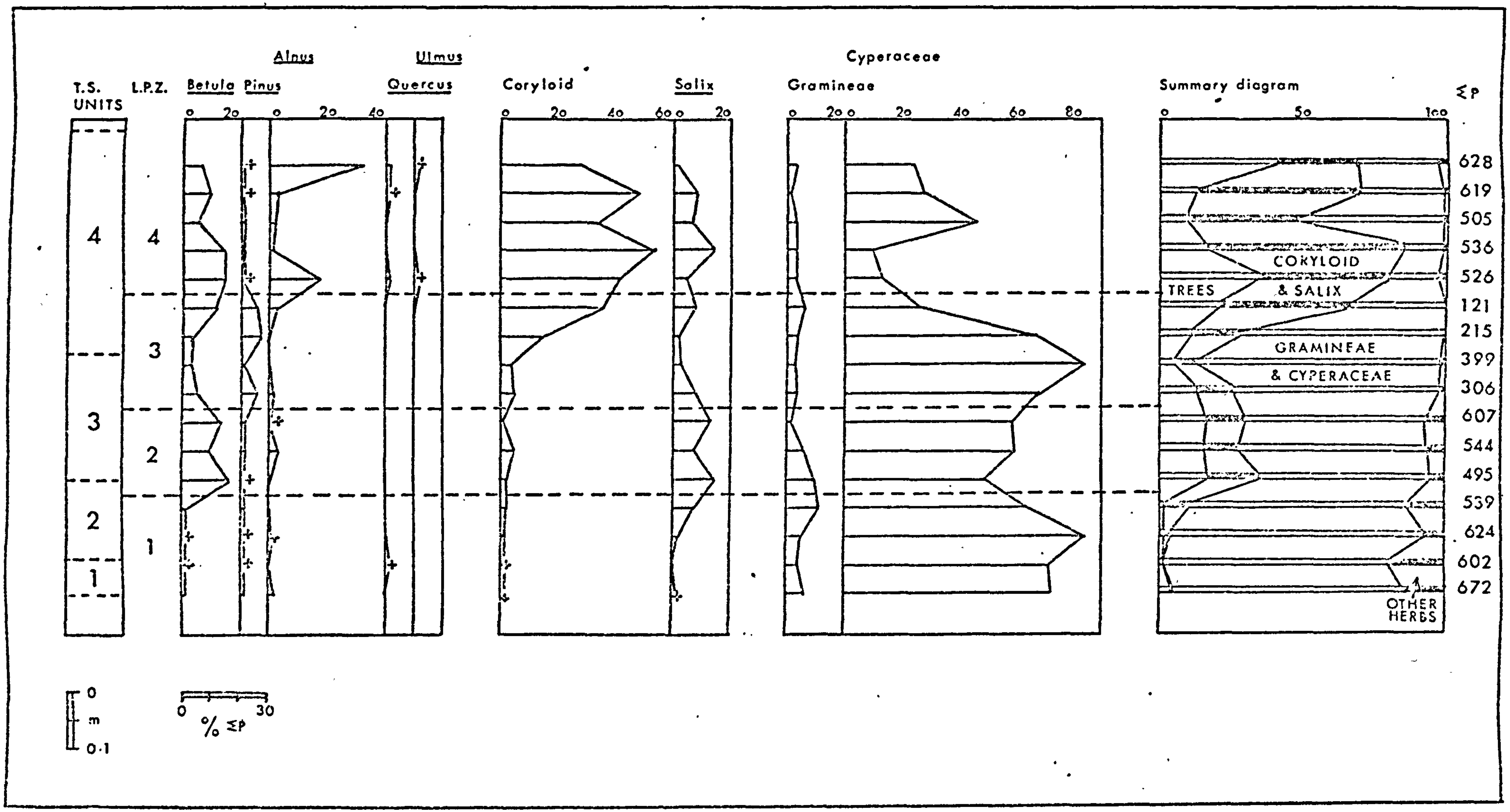


Figure 13.11 Shewalton Moss; SM-81-I: results of the pollen analysis, presented as percentages of total pollen, for selected taxa.

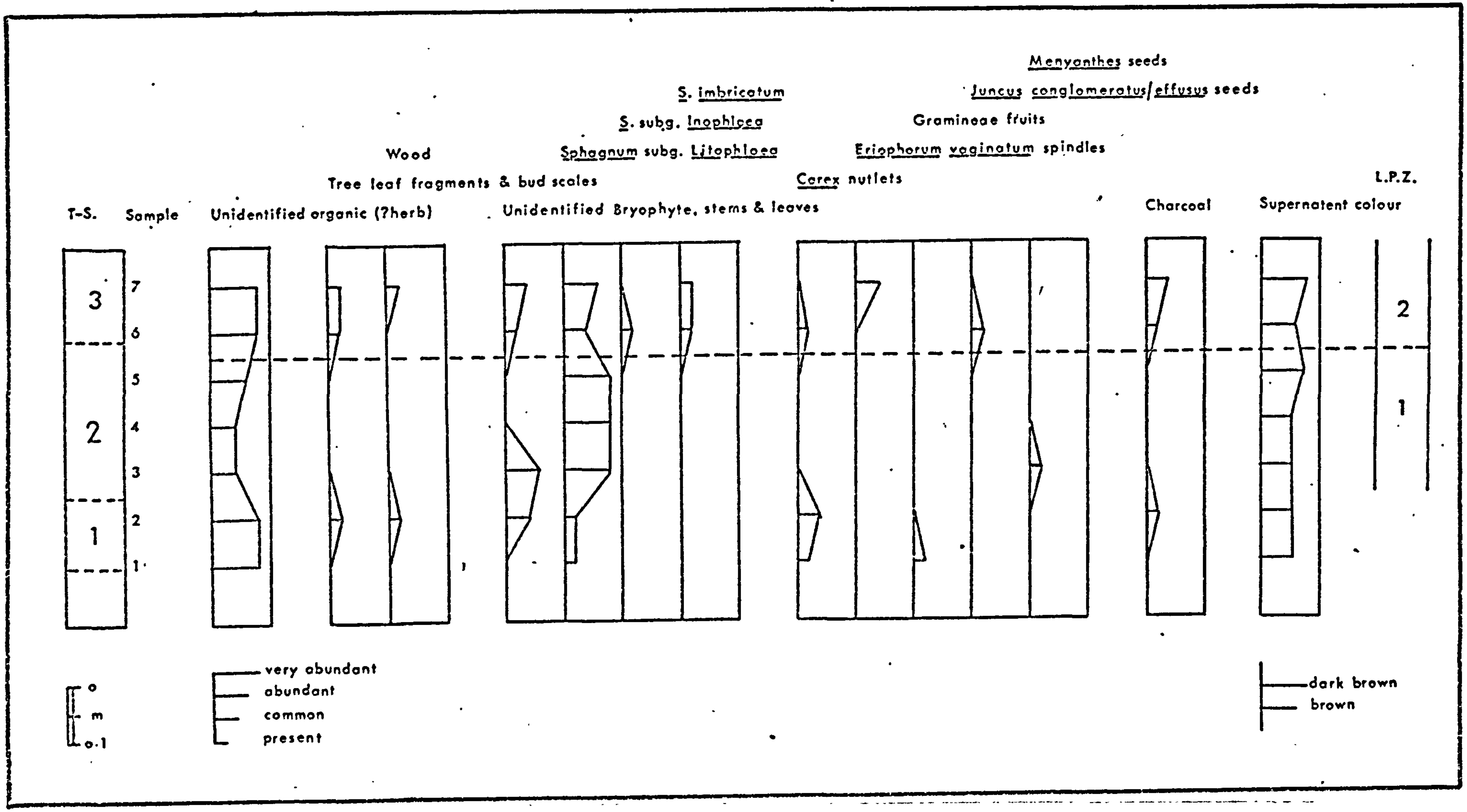


Figure 13.12 Shewalton Moss; SM-81-II; results of the plant macrofossil analysis.

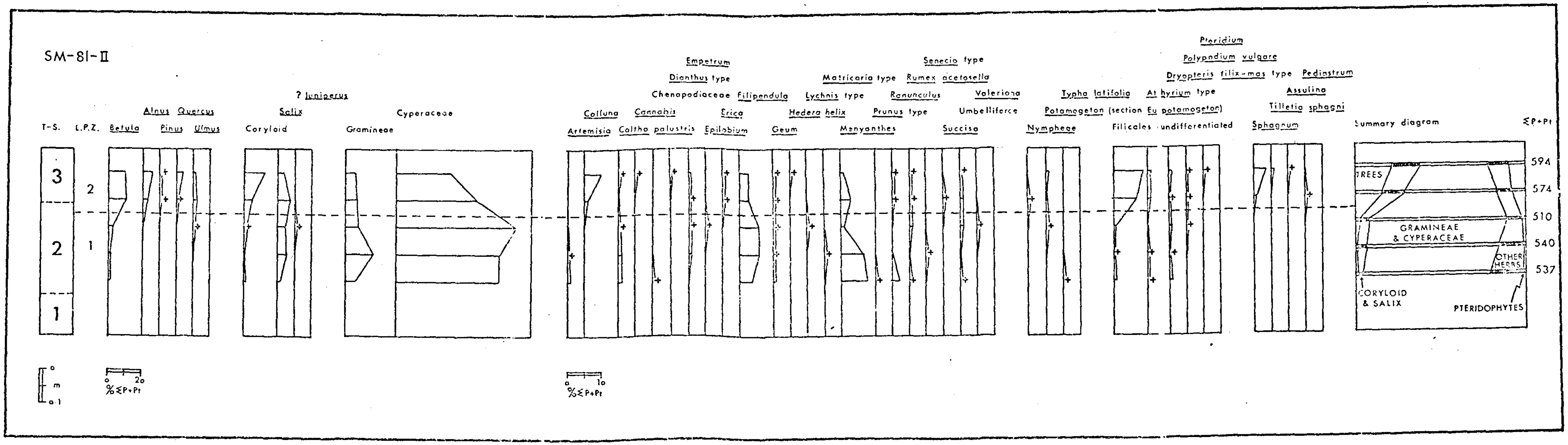


Figure 13.13 Shewalton Moss; SM-81-II; results of the pollen analysis. Values are percentages of total pollen plus pteridophyte spores.

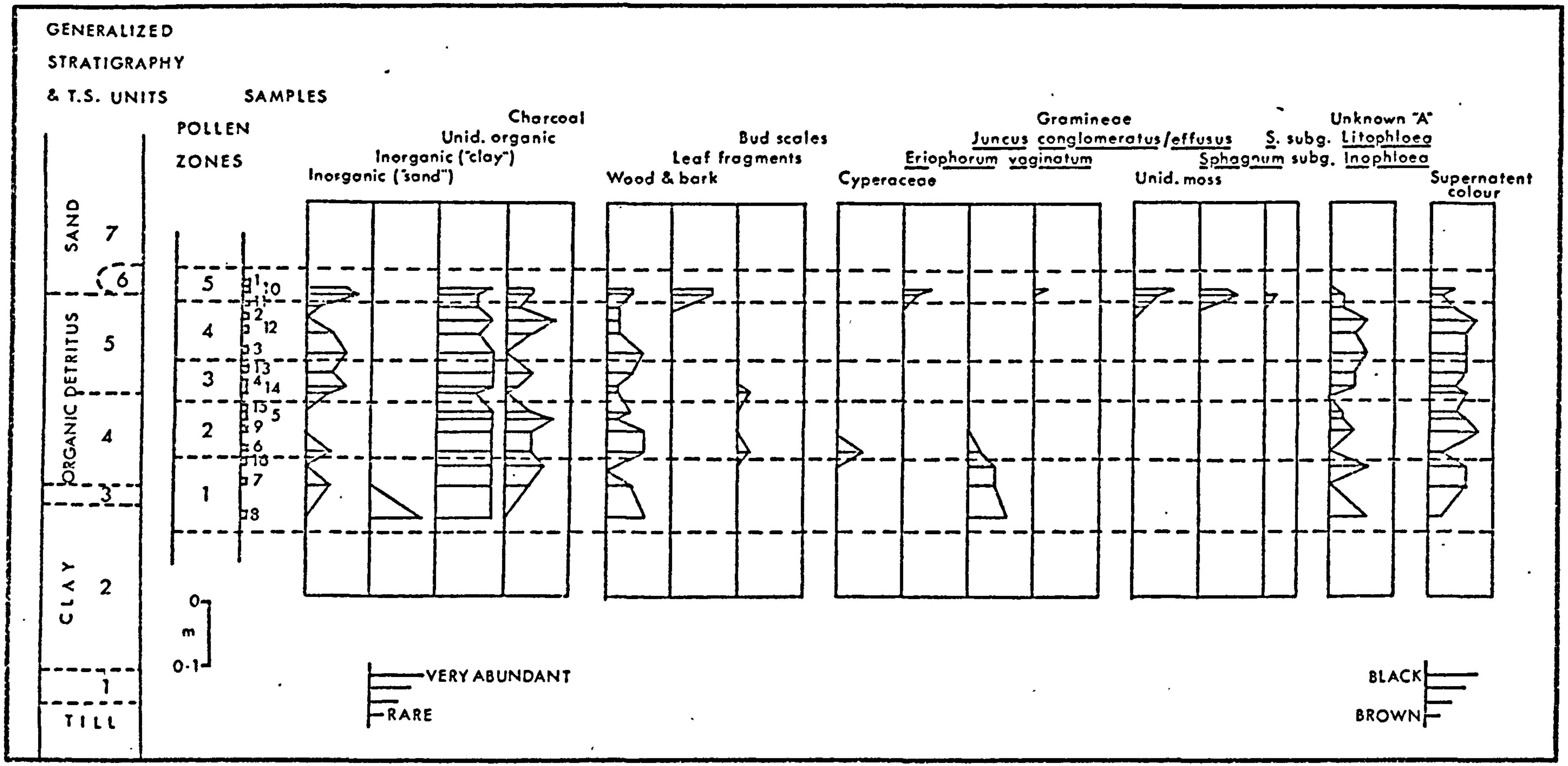


Figure 14.1 Dundonald Burn; DB-81: results of the plant macrofossil analysis.

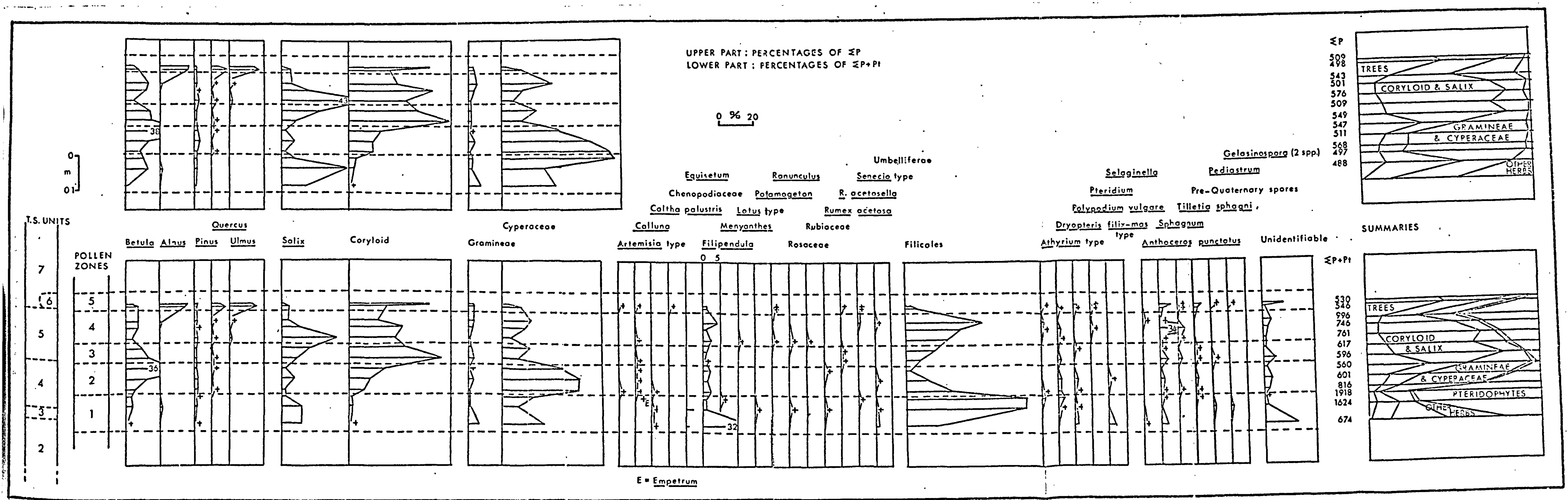


Figure 14.2 Dundonald Burn; DB-81: results of the pollen analysis. The upper part of the diagram shows values, for selected taxa, as percentages of total pollen, and the lower part shows values for all taxa as percentages of total pollen plus pteridophyte spores.

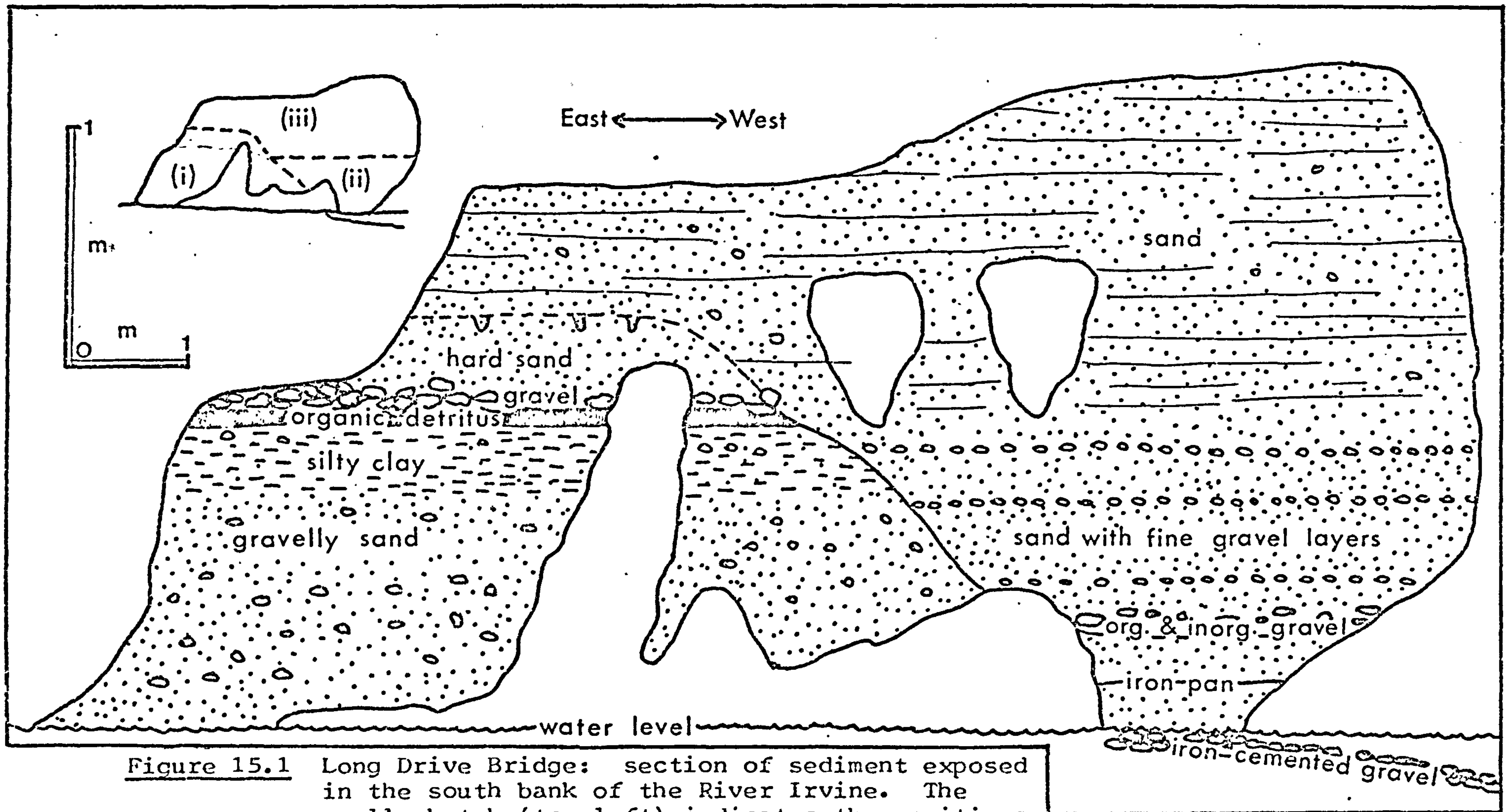


Figure 15.1 Long Drive Bridge: section of sediment exposed in the south bank of the River Irvine. The small sketch (top left) indicates the positions of the sedimentary units discussed in Chapter 15.1. The scale is for the main part of the figure. Vertical exaggeration is x 2.

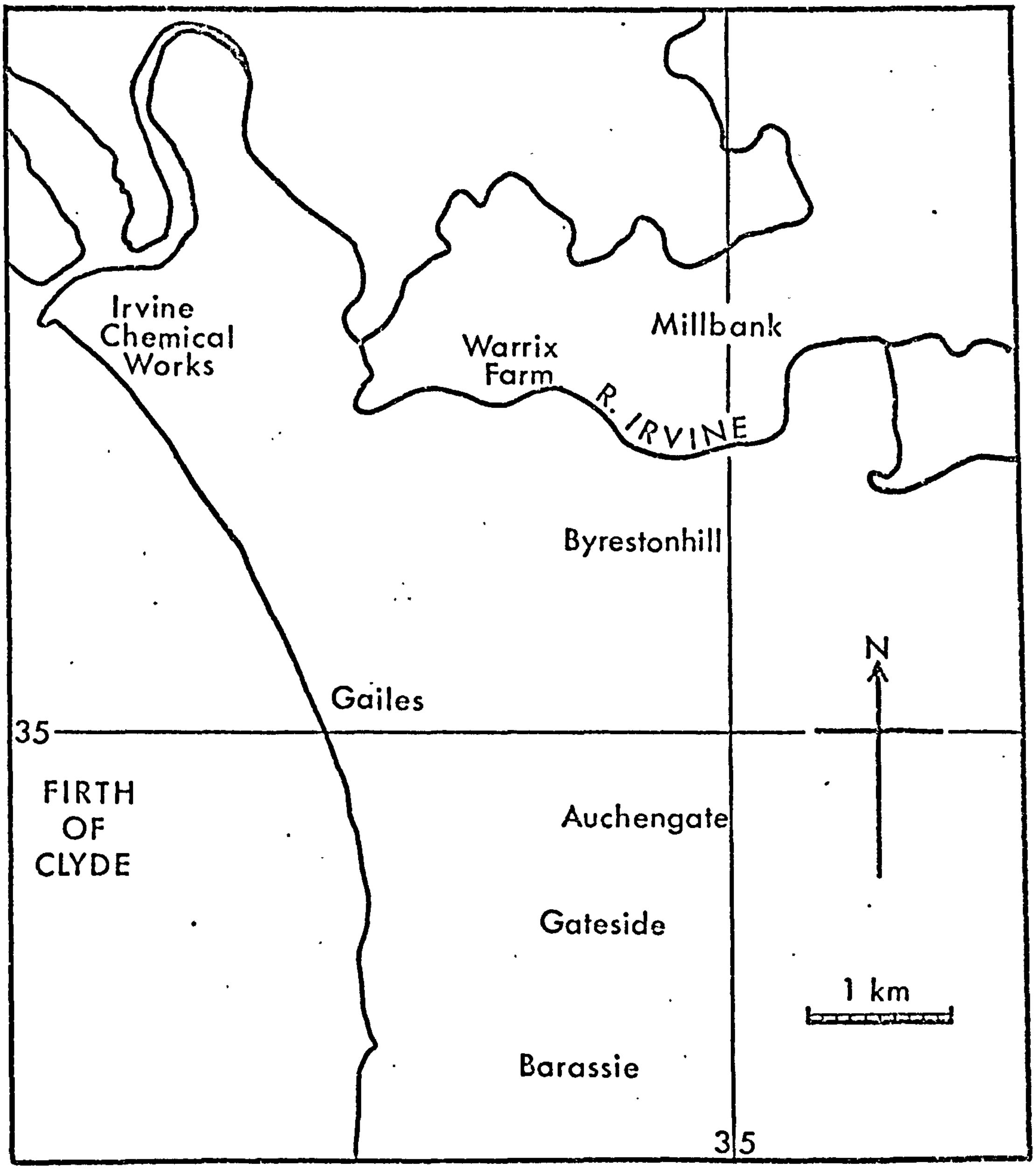
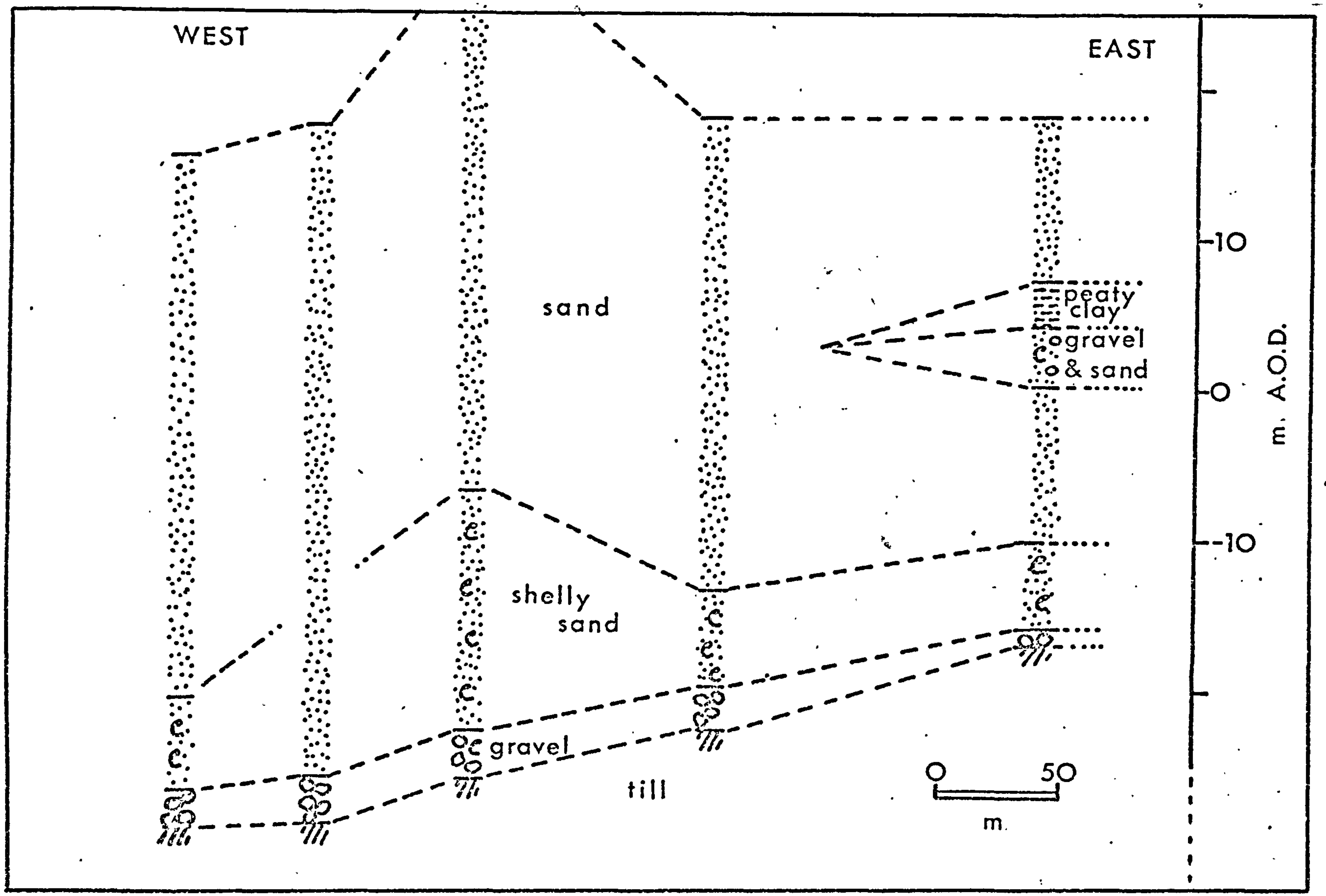


Figure 18.1 Locations discussed in Chapter 18.



<u>Figure 18.2</u> Irvine Chemical Works: section derived from commercial bore-log data.

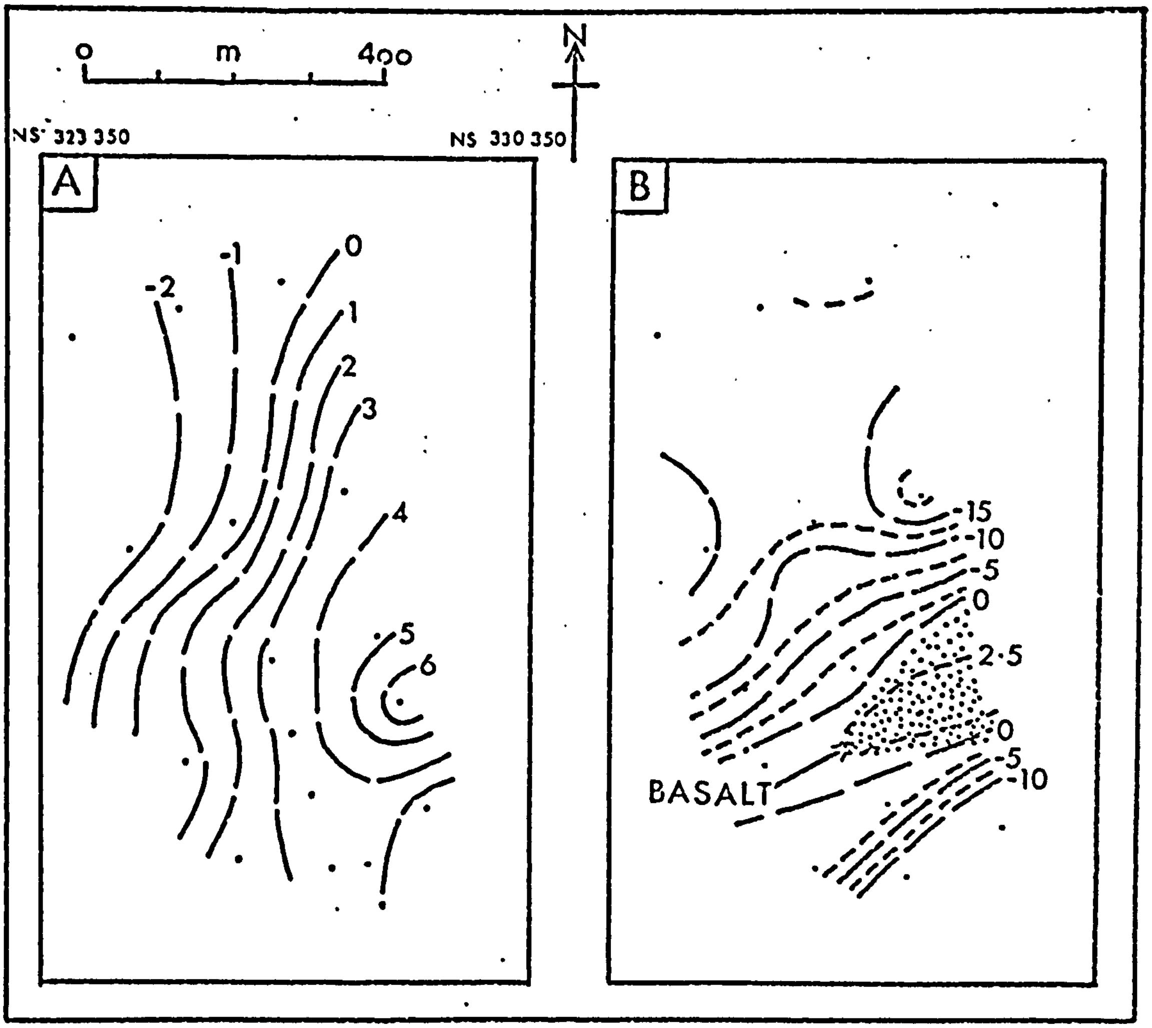


Figure 18.3 Gailes: contours for surface of buried coarse-grained beach (A) and rockhead contours. Contour values are in metres A.O.D.; A and B represent the same areas.

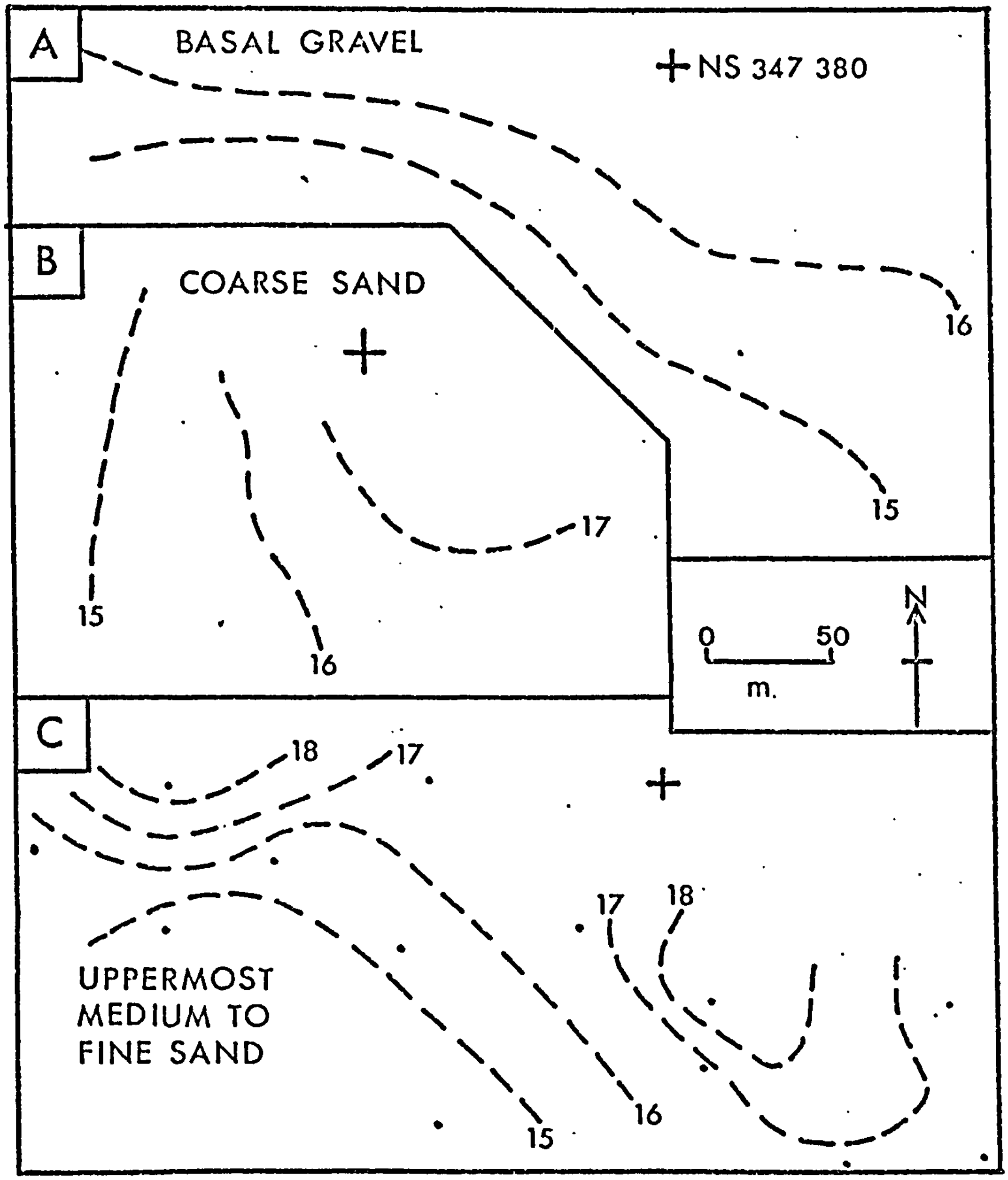


Figure 18.4 Millbank, Dreghorn: contours for three buried beaches. Contour values are in metres A.O.D.; the cross represents a common point, and the points used to construct these contours are shown in part C.

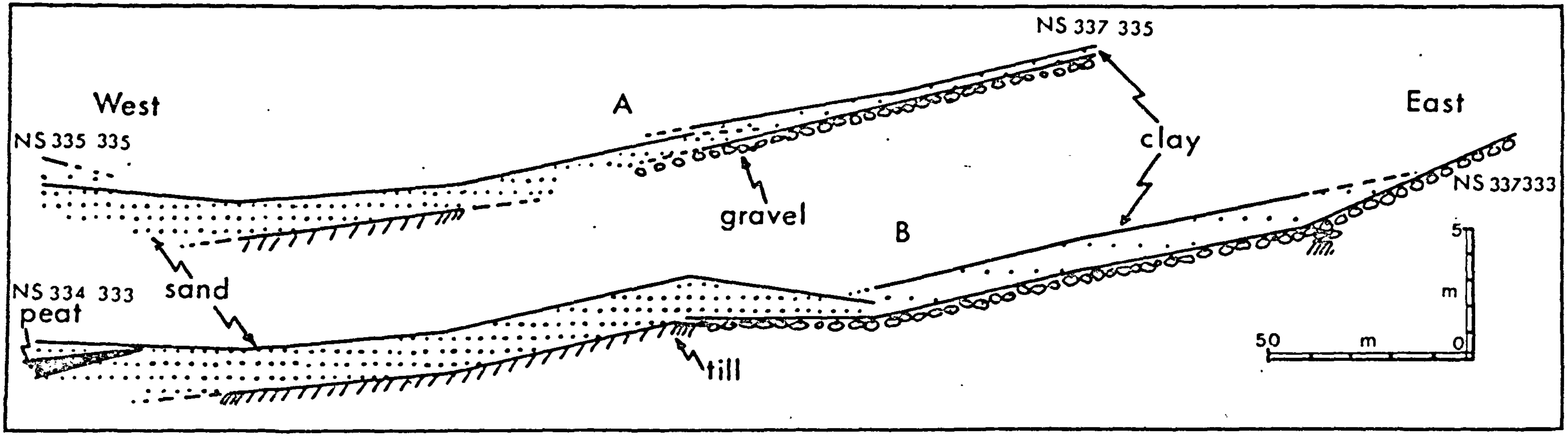


Figure 18.5 Barassie: sections adapted from commercial bore-log data.

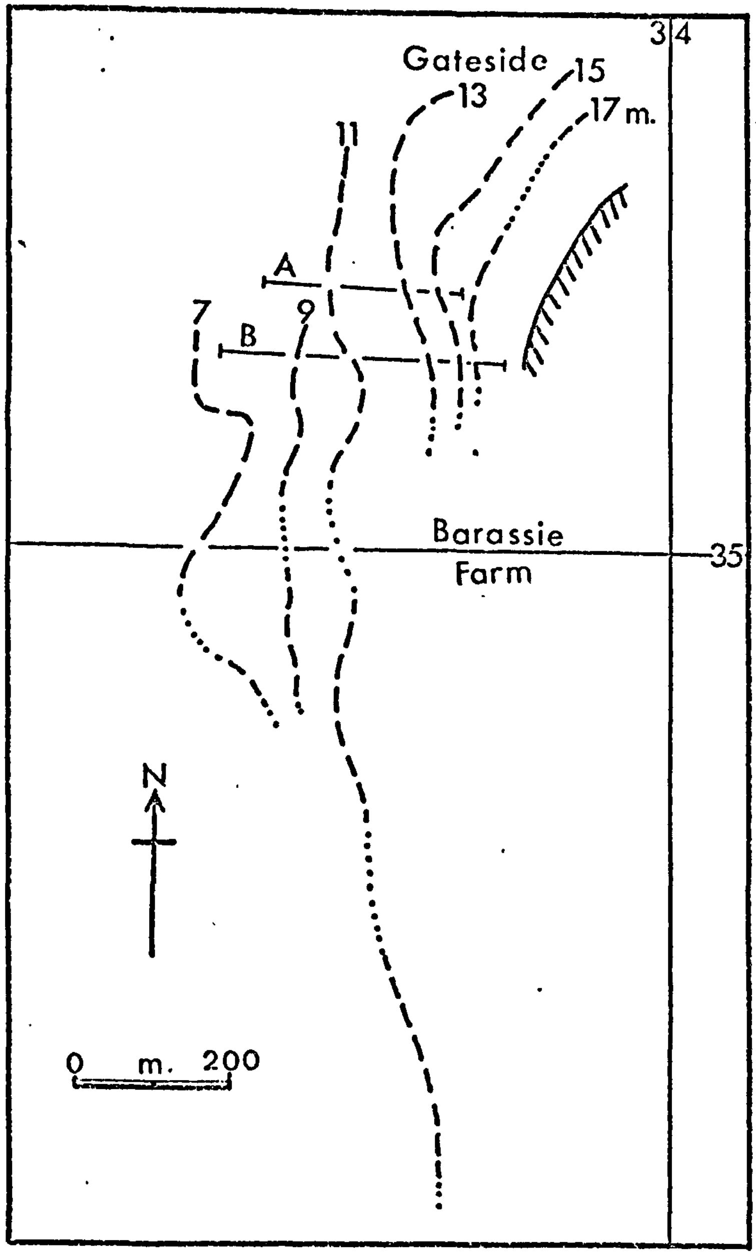


Figure 18.6 Barassie: contours of the surface of a buried gravel beach. Adapted from commercial bore-log data. The hatched line represents the up-slope limit of the buried beach. The locations of section A and B (Fig. 18.5) are shown.

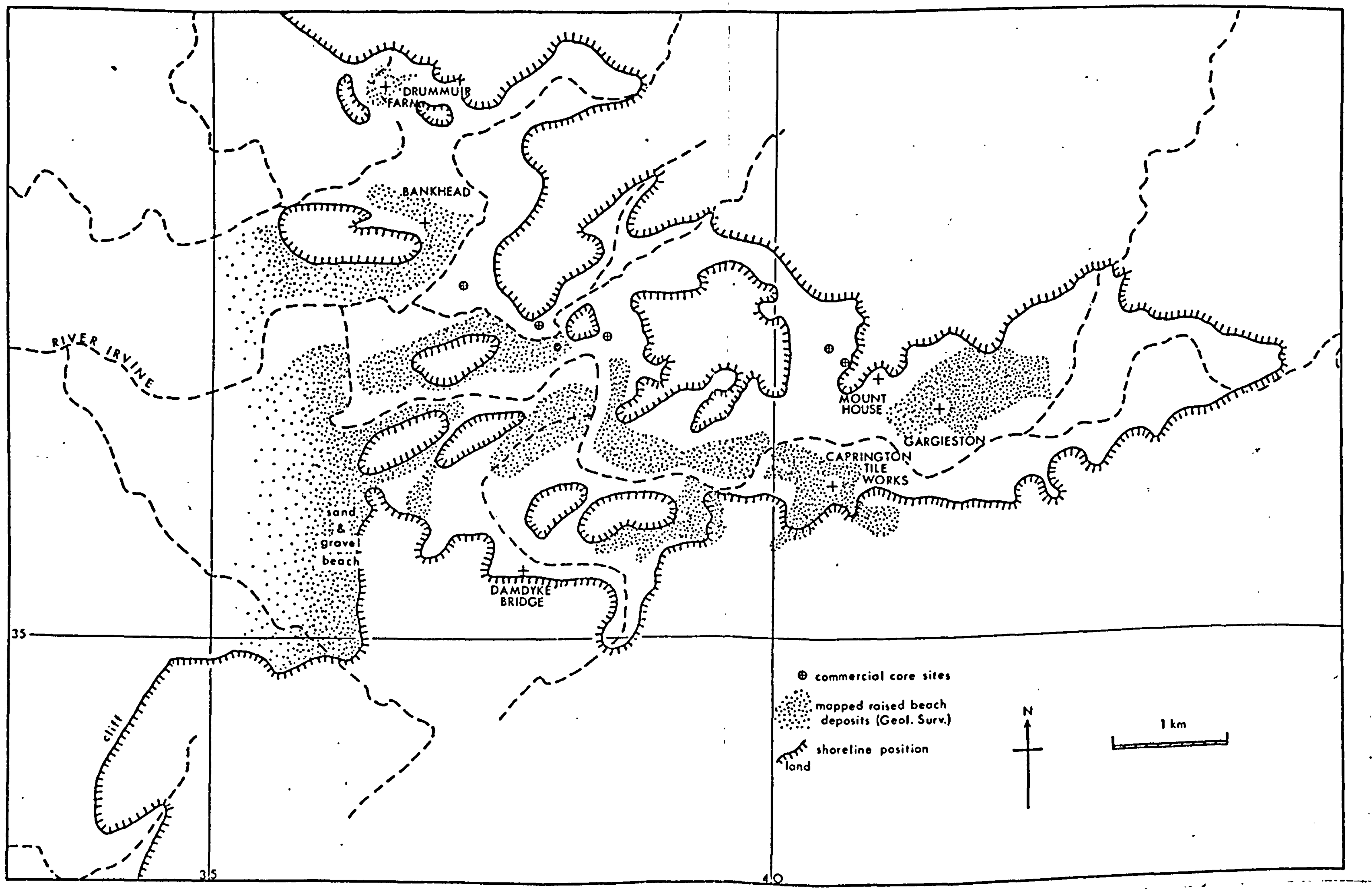


Figure 19.1 Late Devensian Irvine Estuary: conjectural configuration of the coastline during the period in which sea level stood at a maximum elevation of c. 26 m A.O.D. Kilmarnock lies at the east end of the estuary. The raised beach deposits within the estuary consist mainly of fine-grained sediments. Raised beach deposits also occur west of the estuary mouth. The other sediments within the estuary are largely fluvial alluvium and glacial till.

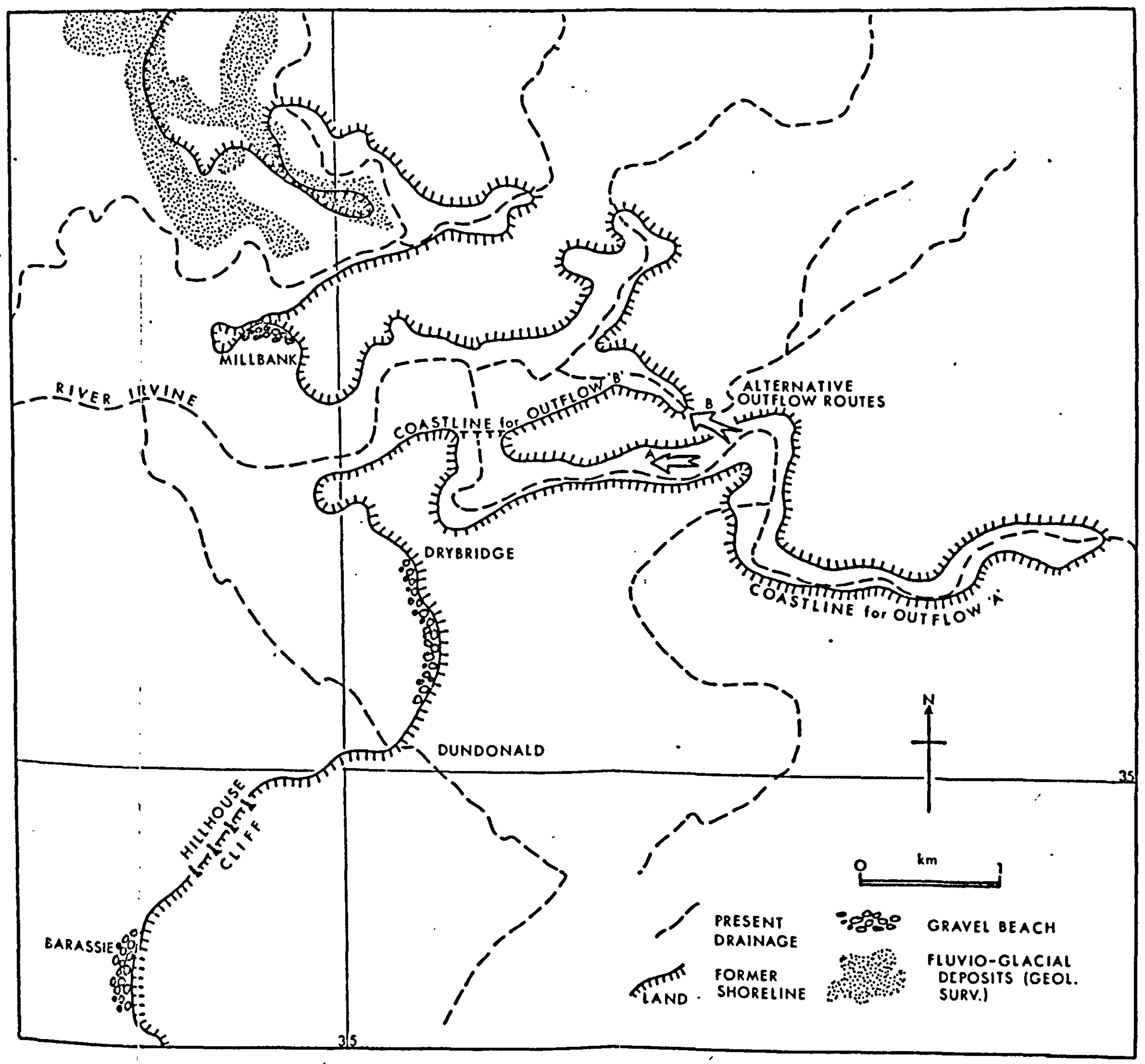


Figure 19.2 Late Devensian Irvine estuary: conjectural configuration of the coastline during period in which sea level was falling. The coastline is drawn for a sea-level altitude of c. 17 m A.O.D. NOTE: this does not represent a period of sea-level still-stand.

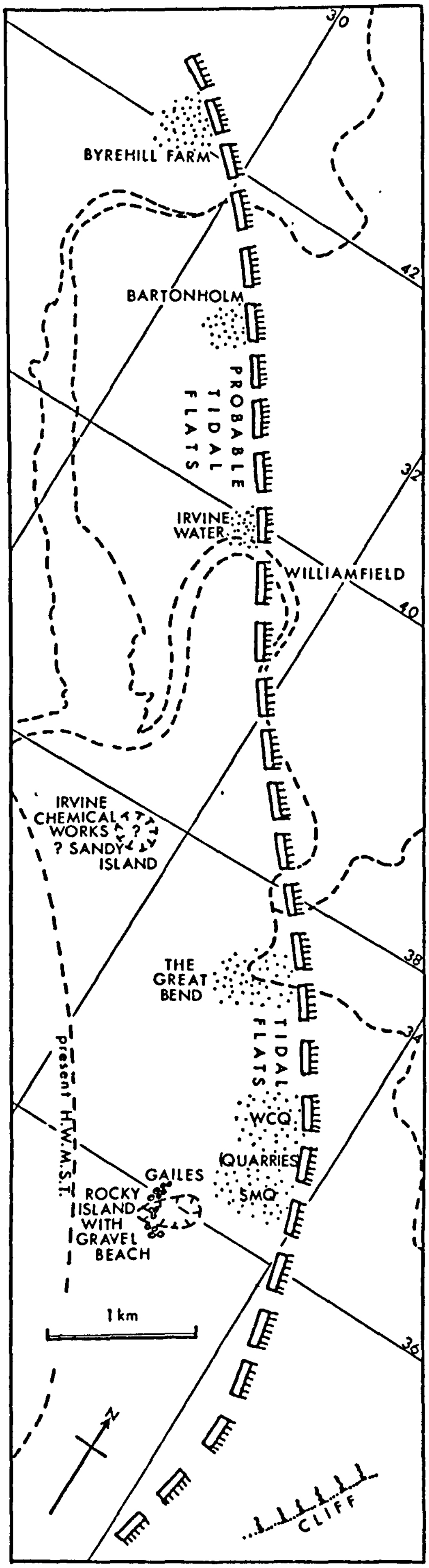


Figure 19.3 Early Flandrian or possibly late Devensian, Irvine area; conjectural configuration during period of low sea level. Sea level at this time lay at a low (minimum) altitude of c. 2 m A.O.D. The shoreline is shown in a deliberately generalised form.

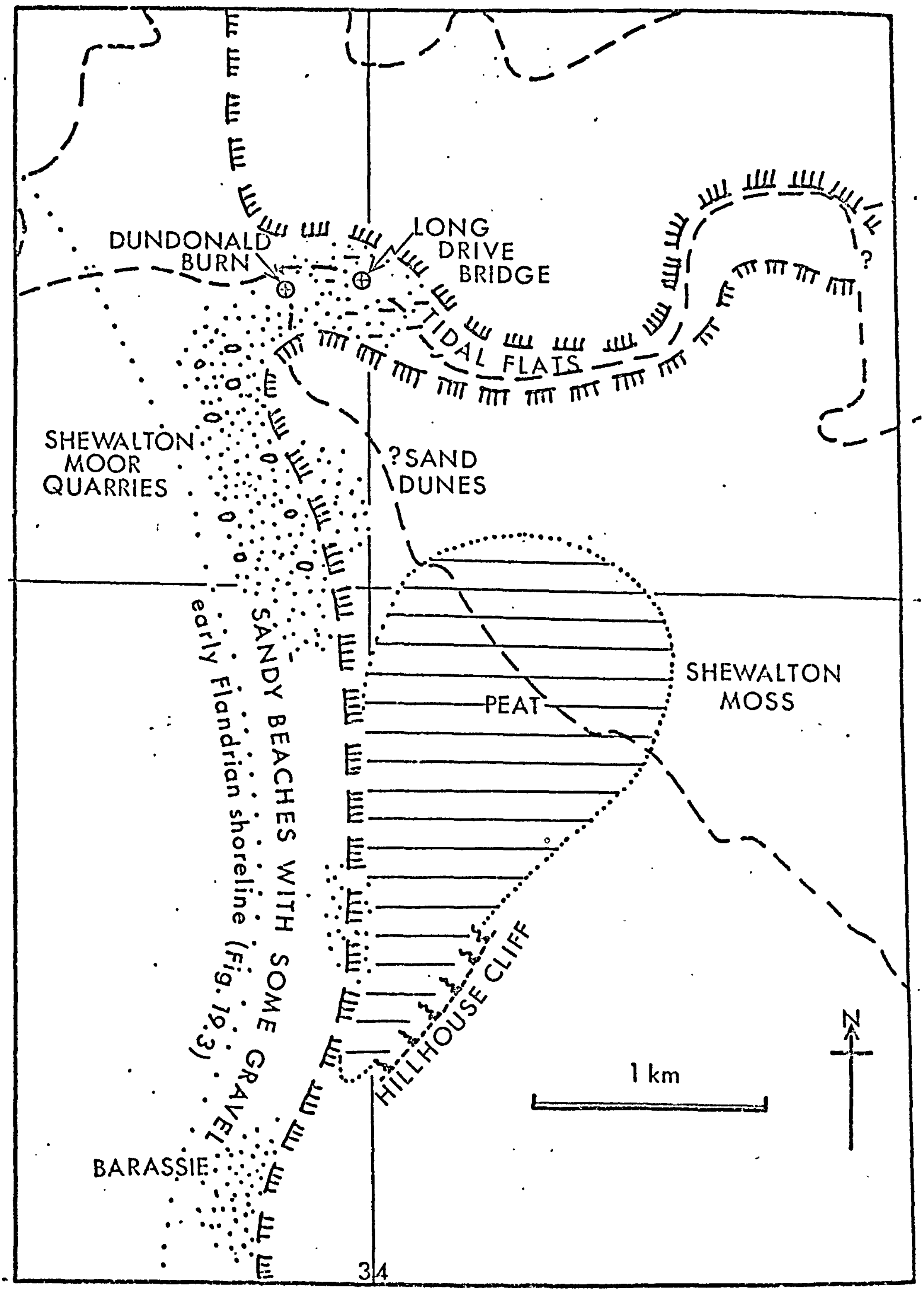


Figure 19.4 Middle Flandrian, Shewalton-Irvine area: conjectural configuration of coastline during period of high sea level. Sea level at this time lay at a high (maximum) elevation of 10 to 12 m A.O.D. The inland extent of the Irvine estuary is unknown.

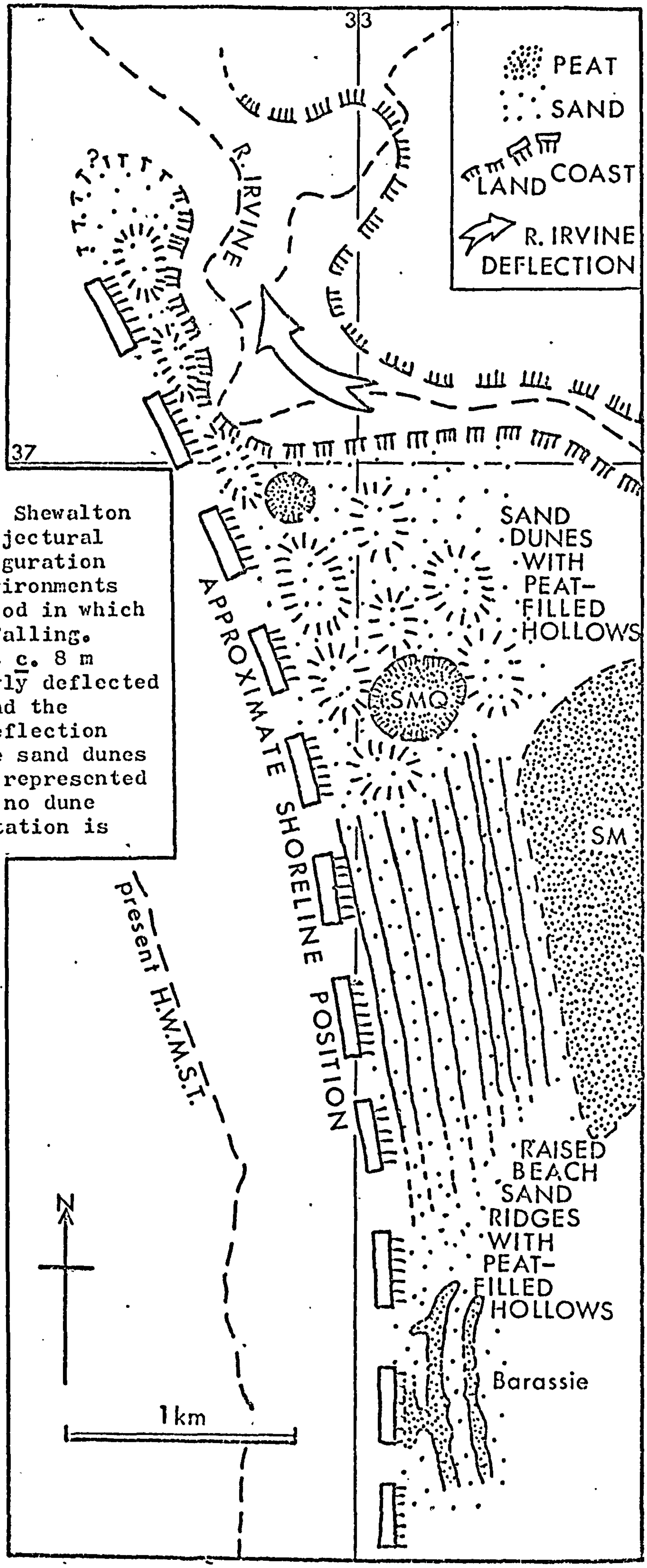


Figure 19.5

Late Flandrian, Shewalton Moor area: conjectural coastline configuration and coastal environments during the period in which sea level was falling. Sea level is at c. 8 m A.O.D. The newly deflected River Irvine and the direction of deflection are shown. The sand dunes and ridges are represented symbolically; no dune shape or orientation is implied.

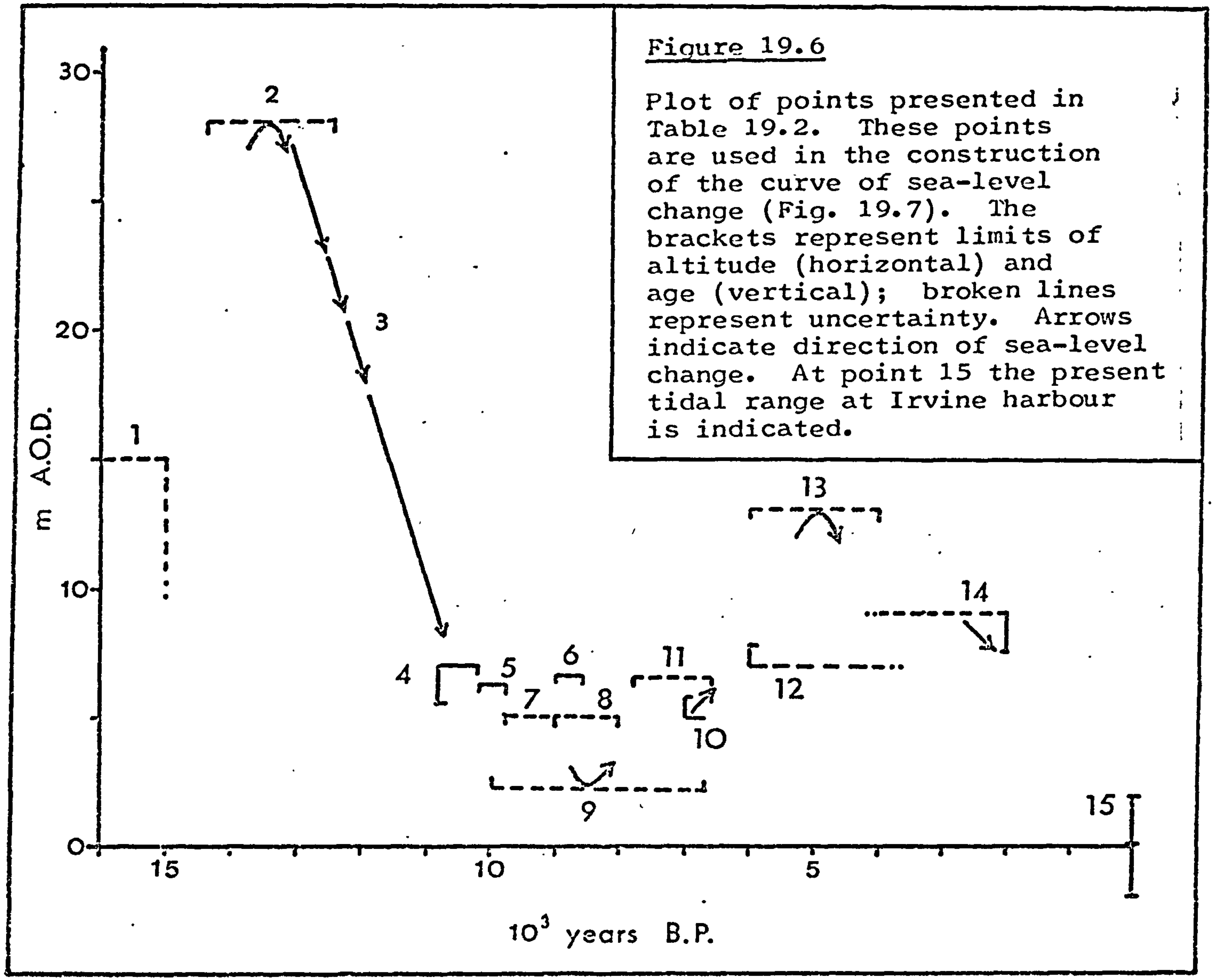


Figure 19.6

Plot of points presented in Table 19.2. These points are used in the construction of the curve of sea-level change (Fig. 19.7). The brackets represent limits of altitude (horizontal) and age (vertical); broken lines represent uncertainty. Arrows indicate direction of sea-level change. At point 15 the present tidal range at Irvine harbour is indicated.

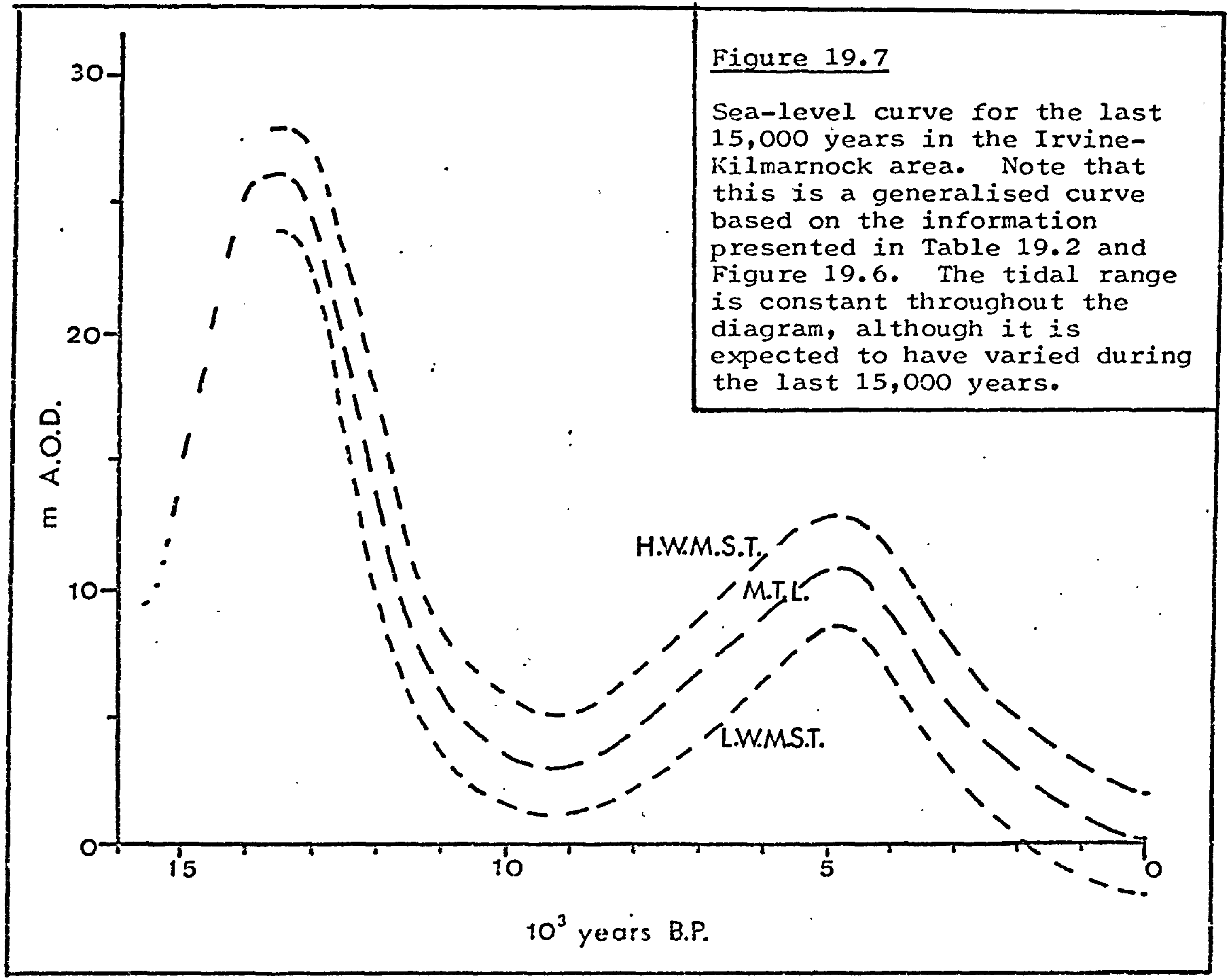


Figure 19.7

Sea-level curve for the last 15,000 years in the Irvine-Kilmarnock area. Note that this is a generalised curve based on the information presented in Table 19.2 and Figure 19.6. The tidal range is constant throughout the diagram, although it is expected to have varied during the last 15,000 years.

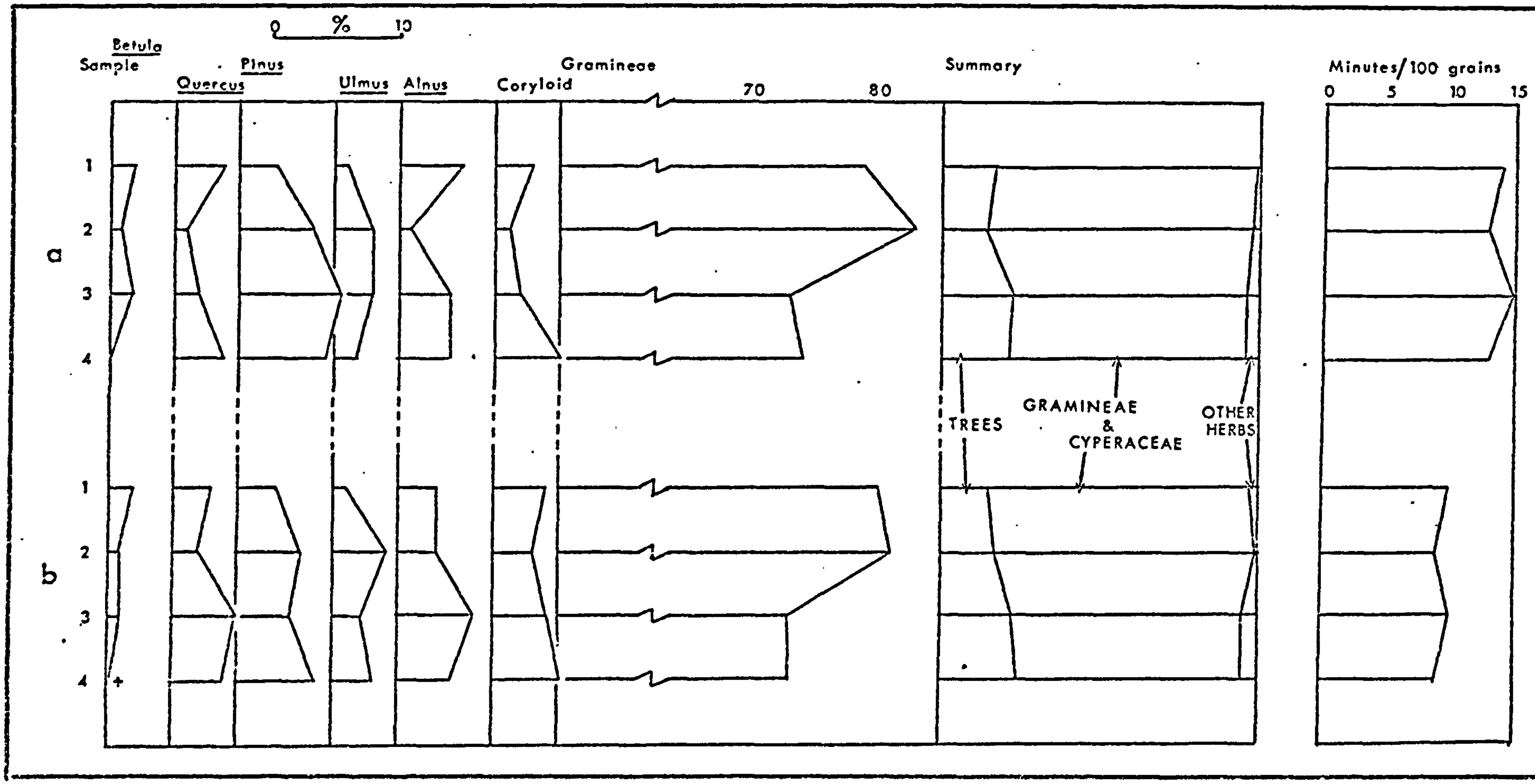


Figure A.1.1 Flanders Moss; results of the pollen analysis for samples from the sub-peat clay. Percentages are of total pollen. Only selected taxa are shown. The results are shown for samples treated with $Na_4P_2O_7$ (a, top) and those not treated (b, bottom).

APPENDIX 5

BOYD, W. E. (1982) Sub-surface formation of charcoal and its possible relevance to the interpretation of charcoal remains in peat. Quaternary Newsletter, 37, 6-8.

SUB-SURFACE FORMATION OF CHARCOAL AND ITS POSSIBLE RELEVANCE TO THE INTERPRETATION OF CHARCOAL REMAINS IN PEAT.

By W. E. Boyd

In this note a process for the formation of charcoal within a peat profile is tentatively proposed. As far as the writer is aware, the process has not previously been suggested, and comments concerning it would, therefore, be welcome.

In part of a pollen diagram from Shewalton Moss (Ayrshire), the Corylus-rise, following a period in which the vegetation is becoming increasingly more open, appears to occur at a time when Cenococcum geophilum, Gelasinospora spp., charcoal and other indications of local dry soil conditions are present (Fig. 1).

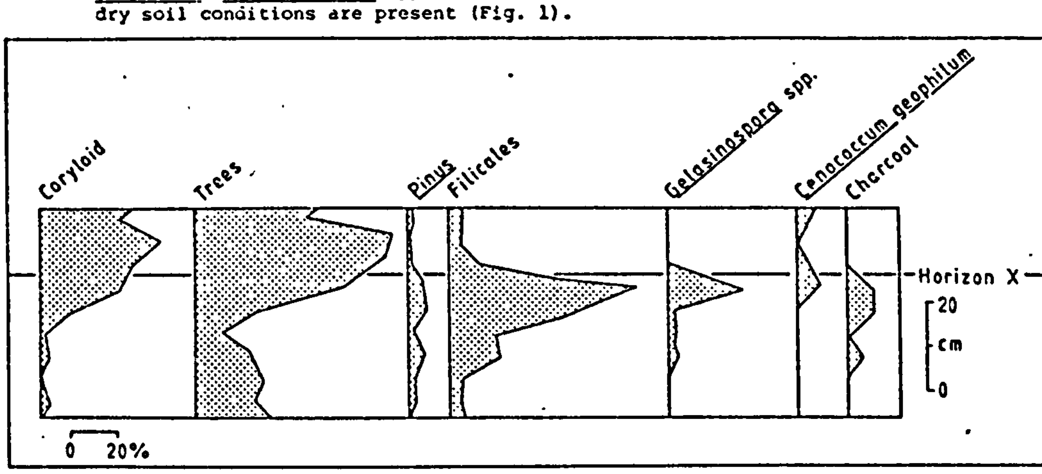


Figure 1. Partial pollen diagram, peat core, Shewalton Moss, Ayrshire (Nat. Grid. Ref. NS 352 360). The Coryloid and Pinus values are % AP, Trees are % of total pollen, Filicales and Gelasinospora spp. are % of total pollen plus pteridophyte spores, and the C. geophilum and charcoal values are points on a nominal 5-point scale (absent to abundant). Soil dryness is indicated by the Pinus and Filicales curves, which show the preferential preservation of these taxa; pollen corrosion of other taxa increases up to Horizon X. Gelasinospora spp. are indicative of dry soil conditions, and C. geophilum is often associated with other evidence for burning. Horizon X represents a probable dry soil surface, although in the core profile it is not a recognisable horizon.

Possible Mesolithic management of Corylus has been discussed by Smith (1970, pp. 82-86) and Simmons et al. (1981, pp. 102-106). At Shewalton Moss, in an area with evidence of extensive Later Mesolithic activity, the presence of charcoal and C. geophilum peaks during the Corylus-rise (Fig. 1, below Horizon X) is suggestive of possible human management of local vegetation. Strictly, however, the presence of charcoal indicates that organic matter, frequently wood, has been burnt, not necessarily that a fire has been started by human agency.

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There is an alternative process which may explain the presence of sub-surface charcoal within peat.

In 1976, the writer assisted in the extinguishing of moor fires in the Kilpatrick Hills near Glasgow. The fires had been caused by solar heating of the peat levels below the surface. Surface fires were relatively limited in extent, but large areas of peat were burnt within the profile. During the summer of 1976 there also were reports from parts of Wales of considerable areas of soil being destroyed by sub-surface burning.

It is suggested that the heating of peat by the sun during a period of unusually warm weather is a process by which charcoal may be formed within the peat profile by natural agency. If this claim is valid, certain important implications follow:-

(1) After as little as one month of unusually warm weather, large areas of peat can be burnt within the peat profile.

(2) It is possible for large areas of peat to be affected without the presence of widespread or large-scale fires, and even without the appearance of surface fires.

(3) Charcoal need not, and probably will not, be produced at the surface at the time of charcoal formation. The stratigraphical position of charcoal produced by this process, therefore, will have little chronological significance, other than providing a minimum age for its formation.

(4) The stratigraphical position of the charcoal may be determined by factors such as the presence of a sub-surface layer or layers of woody peat. Charcoal at various stratigraphical positions may have been formed during the same event.

(5) In explaining the presence of sub-surface charcoal in peat it is not necessary to invoke large-scale forest fires, frequent burning events, abnormally high incidence of lightning (the commonly invoked natural ignition source), large scale climatic fluctuations or human interference, deliberate or otherwise.

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Glasgow G12 8QQ.

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Smith, A. G. (1970), "The influence of Mesolithic and Neolithic Man on British vegetation: A discussion", in Walker, D. & West, R. G. (eds) (1970). Studies in the vegetational history of the British Isles. Cambridge, 266 pp., pp.81-96.

APPENDIX 6

BOYD, W. E. (in press) Archaeological implications of a new palaeoenvironmental model for part of the Ayrshire coast. Glasgow archaeol. J., 10.

Recent research (Boyd, 1982) concerning the Late Quaternary history of the area of Ayrshire in the valley of the River Irvine between Kilmarnock and the coast has provided a new model of coastline position and environmental conditions for the period in which Mesolithic activity may have been important in the area. Details of the research will be published more extensively and completely elsewhere; only the archaeological implications are presented here. The model is based on evidence from a variety of sources, largely from examination of exposures of inorganic sediments and from micro- and macro-fossil analysis of peat.

The new model for shoreline position during the period of culmination of the Flandrian marine transgression (c. 4,000 to 2,000 b.c.) is shown in Figure 1. A sedimentary succession at Dundonald Burn indicates an episode of coastal sedimentation related to a rising sea level, at a time after c. 4,000 b.c. At Shewalton Moor Quarry, peat growth at an altitude above, but not directly upon, raised beach deposits, began perhaps 2,000 years ago or possibly as early as 1,000 to 1,500 b.c.; a radiocarbon age determination from a site nearby (Birm-221; Shotton & Williams, 1971) suggest that terrestrial conditions prevailed at around 1,900 b.c. The maximum inland position of the shoreline at the culmination of the Flandrian marine transgression contrasts with the position formerly suggested by Jardine (1971) (Figure 1).

In the model, several coastal environments are recognised. The open shore, oriented approximately parallel to the present shoreline but about 1.5 to 2 km inland from it, was composed primarily of sandy beaches with a few gravelly areas. The beaches probably were moderately wide, and sloped downwards gently to the west into an open bay, in which sand was the main sediment being deposited and in which several types of shell fish were abundant. To the east lay temporary fresh-water lagoons which were dammed by landward-migrating beach ridges. For at least 3 km upstream of the mouth of the River Irvine, quieter conditions prevailed, in contrast with the medium- to high-energy conditions of the open shore. The mouth of the River Irvine formed a long, slightly sinuous tidal estuary, with sandy tidal flats and, in places, exposures of solid rock. Onshore a variety of coastal environments existed. Immediately landward of the beaches were areas of sand dunes with marshy dune slacks and, perhaps, dune heath being present in places. Some of this area may have been flooded periodically during spring tides or storm conditions and, in places, small peat bodies may have formed. Dominating this coastal area was a large (*c.* 2.5 x 1.5 km) well-established ombrogenous bog (Shewalton Moss). Surrounding Shewalton Moss there was damp woodland containing birch, alder, willow and hazel, and inland there was probably a zone of moderately well-drained terrain on the higher (Late Devensian) raised beach sand and gravel deposits.

Replacing the coastline of the middle Flandrian sea from the inland position suggested by Jardine (1971) to a position some 1 to 1.5 km seawards has some important consequences for archaeological study in this area.

It is becoming increasingly apparent that coastal regions were important locations of Mesolithic activity (Morrison, 1983) whether as part of a semi-nomadic lifestyle (Simmons, 1975; Cullberg, 1980) or a more settled lifestyle (Palmer, 1980). In Cumbria and south-western Scotland it has been demonstrated that Mesolithic sites are clustered immediately above the inland limit of the middle Flandrian coastline (Bonsall, 1980; Morrison, 1980), and a model for expected coastal Mesolithic activity has been proposed (Jardine & Morrison, 1976).

The area around Shewalton has a large concentration of Mesolithic finds, which fall into two groups. The first group comprises finds from the Shewalton Moor area (Smith, 1882; Lacaile, 1930, 1931, 1937) in lag gravel within sand dune hollows. The finds are not stratigraphically in situ, but clearly must post-date the period of high Flandrian sea level. The typology suits such an interpretation of age (A. Morrison, pers. comm.). The second group has provided more problems. The relevant artefacts are scattered finds from an area seaward of Jardine's middle Flandrian coastline, but landward of the coastline proposed here (T. Affleck, pers. comm.). From their distribution, the finds appear to lie on the higher (Late Devensian) raised beach deposits, and frequently very close to, but not upon, the present river terraces. Formerly the distribution of such material on the seaward side of the middle Flandrian shoreline was puzzling, since it did not fit the model (Jardine & Morrison, 1976) which was applicable elsewhere. Consequently, these finds were interpreted as implying a late presence of Mesolithic activity, after the period of maximum sea level rather than during it as appears to have been the case elsewhere in south-western Scotland.

The revised position of the shoreline provides several points of interest for further archaeological interpretation:

(1) Mesolithic finds around Shewalton Moss and in the River Irvine valley need not be late Mesolithic in age, since they do not occur seaward of the inland limit of the middle Flandrian shoreline.

(2) The distribution of finds in this area now conforms to the model produced for sites elsewhere.

(3) The environmental reconstruction provides a wider range of suitable habitats than formerly envisaged. Such a wide range of habitats may have encouraged intensive Mesolithic activity in this area (cf. Bonsall, 1980).

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Figure 1 Coastal area south of Irvine, showing the conjectural position of the shoreline during the culmination of the middle Flandrian marine transgression, and the coastal environments present at that time (c. 4,000 to 2,000 b.c.).