Flandrian sea-level changes in the Moray Firth area

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FLANDRIAN SEA-LEVEL CHANGES IN THE MORAY FIRTH AREA

by

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DECLARATION

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ABSTRACT

The Moray Firth area is recognized as an area deficient in data relevant to sea-level change. This thesis attempts to provide a preliminary assessment of the restoration of sea-level following the last glaciation, particularly the last 10,000 years.

The methodology used is essentially empirical and analytic, based upon stratigraphic description, micropalaeontological investigation and radiocarbon dating of sites in former tidal flat and lagoonal environments.

Three sites at the head of the Beauly and Cromarty Firths, at Barnyards (NH 5247), Moniack (NH 5443) and Arcan Mains (NH 4954) provide stratigraphic and environmental evidence for the interpretation of sea-level change during the Flandrian Age.

A preliminary chronological scheme of positive and negative tendencies of sea-level movement and a time-altitude graph is constructed using information from biostratigraphic and lithostratigraphic sea-level indicators and nine new radiocarbon dates. An attempt is made to assess the magnitude of error inherent at all stages of the analysis.

Correlation is made with other areas of Scotland and Fennoscandia. A comparison is made between the differing methodologies employed in this thesis and other areas of Scotland where sequences of measured and named shorelines have been established.

An isostatic curve for the inner Moray Firth is constructed using eustatic calibration of index point altitude. The results are compared to other published isostatic curves for Scotland.

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CHAPTER 1

INTRODUCTION

I.G.C.P. Project No.61 - 'Sea-Level movements during the last deglacial hemicycle' was initiated on 19 April 1974 and assigned 'Key Project' status. The primary objective of the project was

> "to establish a graph of mean sea-level during the last de-glacial hemicycle (about 15,000 yrs) and continuing to the present. This objective (is to) be realized by establishing sea-level curves based on empirical data from different regions of the world" (Tooley, 1978c, 66)

Additional objectives included the evaluation of vertical crustal movements including glacio-isostasy, hydro-isostasy and epeirogenic movements and the evaluation of the relationship of sea-level change to climatic change and changes in the global hydrological cycle, all of which are of great importance for planning considerations in low-lying coastal areas (Tooley 1979).

Mörner (1976) drew attention to the fact that the present geoid configuration is uneven with, for example, an amplitude of 180 m. between a high point near New Guinea and a low point near the Maldives. Changes in the geoid through time and space therefore militate against a concept of global eustasy.

Recent policy has been directed towards the construction of sea-level curves, the variates of which

> "come from a small homogeneous area so that the effects of tidal inequalities, earth movements and variations in the geoid configuration would be minimized" (Tooley 1978b, 204)

In this way locally consistent data bases could be initiated and improved with the objective of evaluation of the inter-regional differences in the factors of sea-level change.

However a lack of consistency and rigour in methodology still exists and agreement on the exact meaning and relationship of an index point to the contemporary sea-level is still elusive. This means, in effect, that some differences between sea-level curves from different areas are apparent ones rather than real ones. The need is for a consistency in methodology and operational definitions to aid meaningful correlation.

In the remainder of the chapter the objectives of the study, the methodology adopted and definitions of commonly used terms will be outlined.

1.1 Objectives

Certain areas of Britain were identified as deficient in sea-level data including the Moray Firth area. No previous work has dealt explicitly with Flandrian sea-level changes in the area. Ogilvie's (1923) monograph still remains the basic descriptive work on the Moray Firth coastlands and is still widely used by later workers (Sissons 1967, 1976, Steers 1973).

This research is therefore preliminary in nature and broad in outlook. The objectives are

- the description of new sites from former tidal flat and lagoonal environments.
- the use of stratigraphic, pollen, diatom and ^{14}C analyses from these sites to provide new data for sea-level change.
- the interpretation of these data in terms of sea-level movement.
- the establishment of an initial chronology of sea-level movement.
- the construction of a sea-level curve based on ^{14}C dated index points.
- comparison with other areas of Scotland and NW Europe to identify events of regional significance and differences in the registration

of these events between areas.

- an initial estimate of the form of isostatic recovery for the area during the Flandrian Age.

1.2 Methodology

The methodology advanced in this study is well tried by research workers in the Fenland (Godwin 1940a, Shennan 1980), North-Western England (Tooley 1978a), the Bristol Channel (Kidson and Heyworth 1973) and the Netherlands (Jelgersma 1961). It is based on precise instrumental levelling and stratigraphic and micropalaeontological analyses of former tidal flat and lagoonal environments to identify suitable samples for ^{14}C dating and the production of a sea-level curve.

In Scotland the traditional practice has been first to establish the sequence of raised and tilted shorelines (*sensu* Sissons 1966, Cullingford *et al*. 1980) - in effect a form of 'marine limit' sequence - on a regional scale. Once such a sequence has been established it provides an indicator of the direction of sea-level movement and the upper altitudinal limits of rises in sea-level. It also provides stratigraphic control for the interpretation of index points.

In areas such as the Moray Firth where the shoreline sequence has not yet been established rises and falls in sea-level need to be argued from other indicators of sea-level movement. The methodology used is essentially a site-based one aimed at the construction of inductive, locally valid arguments for the nature and timing of sea-level change which can then be compared with similar schemes from other regions.

1.3 Definitions

Flandrian. In recent years the term Flandrian has been used as a formal stage name for the present interglacial stage in place of the equivocal term postglacial. Its use has been recommended in Britain by the Quaternary Era Sub-Committee (Mitchell et al. 1973) and its lower limit is defined as 10,000 B.P. to coincide with the lower limit of the Holocene series. The early use of the term as a local formation name in the Flemish coastal plain has fallen into disuse by present researchers in the area. Indeed the term Flandrian has not been properly defined in the type area (Paepe et al. 1976) and this has led Mangerud and Berglund (1978) to suggest the term should not be used until properly defined in the type area.

Hyvarinen (1978) suggests that much confusion can be avoided by realizing that the chronostratigraphic use of the term Flandrian is different from its original use in the type area. Its basic chronostratigraphic meaning is essentially climatostratigraphic, based on pollen evidence for climatic warming after the last glacial period. As such it is consistent with the original definition and subsequent use of the terms Holsteinian and Eemian. In principle therefore the definition of the Flandrian Stage in chronostratigraphic terms is clear and well used in practice. In this study Flandrian is used as a formal term to denote the present interglacial with a lower limit at 10,000 B.P. The term Flandrian Age is used in a strict chronostratigraphic sense (following Hedberg 1976) while Flandrian Stage refers to the deposits laid down during that time.

Altitude - altitude is used specifically to denote altitude in relation to Ordnance Datum (Newlyn), the national reference level of the United Kingdom, defined as the average MSL at Newlyn between 1915 and 1921. Since 1921 OD (Newlyn) has moved relative to MSL and is today 0.086 m. below MSL at Newlyn. All altitudes are +ve unless shown otherwise.

Depth - depth is used solely for depth below present ground surface and is given in centimetres.

Radiocarbon age - The radiocarbon ages are as given in Radiocarbon. The error quoted is one standard deviation about the mean. All dates are uncorrected and are based on a half-life of 5570 yrs.

Sea-level - sea-level, a term that has been used with many different meanings (Jardine 1975). Mean Sea-Level is a calculated value, in theory the surface level the worlds oceans would adopt if tidal forces ceased. However, values for Mean Sea-Level are only available for the Past c.150 yrs. and have no significance in the sedimentary record. Mean Tide Level, the average of high and low water over time at a particular location can be reconstructed approximately from former indicators of high or low tide and a knowledge of the tidal range. It is therefore Mean Tide Level rather than Mean Sea Level that is commonly used to construct sea-level curves. In this study however Mean Sea Level and Mean Tide Level are considered synonymous within the range of error present in the method.

Eustasy - Eustasy is taken to include all water-based variables affecting the level of the world's oceans and includes glacial-eustasy, tectono-eustasy, geoidal eustasy and local effects on the sea-level surface contributed by meteorology (e.g. barometric pressure), hydrology and oceanography.

Isostasy - Isostasy is taken to represent the variables of crustal movement including glacio-isostasy, tectono-isostasy, hydro-isostasy and local factors such as consolidation of sediments.

Factors of scale operating in time and space affect the status, relationships and measurement of variables. In a study of flood management and prediction, for example, the Anglian Water Authority has shown that the 1953 storm surge in the North Sea was a 1 in 10 yrs event and the 1978 flood a 1 in 75 yr. event. These studies however were based mainly on tidal and meteorological variables with changes in sea-level assuming the status of an independent variable (Tooley 1979). The status would be quite different in a study of changing sea-levels over a 10^3 - 10^6 yr time scale. For instance in a study of sea-level change during the Cretaceous, tidal and meteorological variables are incapable of resolution and variables such as geotectonic movements assume dependent status.

Transgression,Regression and Overlap. Shennan (1980) and Tooley (1982) have effectively summarized the different usage of the terms transgression and regression and the problems this causes in correlation between areas. The main problem has arisen through the mixing of lithologic, process and chronological meanings.

For instance, Jelgersma (1961) suggests the terms transgression and regression should be used to describe a covering and removal of marine deposits with no connotation of process. Jardine (1975) however includes a process meaning since the terms

> "are used to indicate a respectively landward and seaward migration - either by horizontal or by vertical movement or by combined horizontal and vertical movement - of the line of intersection of the surface of the land and the surface of the sea" (p.174)

In 1969 Tooley used transgression and regression in a descriptive sense but by 1974 transgression was associated with a rise of sea-level and regression with a fall (Tooley 1982). Shennan (1980) has shown that the Lytham transgression sequences were constructed using mixed criteria so that a transgression included information from both transgressive and regressive overlaps. The problems occur in correlation between areas when like processes or lithologies are not compared with like.

In this study it is proposed that transgression and regression are used purely for lithologic description in conjunction with the term overlap, a term with a long usage in hard rock geology.

A transgressive overlap is defined as the replacement of terrestrial sedimentation by brackish then marine facies. A regressive overlap is defined as the replacement of fully marine facies by brackish or littoral then non-marine terrestrial facies. No processes are associated with a transgressive overlap, nor are the terms used in the development of a chronostratigraphic scheme. Where reference is made to existing schemes the terms transgression and regression are used in their original sense.

Shoreline. Jardine (1981) defines a shoreline at any given location and any given time as

> "the line of intersection of mean tide level at the given time and the terrestrial surface at the given location" (p.297)

He considers that in practice, however, frequently the mapped shoreline of any given time is a line joining points located at MHWST.

The definition suggests that in former tidal flat and lagoonal zones any transitional contact between terrestrial biogenic and marine clastic sedimentation can be classed as a shoreline. Information on the changes in age and altitude of regressive and transgressive overlaps can therefore chart the change in the position of shoreline positions through time.

This means that the shoreline sequence (sensu Sissons 1966) of the western Forth Valley is in effect a form of 'marine limit' sequence. For instance the Main Buried Shoreline is defined as the maximum altitudinal limit reached by the rising sea-level that deposited the sediments of the Main Buried Beach.

There is a distinction to be made between landward limit and altitudinal limit however. Under certain circumstances of local peat growth and sea-level rise, biogenic and marine sedimentation can keep pace with one another. In such cases the most landward expression of marine deposits may not necessarily represent the limit of the rise in sea-level (e.g. Jardine 1975, Sissons and Smith 1965).

Morrison et al. 1981 define the Main Postglacial Shoreline in eastern Scotland as the highest of several Flandrian raised shorelines formed by the culmination of the Flandrian marine transgression. In a study on the dating of the Main Postglacial Shoreline near Montrose, Smith et al. 1980 described a site at Fullerton. The site, a small gully feature, showed the basal contact of the upper peat to rise in a seaward direction so that the carse deposits at the mouth of the gully are 1 -2 m. higher than the most landward expression. If local compaction factors can be discounted then sea-level was still rising while peat formation occurred. The feature they measured therefore may well be a shoreline prior to the formation of the Main Postglacial Shoreline - a suggestion supported by the subsequent 'old' radiocarbon date.

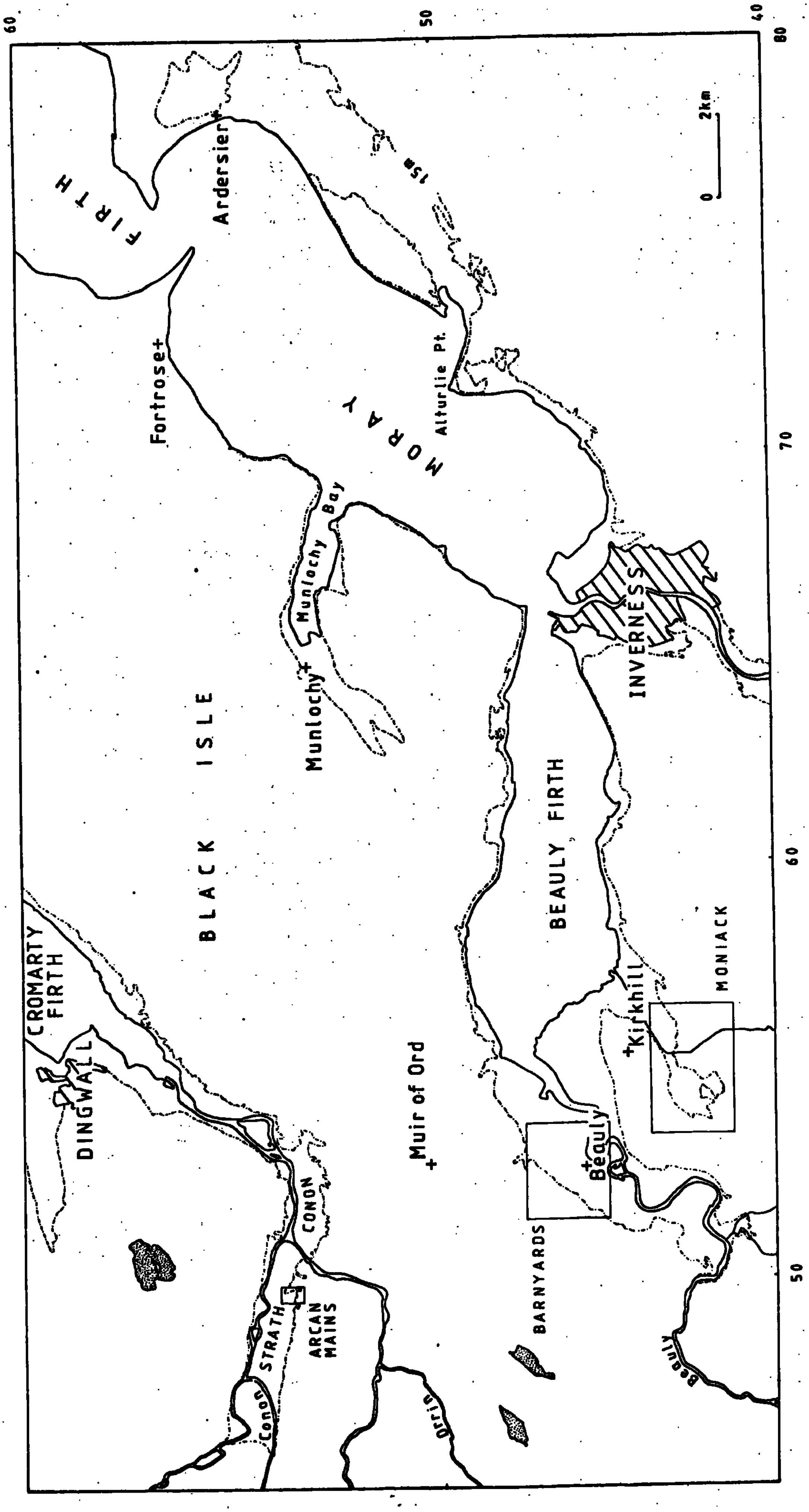
1.4 The study area

It was decided to restrict the area of study to the inner Moray Firth. This effectively means the head reaches of the Beauly and Cromarty Firths.

Three sites, Barnyards near Beauly (NH 5247), Moniack near Kirkhill (NH 5443), and Arcan Mains in Strathconon (NH 4954) provided material for radiocarbon dating. They were initially located from O.S. 6" maps from which areas considered suitable for further investigation were identified. The sites are located in fig. 1.1 together with other place names mentioned in the text.

Three additional sites were investigated at Munlochy Bay (NH 6351), Delny (NH 7372) and Rhynie - Mounteagle (NH 8478). Over 50 boreholes were put down at these later three sites to enable a more regional picture of variation in the age and altitude of measured features to be assessed.

Fig. 1.1 Location of study area


60
50
40
80
70
60
50
MORAY FIRTH
Ardersier
15m
0
2km
Fortrose
Alturlie Pt.
Munlochy Bay
Munlochy
BLACK ISLE
BEAULY FIRTH
INVERNESS
CROMARTY FIRTH
DINGWALL
Muir of Ord
Kirkhill
MONIACK
Beauly
BARNYARDS
CONON
STRATH
Conon
ARCAN MAINS
Orrin
Beauly

Only stratigraphic analysis has been carried out at these sites,their full significance is as yet uncertain and they are not included in this study. Samples for pollen, diatom and radiocarbon analyses will be taken and interpreted at a later date.

1.5 Form of the thesis

Chapters 2 and 3 are primarily concerned with published literature. In Chapter 2 the present knowledge of the geological setting of the study area will be reviewed. The study area lies on the edge of the subsiding Mesozoic Moray Firth Basin yet it is within 50 km. of the main watershed of Scotland - the site of ice accumulation during the Quaternary glacial periods. In Chapter 3 published literature on Flandrian sea-level change in Scotland is reviewed and together the two chapters provide a perspective for the present study. Also in Chapter 3, in a brief section on terminology, it is proposed that a new lithostratigraphic scheme be introduced in Scotland to avoid some of the confusion caused by the well used, but ill-defined terms such as carse clays, sub-carse peat, post-carse estuarine deposits and carse deposits.

In Chapter 4 the techniques used in this study to provide data for sea-level change are outlined.

In Chapter 5 stratigraphic, environmental and chronological data from three sites in the area and in the following chapter these data are interpreted in terms of sea-level movements.

In Chapter 7 the chronological and altitudinal factors of sea-level change are described and a preliminary chronological scheme and time-altitude graph of sea-level change based on nine ^{14}C dated index points are proposed.

The proposed scheme is briefly compared to other areas of Scotland

and NW Europe in Chapter 8. This chapter also contains a preliminary attempt to construct an isostatic recovery curve for the inner Moray Firth. The final chapter contains concluding remarks and suggests further lines of research.

CHAPTER 2

GEOLOGICAL PERSPECTIVE

2.1 Introduction

In sea-level research it is important to appreciate the direction and rate of long term earth movements both horizontally and vertically. The measurement of geological inheritance is however exceedingly difficult since the resolution of such comparatively small rates of change is often encompassed within the accuracy of contemporary measuring techniques. In addition, in areas such as Scotland and Fennoscandia the accumulation and removal of a succession of ice sheets has led to glacio-isostatic depression and recovery which mask the confident identification of long term vertical movements. Between these two areas the northern North Sea Basin has also undoubtedly had a complex history of vertical movements during the Quaternary with peripheral bulging during ice loading and subsidence during ice decay. The study area is located on the edge of the Moray Firth Basin which is genetically linked to the slowly subsiding North Sea Basin yet it is within 45 km. of the main watershed, the high ground of which nourished the last ice sheet and presumably its antecedents.

An equally important feature in the geological setting of the area has been activity along the Great Glen and related faults such as the Strath Glass and Strath Conon faults. The Great Glen Fault runs from Inverness in a north-north-easterly direction controlling the course of the coastline between Ethie and Tarbat Ness downfaulting the later Jurassic sediments against the Old Red Sandstone. It is a complex zone with a long history of activity and in this light the possibility of dislocation of shorelines in the inner Moray Firth as reported from the Forth Valley (Sissons 1972) should be noted especially since the Beauly Firth may also be fault controlled (Armstrong, 1977).

The intensive search for oil and gas reservoirs since 1959 and the beginning of offshore research by institutions such as the I.G.S. has resulted in a proliferation of basic data that has prompted an improvement in the knowledge of North Sea stratigraphy and the wider geological evolution of the North West European continental margin. In this chapter the evidence for long term vertical and horizontal earth movements, the extent of the last ice sheet and its implications for Quaternary uplift and subsidence and Late Devensian ice retreat and sea-level change will be reviewed.

2.2 Pre-Quaternary Geology

The whole of the North Sea area has been dominated by subsidence and deposition since at least Devonian times, though the exact nature and extent of the Devonian and succeeding Carboniferous basins is unclear at present, especially in the northern North Sea. During the Devonian the Caledonian massifs of Wales, London-Brabant, the Pennines, Southern Uplands and Highlands provided stability to the west and south whilst to the east and north-east the Ringkøbing-Fyn high and Fennoscandian massifs stood essentially in the same relationship they show today (Kent 1975 and fig. 2.1).

The geological evolution of the North Sea area, though possessing several tectonic and depositional cycles, can be traced to this time and is to be seen in view of the subsequent responses of these fragmented yet stable elements to deformation caused by global plate movements. Since Devonian times the North Sea area has been occupied by a number of intracratonic, subsiding sedimentary basins each of which is the response to different tectonic settings (P.A. Ziegler 1975).

The Old Red Sandstone initially described by Murchison (1839, 1859 in Small and Smith 1971) and by Miller (1841) is the dominant rock type of the Moray Firth coastal belt (fig. 2.2). It was laid down in large

Fig. 2.1 Major Permian to Mesozoic tectonic elements of the North Sea (Ziegler and Louwerens 1979)

1. Thick Jurassic series
2. Sedimentary basins
3. Highs
4. Boundary of Zechstein salts
5. Faults

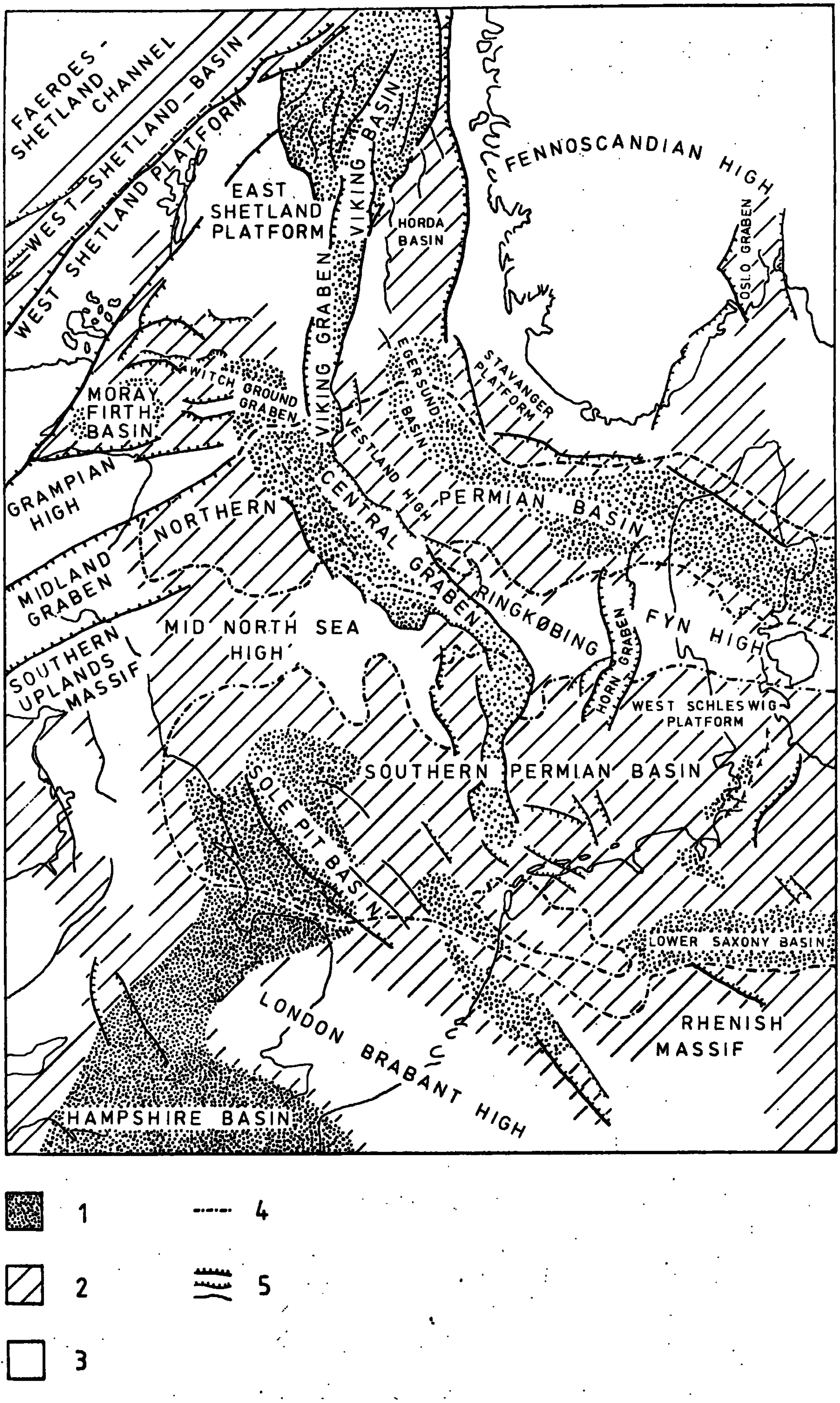
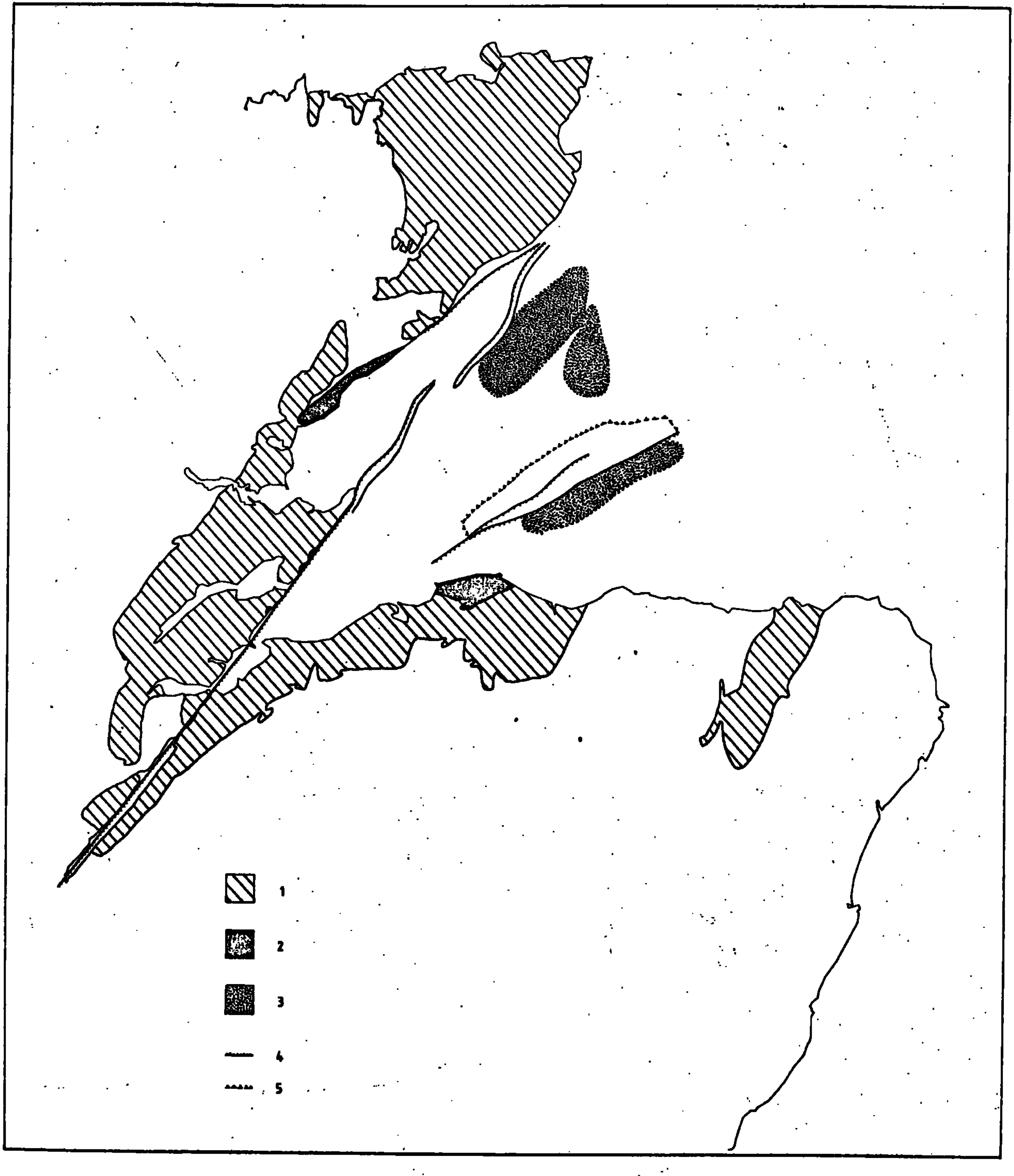

FAEROES - SHETLAND CHANNEL
WEST SHETLAND BASIN
WEST SHETLAND PLATFORM
EAST SHETLAND PLATFORM
VIKING BASIN
VIKING GRABEN
HORDA BASIN
FENNOSCANDIAN HIGH
OSLO GRABEN
EGERSUND BASIN
STAVANGER PLATFORM
MORAY FIRTH BASIN
WITCH GROUND GRABEN
VESTLAND HIGH
GRAMPIAN HIGH
NORTHERN PERMIAN BASIN
CENTRAL GRABEN
MIDLAND GRABEN
RINGKØBING FYN HIGH
HORN GRABEN
MID NORTH SEA HIGH
SOUTHERN UPLANDS MASSIF
WEST SCHLESWIG PLATFORM
SOUTHERN PERMIAN BASIN
SOLE PIT BASIN
LOWER SAXONY BASIN
RHENISH MASSIF
LONDON BRABANT HIGH
HAMPSHIRE BASIN
1
2
3
4
5

Fig. 2.2 Distribution of Old Red Sandstone in the Moray Firth area including limits of the Mesozoic sedimentary basin (Chesher and Bacon 1975)

1. Old Red Sandstone
2. Permian to Jurassic outcrops
3. Basin centres
4. Major faults
5. Zones of Uplift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a thick granitic body at shallow depth (Collette 1960 in Sunderland 1972). A programme of research undertaken by the I.G.S. beginning with shallow seismic profiling (Eden et al. 1970), drilling (Chesher et al. 1972) and followed by a further deep seismic survey (McQuillin and Bacon 1974) indicated the presence of two Mesozoic basins, one to the north-east, the other to the south and separated by a prominent zone of uplift (Chesher and Bacon 1975 and fig.2.2). This complex basin probably has its origins in the early Permian and is genetically linked to the Northern Permian Basins of the North Sea. Its importance lies in the fact that such a basin has controlled sedimentation in the area ever since and its continuing subsidence contributes one factor in the complex history of vertical movements in the area.

The simple two-basin sedimentation was interrupted by the initiation during the early Permian of a complex graben system forming part of the northern North Atlantic - Norwegian - Greenland Sea - Eurasion Arctic rift system which gradually widened during the Mesozoic leading to the early Tertiary separation of the North American - Greenland and European plates and the onset of sea-floor spreading (Ziegler and Louwerens 1979). The two-basin system in the North Sea was gradually modified by the development of a north-south graben system that breached the east-west Mid North Sea - Ringkøbing - Fyn high. The formation of the Viking and Central grabens, the Horn graben and the Horda fault system - which has been likened to a false start in the opening of the Atlantic Ocean - allowed thick accumulations of Mesozoic, Tertiary and even Quaternary strata (Caston 1977).

Through the Tertiary the entire North Sea area developed as a single, synclinal, subsiding basin centred on the main rift system and showing an absence of fault control. This pattern came into being during the Eocene since by this time the North American - Greenland and European plates had separated, sea-floor spreading had commenced and as a result the extensional stresses produced ceased to affect the North Sea graben system. Thicknesses of Tertiary strata of the order of 3500 m. were deposited in the Central graben near Ekofisk.

Clarke (1973) in an examination of data from fourteen wells from the central area (56^{o}- 58^{o}N, 1^{o}- 3^{o}E) of the North Sea has noted accelerated subsidence throughout the Tertiary from just over 0.01 m./1000 yrs. during the Cretaceous to over 0.5 m./1000 yrs. during the Quaternary.

Overall the North Sea has been dominated by negative movements since the Caledonian orogeny. In the central North Sea if Devonian sediments are taken into account subsidence of some 10 km. must have occurred at rates of 0.003 to 0.05 m./yr. in pre-Tertiary times (Collette 1971) while peripheral areas such as the Scottish and Fennoscandian massifs appear to have undergone complimentary uplift and erosion. Other blocks such as the Southern Uplands, Mid North Sea High and Ringkøbing - Fyn High have, however, remained static, nearer sea-level (Kent 1975).

The mechanism of subsidence is not entirely known. Bott (1971, 1975) considers the cause of subsidence to have been an isostatic response to crustal thinning and suggests this may be related to continental margin development. Stresses set up in the crust at this time could lead to flow in the mantle resulting in regional and local subsidence with normal faulting in the brittle crust.

Collette (1968, 1971) proposes that non-mechanical processes involving a load-controlled transformation of basalt to eclogite in the lower part of the crust can explain the amount of crustal thinning needed to explain the observed amounts of subsidence.

Ziegler and Louwerens (1979) accept that thinning of the crust may have been accomplished by extensional stresses causing flow in the mantle and also by subcrustal erosion. However, they propose that the main features of the Mesozoic rifting stage and later events could be explained by the emplacement and subsequent disappearance of a rift cushion at the crust-mantle interface, resulting in bulging and volcanism followed by collapse and subsidence which, in turn, caused the development of the single, broad, saucer-shaped North Sea basin that has characterized the Cainozoic.

In addition to vertical earth movements associated with basin development the Great Glen Fault and associated features have provided a complex history of horizontal as well as vertical displacement.

The Inverness area is certainly one of the more seismically active in Britain. Between 1768 and 1906 more than 56 earthquakes have been recorded on the fault, primarily from three active seismic centres (Ahmad 1967), the three largest tremors having taken place in 1816, 1901 and 1934 (Lilwall 1967). The fault is only one of a suite of faults trending SE - NE (the main Caledonian trend) both north and south of Glen More itself. There is some suggestion that the Great Glen Fault had its origins during the Caledonian diastrophism caused by the collision and relative shearing of the Asian and North American plates, a process lasting from Cambrian to Devonian times, through the absence of suitable time-markers makes a definite statement on the early movement of the fault impossible (D.I. Smith 1977).

The fault comprises a central zone of crushed and comminuted rock some 2.5 to 4 km. wide with a zone of decreased breakage extending away from the main hollow. Chesher and Bacon (1975) have traced its continuation offshore some 70 km. to the north-east (fig. 2.2) while Flinn has suggested that the Walls Boundary Fault is perhaps its continuation in Shetland, a possibility refuted by Mykura (1975).

Before 1946 the accepted view was that it had acted exclusively as a normal fault. Horne and Hinxman (1914) proposed that in the Inverness area the land to the east had been downfaulted some 1800 m. In 1946, Kennedy (in D.I. Smith 1977) made the revolutionary suggestion that the main movement had been a transcurrent one. He proposed a sinistral movement of 104 km. during Devonian-Carboniferous times which was based on all the information then available. A second detailed piece of work by Holgate (1969) suggested that the available evidence pointed to two periods of transcurrent movement, the first being a sinistral shift of 133 km. during the Lower and Middle Devonian and the second one of 29 km. in a dextral sense during the Eocene. Garson and Plant (1972) however proposed two phases of transcurrent faulting in the reverse sense to Kennedy and Holgate, a dextral movement of 120 km. during the Lower Devonian and a second dextral movement of 32 km. in the Upper Cretaceous. Offshore seismic work by Bacon and Chesher (1974) points to activity in a normal sense during the Mesozoic which seems at variance with the Eocene transcurrent movements of Holgate.

There is today a wide variety of opinion concerning the nature and timing of movements on the fault, evidence of differing kinds being put forward to postulate normal or transcurrent displacements of various sizes and directions. Undoubtedly the fault is a complex zone with a long history of activity. Moreover its Tertiary and Quaternary expressions still remain largely unknown. Mörner (1979a) considers that the Fennoscandian uplift is by no means as uniform as previously claimed. Isobase irregularities are found at many major bedrock seams and old faultlines and he has established postglacial faulting at several places. In Scotland the only detailed investigation of this type has shown the main buried shoreline of the Forth Valley to have been dislocated by neotectonic block movements in two places (Sissons 1972).

2.3 The Quaternary Period

It is probably correct to suggest that in Scotland Quaternary erosion processes merely modified in detail a landscape inherited from Tertiary and earlier times (Linton 1959). The Quaternary glaciations may be regarded as an exceptional event in the geological time scale. In particular the deposition of large quantities of unconsolidated material, the products of glacial erosion created a vast potential for subsequent reworking by the sea. Of greater importance has been the glacial-eustatic control of sea-level. Most authors agree that the lowest position of Devensian sea-level was reached at about 18000 B.P., coinciding with the maximum extension of land ice. At this time sea-level is considered to have been some 120 to 130 m. below present sea-level (Jelgersma 1979). In addition, as glacio-isostatic recovery is the main contributor to the raising and tilting of Quaternary marine landforms and sediments relative to sea-level an understanding of the glacial sequence is required.

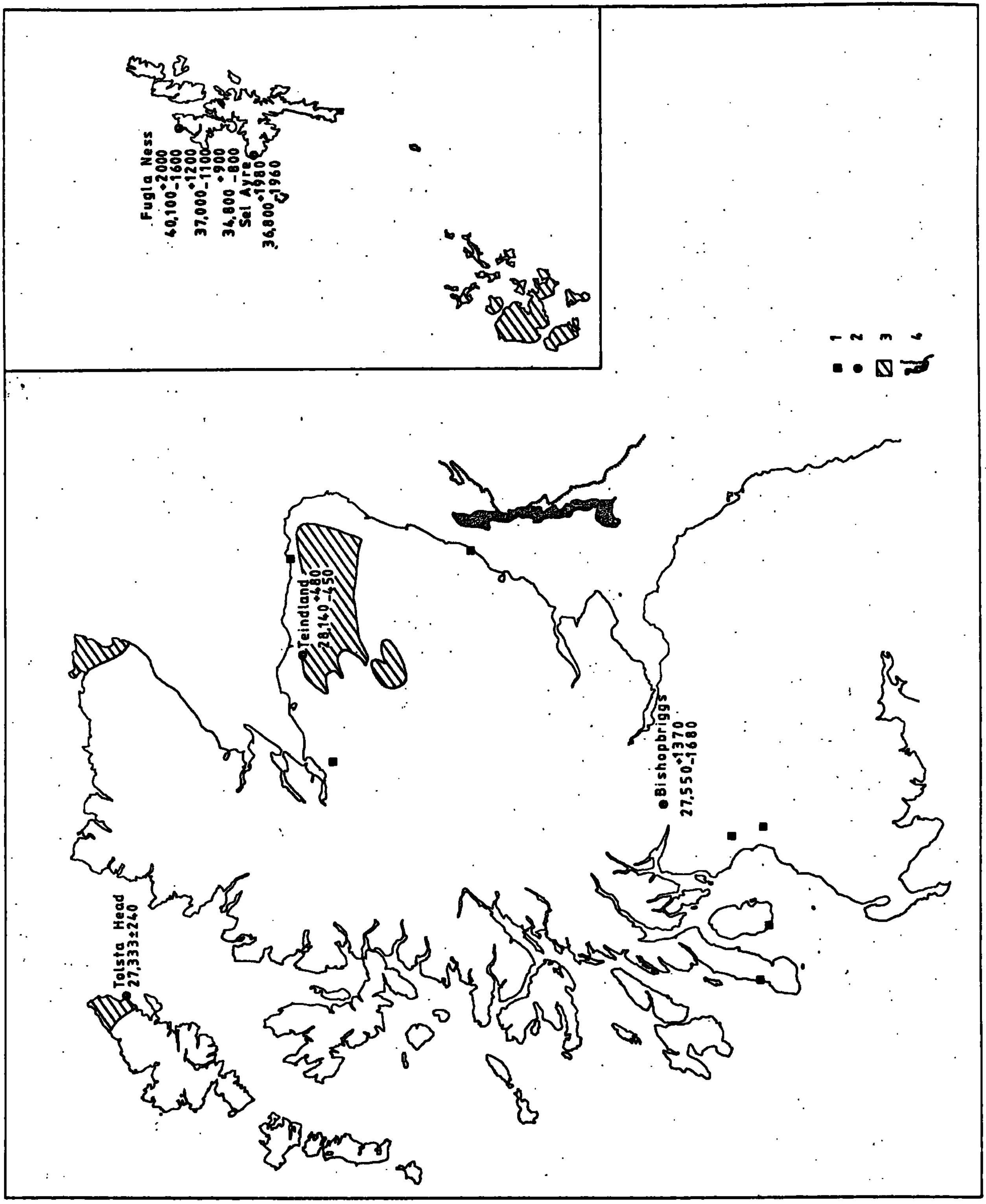
2.3.1 Quaternary events prior to the Devensian in Scotland

Evidence from East Anglia has demonstrated a succession - perhaps as many as fourteen - of colder and warmer stages since the beginning of the Quaternary (Mitchell et al. 1973, West 1981). Shotton (1975) considers that the cold cycles were not severe enough for the production of glaciers until the beginning of the Anglian stage. This means, however, that Scotland as the supposed main ice-accumulation area in Britain during the Quaternary has probably been overrun by ice at several times since the Anglian glaciation. Due to erosion during each successive advance, the ice sheets have tended to produce a clean slate for deposition during deglaciation with the result that very little is known about pre-last ice sheet events.

A number of interglacial sites has been suggested for Scotland, two

Fig. 2.3 Interglacial and interstadial sites in Scotland

1. High level in situ early glacial shell beds (Sutherland 1981)
2. Interglacial/interstadial sites
3. Unglaciated areas (Synge 1977)
4. Wee Bankie Moraine and eastern limit of Scottish Devensian ice (Thomson and Eden 1977)


Fugla Ness
40,100 +2000 −1600
37,000 +1200 −1100
34,800 +900 −800
Sel Ayre
36,800 +1980 −1960
Teindland
28,140 +480 −450
Bishopbriggs
27,550 +1370 −1680
Tolsta Head
27,333±240
1
2
3
4

in Shetland at Fugla Ness (Birks and Ransom 1969) and Sel Ayre (Birks and Peglar 1979) with a third at Teindland in Moray (Edwards et al. 1976).

The Fugla Ness peat has been dated three times, Sel Ayre once and all four determinations show an unexpected finite age (fig. 2.3). In the light of Sutherland's warning (1980) concerning the effects of contamination on samples with a radiocarbon activity close to background or containing small amounts of carbon, such dates should be treated with caution. The age of the proposed interglacial at Teindland has not been dated, it can only be presumed earlier than a higher horizon dated at 28, 140 $\pm^{480}_{450}$ B.P.

The assignation of these sites to the Ipswichian interglacial is based only on pollen and stratigraphic criteria, radiocarbon dating does not provide an answer. With the nearest Ipswichian sites in northern England at Hutton Henry (Beaumont et al. 1968) and Scandal Beck (Carter et al. 1978) a considerable distance to the south, it must be realized that correlation of pollen assemblage zones over such distances must be regarded as tentative especially since Shetland is known to have exhibited a different vegetation history to Scotland in the Flandrian interglacial.

Evidence for Ipswichian sea-levels in the North Sea basin is fragmentary. Jardine (1979) references a number of sites where Ipswichian sea-levels have been studied on the east and south coasts of England. Because of the uncertainties involved in dating these fragments it is by no means certain that at each site the same event is recorded and statements on possible post-formational warping must remain exceedingly speculative.

In western Scotland there are a number of fossil rock platforms and cliffs that have been attributed to an interglacial (=Ipswichian) age. One recent contribution (Sissons 1981c) suggests there are three sets of platform present, an interglacial suite, a glacial suite and a Late-Devensian feature, each exhibiting different attributes of height and gradient. The interglacial set, unlikely to have survived in the altitudinal zone affected by later erosion is suggested to be present in the intertidal zone and a few metres above and below present sea-level. The fragments are often ice-moulded and striated and probably do not represent a single horizontal platform (c.f. Dawson 1980) rather they suggest the existence of more than one horizontal or gently sloping shoreline. The fact that they lie close to present sea-level has been taken to suggest that glacio-isostatic recovery for Scotland is almost complete.

On the east coast of Scotland there are no undisputed interglacial shorelines recorded. However Eden et al. (1977) propose that the clear expression of the Main Lateglacial Shoreline at Burnmouth and its occurrence over an altitudinal range of several metres could mean it may be an older shoreline that has been exhumed. This might not be unexpected due to the close altitudinal association of the Main Lateglacial Shoreline and interglacial suite of rock platforms in western Scotland.

2.3.2 The Devensian ice maximum

The amount of Late Devensian and Flandrian isostatic uplift in areas formerly under direct ice load and the characteristics of forebulge migration and subsidence in peripheral areas is directly related to the extent, thickness and timing of the last ice sheet. However the present state of knowledge concerning these variables has probably never been in such confusion despite the ever-growing body of data. The situation is so complex that Sissons (1981a) correctly states that :

> "after 140 years of research it is surprising how little we really know about the extent of the last Scottish ice-sheet and associated events." (p.16)

It is not known from continental evidence alone when the last Scottish ice sheet began to build up. However, the oxygen isotope stage 5/4 boundary from the Pacific core V28 - 238 (Shackleton and Opdyke 1973) dated at c 75,000 B.P. suggests a major global build up of glaciers, a feature also noted for the Atlantic (Ruddiman et al. 1981). This fact has led Sutherland (1981) to depart from accepted theory and propose that the last Scottish ice sheet accumulated extremely rapidly some 75,000 years B.P. enabling rapid isostatic depression allowing a marine transgression to deposit the high level shell beds subsequently covered by till that are known to be present at a number of localities close to the present coast of Scotland (fig. 2.3). The in situ nature of some of these deposits as claimed by Sutherland for all must be called into question especially those from Clava (Peacock 1975a) and Gardenstown (Peacock 1971).

The accepted date for last ice sheet initiation is around 27,000 B.P. though this suggestion is in fact based on only two radiocarbon assays from the Scottish mainland. Teindland, dated at 28,100 $^{+480}_{-450}$ B.P. and Bishopbriggs, dated at 27,333 ± 240 B.P. supposedly illustrate that Scotland was ice free prior to this time. Recently the validity of the inferences based on these dates has been called into question (Sissons 1981a).

The Teindland date is from a buried soil horizon overlain by a minerogenic deposit. Detailed analysis by Edwards et al. (1976) suggest the overburden is till which would make the date a maximal one for the arrival of glacial conditions. Romans et al. (1966 in Edwards et al.1976) provide an alternative theory that it may be soliflucted material. The additional fact that Edwards et al. 1976 propose that the organic horizon is interstadial underlain by a yellow sand showing a possible and inter-glacial (Ipswichian?) pollen flora renders the site unique in Scotland. As Sissons (1981a) comments both interstadial and interglacial sites are rare in Scotland and to have both at one site separated by less than one metre is exceptional. Consequently the interpretation of the Teindland site must remain enigmatic and firm inferences using it must be viewed with caution.

The Bishopbriggs date is from a woolly rhinoceros bone embedded in fluvioglacial deposits beneath till. However when compared to two nearby dates from Kilmaurs, 30 km. south west of Glasgow, in essentially a similar stratigraphic position, all three give widely differing results. It may be concluded that the data previously held to suggest Scotland was ice free prior to 27000 B.P. is equivocal.

In addition to the lack of data concerning last ice sheet initiation there is confusion over the number and extent of ice sheets needed to explain the existing evidence. The problem lies not in central areas but in the peripheral areas of Aberdeenshire, Banffshire, Orkney, Shetland, Caithness, the Outer Hebrides and the North Sea.

Aberdeenshire and Banffshire have proved to be one of the more enigmatic of such areas. Here there are till sheets, often superimposed, that are related to ice masses from different sources. T.F. Jamieson (1906a) recognized three different tills at Ellon related to two glacial episodes and a third local ice readvance down the Dee Valley. Further schemes involving mutliple glaciation were proposed by later fieldworkers such as Bremner, Simpson, Charlesworth and Synge and a summary of their most important contributions is given by Gemmell (1975). Synge (1956) offered one new development involving obstruction of ice flowing to the north east by Scandinavian ice causing a bifurcation which left 'moraineless Buchan' ice-free (fig. 2.3).

Recent papers by Clapperton and Sugden (1972, 1975) and Sugden and Clapperton (1975) have tended to reject Synge's 'moraineless Buchan' theory believing instead that the continuity of landform mapped could best be explained by the downwasting of only one ice sheet retreating westwards. Their work is primarily of a morphological nature however and there still remains a basic lack of stratigraphic and time control for the north-east of Scotland.

Organic horizons which could eventually provide that time control for interglacial or interstadial events are known from various localities but their exact relationships remain unresolved. One radiocarbon assay has been carried out on lenses of peat in the basal layers of Late Devensian red till at Burn of Benholm near Inverbervie. It gave an age of >42,000 B.P. (Donner 1979) which negated an earlier hypothesis that the peat erratics were Late Devensian (Donner 1960). The only conclusion that is possible from this site is that the peat and grey shelly till which occur as erratics within the red till predate the deposition of the latter, it does not give evidence for a pre-Late Devensian glaciation. Peacock (1980b) has recently recalled the earlier literature of Bremner and drawn attention to two other sites showing peat horizons beneath the red Strathmore drift at Tipperty and Balmedie. Edwards and Connell (1981) review the options available from these and similar sites and conclude that no firm deductions can be made concerning a pre-Late Devensian interglacial or interstadial event and by implication pre-Devensian glaciation in the area at present.

A second peripheral area, Caithness and Orkney exhibit widespread deposits of shelly till with striae and erratics indicating a general north-westwards flow of ice classically attributed to the deflection of Moray Firth ice by ice from Scandinavia. There is conjecture that these tills represent a pre-Devensian glaciation the evidence for this consisting of infinite ^{14}C dates and intense periglacial modification of drift. However, the inference that the age determinations prove these tills to be pre-Devensian is not valid. When allochthonous material is dated it merely gives a maximal age, the incorporation could have occurred at any time afterwards and when the date is infinite not even that supposition can be held.

A third peripheral area, the Outer Hebrides, is at present the object of controversy concerning glacial events. Flinn (198o) and Peacock (1980a) give evidence for easterly ice flow in Lewis, Harris, the Uists and Benbecula and suggest the Hebrides nourished a local ice cap with an ice sheet to the west of the present watershed, it also implies modification of views concerning the extent of the mainland Scottish ice sheet westwards. Sissons (1980, 1981a) infers from climatic and topographic data that the Outer Hebrides could not initiate an independent ice mass. He envisages a maximum extent of the Scottish ice over the Outer Hebrides with subsequent separation due to calving in the Minch. Peacock (1980a) questions the validity of using data from mainland erratics to prove Scottish ice sheet invasion and suggests that other evidence for mainland ice may relate to an earlier, pre-Late Devensian glaciation. There is however the suggestion that mainland ice may have reached the north of Lewis since at Tolsta Head (fig. 2.3) a limnic deposit containing an interstadial pollen flora and dated at 27,333 ± 240 B.P. (Von Weymarn and Edwards 1973) is covered by till with a north westerly component of flow.

The North Sea is classically the area of conflict between Scottish and Scandinavian ice and as such should give information regarding the eastward extent of Scottish ice. In this area too, however, there is controversy. From seismic records and borehole data a provisional succession has been outlined for the Quaternary in the central North Sea. Holmes (1977) suggests that at the Devensian maximum the central North Sea area between 56° and 58°N was ice covered to the median line. The maximum is thought to correlate with the Lower Channel Deposits, tunnel valleys formed in proximity to an ice margin. Janssen et al. (1979) produce a map depicting the Scottish and Fennoscandian ice sheets confluent at the latitude of Orkney but he suggests they did not meet in the central North Sea. Sissons (1981a) in an intentionally speculative paper concludes that the two ice sheets were never confluent and that a delta was situated in the eastern central North Sea fed from the Scandinavian ice sheet, the gradual subsidence of which is seen to explain the cut and fill episodes of the deep Lower Channels. The arguments are complex and rely heavily on the interpretation of sporadic data. The only incontrovertable evidence in the North Sea for a glacial limit, however, is the Wee Bankie moraine system (Thomson and Eden 1977).

Taken together the evidence from peripheral areas relating to the extent of the last ice sheet is inconclusive, it cannot be proved that Orkney, Caithness, the Outer Hebrides, North-East Scotland and the mid-North Sea were reached at the last ice maximum. This has tremendously important repercussions on the amount and nature of isostatic recovery and its effect on raised shorelines. With a 'small' Scottish ice sheet coming into favour it also influences the extent and timing of the English glaciations. Long held views that the last Scottish ice sheet built up some 27,000 years ago, advanced into the Midlands of England, overran the Hebrides, became confluent with the Fennoscandian ice and then retreated from 18000 B.P. are being called into question. It could be that the 'normal' conditions for the Devensian included a smaller Scottish ice sheet in a state of equilibrium, grounded in the Inner Hebrides to the west and close to the present Scottish coast on the east. Such limits also mean that complex and elaborate models of glaciation (e.g. Boulton _et al_. 1977) are shown to be based on doubtful premises.

If the extent of the last Scottish ice sheet is not known with certainty then ice thicknesses cannot be calculated and this has serious repercussions for glacial isostasy. Sissons (1981c) suggested that since the proposed interglacial suite of rock platforms are at and around the altitude of present mean sea-level on the west coast most, if not all, loading effects due to glacier ice have been compensated for. If true, this could mean the figure of c 3.5 mm./yr. present uplift for the central Highlands (Valentin 1953) represents a pure tectonic movement. Gordon (1957) in a less publicized paper refutes much of Valentin's conclusions as unsupported by the evidence and that the contour map of present uplift (Valentin 1953, fig. 2) is almost entirely conjectural. Gordon concludes that

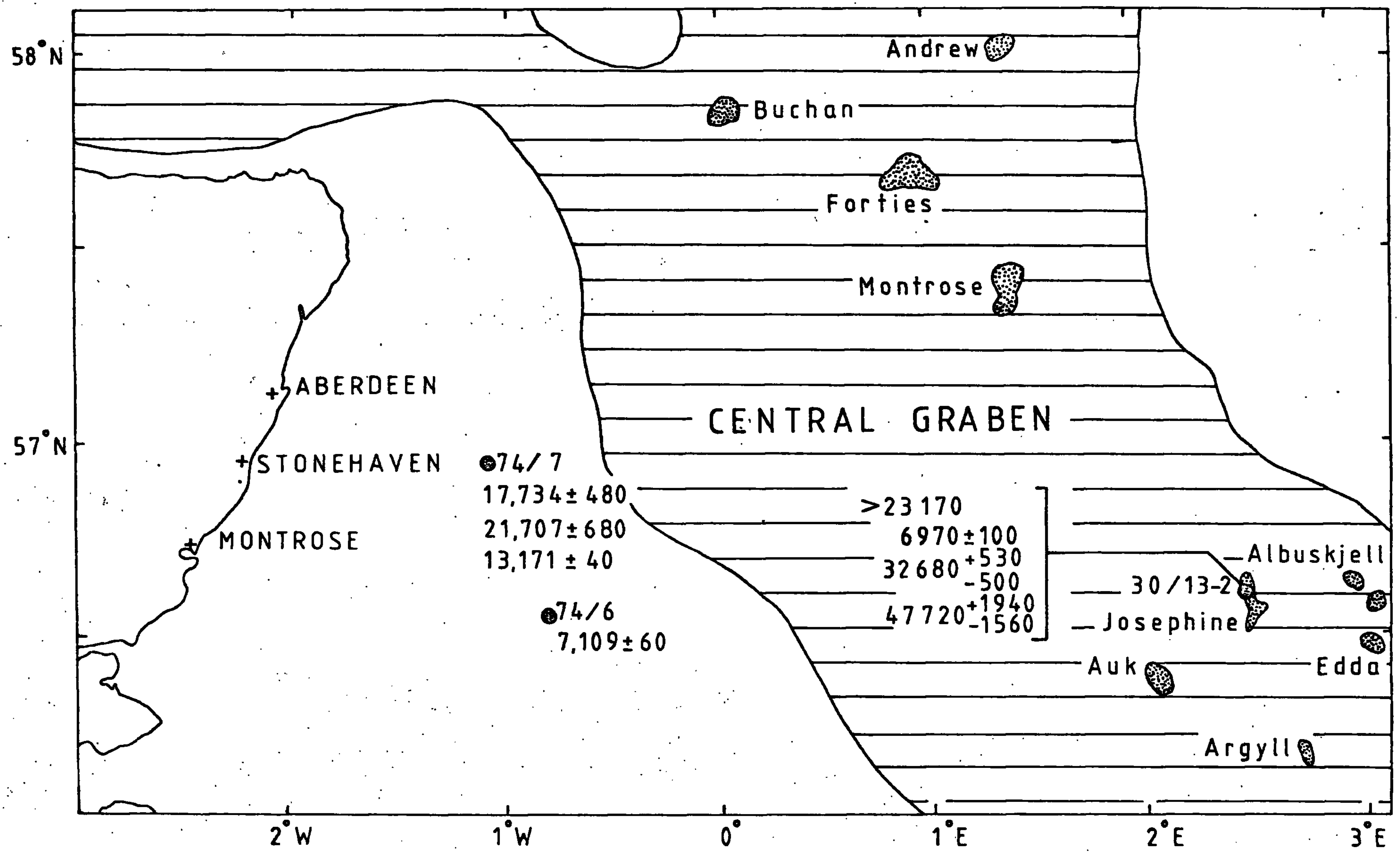
> "in Scotland such evidence as there is for supposing that the highlands are rising is purely geological - and geological theory at that" (p.32)

An interesting postscript is given by Mörner (1979a) who has identified a long term trend of subsidence in Fennoscandia upon which isostatic recovery has been superimposed. He considers that the exponential isostatic factor ceased at c 4500 B.P. but from c 8,000 B.P. there has also been a linear uplift factor, of as yet unexplained origin, of c 10 mm./yr. Here it should be noted that total absolute uplift in Fennoscandia due to ice-loading is 830 m. in Angermanland, three times that of Scotland so there is much more chance of isolating such factors. Such a difference in total absolute uplift implies a great difference in size of the ice sheet and if Mörner (1979a) is correct in suggesting isostatic recovery is complete for Fennoscandia, it could be also for Scotland. The near-horizontal gradients of the Main Postglacial Shoreline of the Forth Valley (Sissons 1976) suggest it could be the case. The field is certainly wide open for further study.

2.3.3 Quaternary subsidence in the North Sea area

In the northern North Sea the thickness of deposits formed during the last 75,000 years is equal to that of those formed during the whole of the Quaternary. Subsidence rates cited by Clarke (1973) and Eden et al. (1977) show a marked increase towards the present from 0.01 m./1000 yrs. during the Cretaceous to over 0.5 m./1000 yrs. during the Quaternary and even higher rates of 2.04 m./100 years during the Middle and Late Devensian.

Fig. 2.4 Central North Sea with location of boreholes and radiocarbon dates used to calculate sedimentation rates. (Holmes 1977)


58°N
57°N
2°W
1°W
0°
1°E
2°E
3°E
Andrew
Buchan
Forties
Montrose
CENTRAL GRABEN
ABERDEEN
STONEHAVEN
MONTROSE
74/7
17,734± 480
21,707±680
13,171 ± 40
74/6
7,109±60
>23170
6970±100
32680+530 -500
47720+1940 -1560
Albuskjell
30/13-2
Josephine
Auk
Edda
Argyll

Taken together there does seem to be a trend of increase in the average sedimentation rate from the Tertiary and that in many areas Devensian sediments occupy a disproportionate thickness with respect to the Quaternary sediments as a whole. Undoubtedly one factor is that of peripheral response to glaciation.

If much of the central North Sea rose in response to glaciation of adjacent land areas then erosive episodes could have removed much of the earlier Quaternary deposits. During deglaciation the North Sea in subsiding would provide excellent conditions for the preservation of sediments at a rate superimposed on the underlying tectonic subsidence.

One example however may serve to illustrate the inaccuracy in data used to calculate subsidence rates. Eden et al. (1977) provide a table of subsidence rates calculated from a small number of radiocarbon dates and estimates based on geological position. The location of the radiocarbon dates and boreholes is given in fig. 2.4. They propose that between 32,700 B.P. and 21,760 B.P. rates of subsidence in the Western Platform and Josephine Field areas was 2.04 m./100 yrs. - an anomalously high figure. This is based on two dates, one from each area, and correlation is derived from unsupported seismic evidence. The $32,682 \, ^{+530}_{-500}$ B.P. date is from partially lignitized wood from 320 - 328 m. beneath sea-level and is clearly allochthonous suggesting that the sediments containing the wood fragments could be younger, or the sample could have been contaminated by younger material (c.f. the finite "interglacial" dates from Shetland). Of two dates in the same borehole above the allochthonous wood at 183 - 201 and 259 - 267 m. below sea-level, the first is infinite at >23,170 and the second on marine shells, 6,970 ± 100, is ignored without further explanation.

The 21,768 ± 630 B.P. date used by Eden et al. (1977) is the same as the 21,707 ± 680 B.P. date reported by Holmes (1977) though no correction factor is mentioned. The sample is from fine lignite particles sieved from 1.5 m. of fine sand attributable to the Marr Bank Beds and as such is open to contamination. The lowermost date from this borehole, 74/7, shows an age inversion and is ignored in subsequent treatment. Therefore, the apparent average subsidence rate of 2.04 m./100 yrs. is based on unsound premises. The argument is not against a substantial increase in subsidence during the Middle and Late-Devensian but to illustrate that apparently accurate figures of subsidence quoted to two decimal places could be an order of magnitude in error.

Eden et al. (1977) consider the best explanation for peripheral bulging and subsidence in the North Sea is for mass transfer from the ice accumulation areas of Fennoscandia and Scotland, in a low viscosity channel in the upper mantle. They consider stable massifs to the east of Fennoscandia and west of Scotland could produce a preferential movement in towards the North Sea where the graben system is probably underlain by a more mobile mantle showing a relatively high heat flow and also that a position on the meeting edge of such channel flow would be conducive to enhanced bulging and subsidence. This has interesting repercussions for, if true, the raised shorelines on the east coast of Scotland should exhibit steeper gradients than those on the west, though of course unequal ice loading could produce the same effect.

Mörner (1979a) has delineated an uplift cone surrounded by a subsidence trough for the Fennoscandian Shield area. Calculations of mass suggest they are roughly equal at c 7.0 x 10^5 km^3 and this is taken as proof of rapid deformation and lateral transformation of mass almost entirely within the aesthenosphere. On deglaciation he considers the disappearance of mass from the forebulge was exponential and took c 8,000 years (c 16,000 - 8,000 B.P.) and the appearance of mass in the uplift cone was sigmoidal in shape and took 9,000 years (13,000 - 4,000 B.P.). However, these conclusions are subject to many caveats. Some of them include:-

- all radiocarbon dates are converted to sidereal years
- the Scottish ice sheet is not taken into account
- an homogeneous upper mantle is assumed under and around the Fennoscandian shield
- A constancy of shape of the forebulge trough is also assumed.

The effect of a rapid disappearance of a forebulge in the North Sea would be to increase the subsidence rates dramatically, initially they could be very great indeed. Mörner (1979a) has suggested that all isostatic recovery had taken place by c 4,000 B.P. In this case the decrease in subsidence rates of the North Sea proposed by Eden et al. (1977) during the Flandrian should be noted. Perhaps as on the Scottish mainland continuing tectonic movement in a vertical sense is related to old geological trends. The whole question of modern crustal movement and its component parts still await accurate measurement. In addition a further unknown factor on isostatic recovery is the effect of the accumulation and disappearance of the Loch Lomond Readvance ice sheet.

2.3.4 Late Devensian ice limits and sea-levels

The Scottish ice sheet retreated towards its source areas prior to 13,000 B.P., the result of climatic amelioration (Gray and Lowe 1977). Contemporaneous with the decay of the ice sheet there occurred isostatic recovery and a complementary eustatic rise in world sea-level. Apart from a few shorelines cut in rock on the west coast of Scotland assigned to an interglacial age (Dawson 1980, Sissons 1981c) the remaining shorelines on both east and west coasts owe their altitude and gradient to the single though complex process of isostatic recovery.

Some shorelines can be traced to contemporary ice limits (Sissons et al. 1966). However, there is a danger that ice front positions may be located wrongly using the evidence of the furthest inland expression of any particular Late Devensian shoreline. For example, Cullingford (1977) has located an ice front inStrathearn at Dunning, the furthest west that the Main Perth Shoreline has been traced.

Armstrong et al. (1975), Browne (1980) and Browne et al. (1981) have cogently argued that the occurrence of high level arctic marine clay to the west of any recognizable shoreline and at higher altitudes must mean the contemporaneous ice front lay similarly further west. In the case of the example given, the presence of marine clay at Crieff to the west of the last trace of the Main Perth Shoreline and at higher altitudes must mean the ice front lay not at Dunning but some 18 km. to the west (Browne et al. 1981).

Similarly marine limits that drop sharply over the proposed boundary of an ice limit have often been used to conclude that ice occupied or readvanced to that limit and remained there for some considerable time allowing isostatic uplift to cause a fall in relative sea-level which is recorded inside the limit once the ice retreats. For example Sissons (1976) noted an abrupt fall in the marine limit from 38 m. to 20 m. at the Stirling gap. In the Moray Firth area Synge (1977a) also recognized a 'dramatic' drop in the marine limit from 42 m. at Lochardil to 26 m. at Balblair (fig. 2.5) suggesting ice occupied the Beauly Firth for some time.

West of the Stirling gap new deposits of marine clay have been found at 34 m. proving an actual drop in the marine limit, not of 18 m. but of no more than 5 m. As Browne et al. (1981) correctly state :

> "the terminus of a marine feature may not represent the contemporaneous ice front and that the highest shoreline in the area may not represent the marine limit" (p.13)

Great caution must therefore be exercised when accepting the current scheme of ice limits and sea-levels for the Moray Firth area. High level marine clays with an arctic-subarctic fauna are known at Ardersier (Wallace 1882), Fort George (Wallace 1883), Muirton Mains in the Conon Valley (Horne and Hinxman 1914) and possibly some of the brick-clay sites reported by Eyles and Anderson (1946) may be included here, moreover there probably remain more.

Westwards from Elgin to Ardersier the interconnected and uninterrupted nature of meltwater channels and esker ridges suggest a continuous phase of down and backwasting ice. At Ardersier however there is a large and complex cuspate landform interpreted by Horne et al. (1923) as a high raised beach. The discovery of arctic shells by Jamieson (1865) and Wallace (1882) in a clay stratum associated with the feature together with its morphology and composition (predominantly sand and silt) has led J.S. Smith (1977) to consider it as a readvance moraine, the shells presumably dredged from the floor of the Inverness Firth. Subsequent sea-levels have trimmed the feature to its present complex cuspate form (Ogilvie 1914).

The next stage in deglaciation is thought to be represented at Alturlie, some 7 km. east of Inverness. Synge (1977a) notes a complex of asymmetric ridges linked by shingle bars. However, inspection of the Alturlie feature reveals it as a large mass of fluvioglacial sand and gravel, the surface expression of which shows kame and dead ice hollow forms, it is certainly not a true moraine and as such may not represent a marked ice front position, rather it could be a remnant of outwash from an ice front further west.

The earliest juxtaposition of ice front and sea-level is reported from Inverness where the Lochardil delta grades to a level of 42 m. O.D. (Synge 1977a). It is proposed that since no marine features are found westward at levels of over 34 m. i.e. a drop in the marine limit, the ice front stood at Inverness for some time. A steep slope just to the south is interpreted as an ice contact feature lending support for this hypothesis.

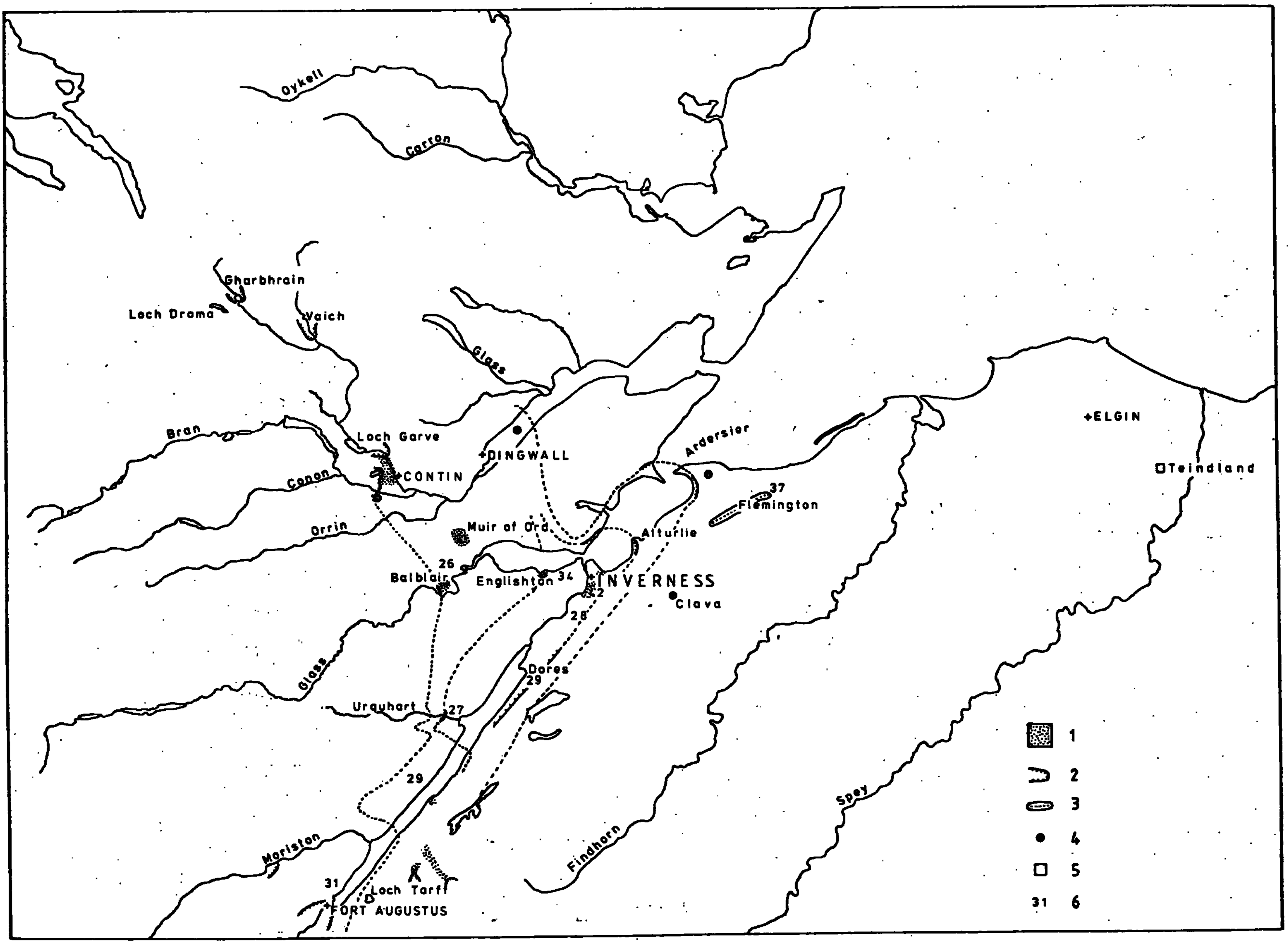
The Lochardil delta provides one point for Synge's highest 'shoreline' (the a_1 or Kildrummie shoreline). The only other point is to the east where the eastern end of the Flemington esker is considered to have been washed by the sea at 38 m. Further to the east Peacock et al. (1968) have identified fragments of Late Devensian shorelines, the highest at 27.5 m., on Clarkly Hill, but correlation with any of Synge's features is impossible.

There is apparently no evidence for this high sea level between Kildrummie and Lochardil, however at Ardersier there is a lower bench cut at 32 m. (the a_2 or Culcabock shoreline) trimming the glacial sands and silts and forming beach ridges as noted by J.S. Smith (1968) at Hillhead Farm. This level is also represented at Alturlie and Culcabock in Inverness where a lower delta formed while the ice front remained near Lochardil. At this time a slight recession of the ice front is presumed allowing marine activity to enter the Ness narrows to Clachnahulig where a kettlehole is apparently infilled by what is termed beach material (Synge 1977a).

At Englishton an impressive flat-topped delta at c 34 m. O.D. is fed by a large meltwater channel (fig. 2.5). Classic foreset bedding with included till balls (R. Cornish, pers. comm.) capped by topset bedding does suggest the proximity of ice. West of the delta there is reported to be another drop in the marine limit to 26 m. at Balblair (Synge 1977a). A supporting line of evidence given is the large gravel fan at Bunchrew 0.5 km. to the east which is graded towards present sea-level i.e. much lower than the Englishton delta. The size of this delta is taken to suggest it was deposited by glacial meltwater while the

Fig. 2.5 Late Devensian ice retreat stages and marine limits of the inner Moray Firth (Synge 1977a and J.S. Smith 1977)

1. Fluvioglacial outwash
2. Ice limits
3. Esker systems
4. Arctic marine faunas
5. Interstadial/interglacial site
6. Marine limit


Oykell
Carron
Gharbhrain
Loch Droma
Vaich
Glass
Bran
Loch Garve
+CONTIN
+DINGWALL
Canon
Orrin
Muir of Ord
26
Balblair
Englishton
34
INVERNESS
2
Clava
Alturlie
Ardersier
37
Flemington
+ELGIN
Teindland
28
Dores
29
Glass
Urquhart
27
29
Moriston
31
Loch Tarff
FORT AUGUSTUS
Findhorn
Spey
1
2
3
4
5
31 6

ice stood nearby. The fact that it is graded to a much lower level supposedly illustrates a dramatic fall in sea-level accompanied the halt at this stage.

However, a diagram given by Synge and Smith (1980, site 9) for the Englishton delta shows its surface slopes from 37.8 m. to 28.4 m. not far removed from the 26 m. marine limit at Balblair illustrating the main problem with deltas that subsequent erosion can remove much of the distal end reducing the accuracy of the indicative meaning. In addition the knowledge that high level shell beds have been reported but not rediscovered at c 30 m. above Cononbank Farm and adopting the caution advised by Browne <u>et al</u>. (1981) it would be unwise at this time to suggest a long halt at the Englishton limit.

There may well have been a dramatic fall in sea-level as evidenced by the Bunchrew delta but there are some doubts : firstly, the duration of the halt at Englishton has been questioned and secondly, the vast Flandrian expression of the Moniack delta further to the west (see Chapters 5 and 6) casts doubt on the line of argument that suggests simply because of large size and constituent composition a glacial origin is the only one possible for the Bunchrew delta. Similar inferential arguments have been used in other areas of Scotland and without firm dating are dangerous foundations on which to build interpretation.

Synge's 'b' series of shorelines is the most prominent and widespread rising from 24 m. at Ardersier to 26 m. at Balblair where a delta with backing ice contact slope proves the juxtaposition of ice and sea-level at this locality.

There is also evidence of marine penetration accompanying ice retreat into the Conon Valley. Horne and Hinxman (1914) record finely laminated blue and grey estuarine clay near Muirton Mains yielding an arctic fauna.

Below the Falls of Rogie there is a large dissected outwash fan composed of coarse gravel in its upper parts but fining towards Contin (J.S.Smith 1968). Kirk,Rice and Synge (1966) consider the evidence consistent with a marine inlet in the Conon Valley with the prograding Contin fan at its head fed by an ice front in the vicinity of Loch Garve, the rock bar at Rogie protecting the fan from later destruction as the ice retreated.

The Muir of Ord fluvioglacial complex has traditionally been explained as a stage in ice retreat from Beauly to Conon Bridge and Contin (J.S. Smith 1977). A more logical explanation could be that the sea penetrated from the north down the Cromarty Firth and from the south via the Beauly Firth cutting off a lobe of ice in the isthmus of Ord (Ogilvie 1923) and allowing it to stagnate, thereby explaining the vast amount of dead ice topography, eskers, kames and kettles in the vicinity.

A date from basal organic silts at Loch Droma of 12810 ± 155 B.P. (Kirk and Godwin 1963) has long been relied upon to suggest deglaciation of most of the Northern Highlands by this time. The date is from allochthonous plant debris probably derived from material from recently deglaciated terrain and is therefore open to many possible sources of error (Sutherland 1980).

A subsequent readvance termed the Gharbhrain stage (J.S. Smith 1977) was characterized by a readvance to the limit of the Gharbhrain moraine (fig. 7.4). One controversy here concerns glacial activity at this time in adjoining glens. Kirk et al. (1966) suggest the glacial sequence in Strath Vaich to the east is equivalent however Sissons (1977) in his treatment of the Loch Lomond Readvance in the Northern Highlands ignores the Strath Vaich evidence presumably not regarding it as equivalent to the Gharbhrain stage. It must be remembered that Late Devensian pollen sites and radiocarbon dates only provide negative evidence for glacial episodes and to place so much reliance on one date from derived material gives a false precision to the interpretation. Much more work needs to be undertaken on the glacial chronology of the area with greater emphasis on time control.

The 'b' shoreline series that Synge (1977a) traces in the Beauly and Inverness Firths is also apparently found around the shores of Loch Ness. The question of marine penetration into Loch Ness is an interesting one especially in the light of new theories put forward by Sissons (1981b). Synge (1977a) traces a 'prominent marine shoreline' 10 to 15 m. above the present surface of the loch. At Dores it consists of a fine arcuate beach ridge at 29 m. O.D. (fig. 2.5). Field observation shows two other beach ridges at 19-20 m. and 18.5 m. both of which, though identical in appearance are termed lacustrine. Further notches are described at Inverfarigaig (28 m.), Foyers (28.9 m.), Rubha Ban and at Dunain in the Ness narrows where the 'b' shoreline is seen to truncate a terrace graded to a low relative sea-level indicating perhaps the 'b' shoreline is a transgressive feature (Synge and Smith 1980).

One site critical to interpretation is at Borlum near Fort Augustus where a break in slope at 22.5 m. O.D. is not termed marine by Synge since it is within the proposed Loch Lomand Readvance limit - a younger event.

The age of the proposed marine incursion into Loch Ness is inferred from indirect evidence. Peacock 1974 and Peacock et al. (1980) in their study of Late Devensian and Flandrian stratigraphy and marine faunas from two boreholes in the Cromarty Firth found no strata similar to the Errol clays of the Tay estuary with their characteristic arctic fauna (Peacock 1975) though admittedly the base of the marine succession was not reached. The lowermost strata (Lower Findon Beds) contained high boreal to low arctic marine faunas similar to the Late Devensian Clyde Beds of western Scotland dated between 13,000 and 10,000 B.P. (Peacock et al. 1978). This suggests the earlier arctic marine conditions characterized by Errol clay elsewhere in eastern Scotland and further out in the Moray Firth

(Chesher 1977) were excluded from the Cromarty Firth by the presence of ice. Synge (1977a) therefore proposes that as the marine limit in the inner Firths is formed by the 'b' shoreline series it seems reasonable to assume an age of c 12,600 B.P. based on Clyde Bed dates elsewhere in Scotland. Hence the marine incursion into Loch Ness is inferred at that date also.

The fact of marine penetration into Loch Ness has been called into question by Sissons who finds the evidence difficult to reconcile with his work in the vicinity of Glens Roy and Spean (Sissons 1979a, b, c, 1981b) which suggested that the 260 m. ice dammed lake held up in these valleys finally drained catastrophically through the Spean gorge, along the Great Glen, through Loch Ness and out to sea at Inverness. Such was the proposed volume of water, 5 km^3, that it is suggested the level of the loch was raised c 8.5 m. in about 6 hours and the large plug of glacial drift in the Ness narrows was removed and deposited in the sea at Inverness, the contemporary sea-level being 1.o ± 0.5 m. O.D. (Sissons 1981b).

One crucial point of evidence relates to the large spread of chaotically kettled outwash to the south west of Fort Augustus which ends at Borlum overlooking the loch at 31 m. O.D, some 15 m. above the present level of the loch. Sissons considers this feature as having been laid down by the jökulhlaup and a notch at 22.5 m. is considered lacustrine - the same notch termed non-marine by Synge (1977a, above).

There is little doubt that the Loch Lomond Readvance limit is present at Fort Augustus since cores within and without the limit at Lochs Oich and Tarff (fig. 2.5) show respectively the presence and absence of a full Late Devensian sequence (Pennington et al. 1972).

Synge needs the limit to extend north east into the loch beyond Fort Augustus to erode the evidence of previous marine shorelines, hence the erosional notch at 22.5 m. is not considered marine. Sissons however proposes that the notch is a high lake shoreline post-dating the jökulhlaup deposit. He reasons that it must be lacustrine since evidence from elsewhere in the Inverness area suggests that no sea-levels have reached the threshold to Loch Ness since Loch Lomond times.

The situation is complex and the correct interpretation is impossible to evaluate on morphological grounds alone. There appear several possibilities -

(a) Synge's hypothesis is correct, there was a marine incursion into Loch Ness at c 12,600 B.P. cutting the 'b' series of shorelines and predating the Loch Lomond Readvance.

(b) Sissons' hypothesis is correct; the marine incursion is not proven but all the features described by Synge as marine are in fact high lake shorelines postdating the jökulhlaup deposit.

(c) Both are correct. It seems certain that a marine incursion could only have occurred prior to Loch Lomond times during ice sheet decay. In addition the loch may have occupied a similar level subsequent to the jökulhlaup. While this is not a very satisfactory explanation it must be stated that it is not known if more than one shoreline is present at the approximate level of Synge's 'b' series stated heights for this feature range from 25 - 31 m. O.D. around Loch Ness, a wide range in altitude. Certainly the area needs to be mapped objectively and levelled in detail.

The answer, however, may lie in the sedimentary sequence. Pennington _et al_. (1972) have taken several Mackereth cores from Loch Ness, four from Inchnacardoch Bay to the south west and two from Dores Bay to the north west (fig. 2.5). They found no deposits of organic lake mud or microfossils, the cores consisting of grey microlaminated glacial clay. They attribute this lack of organic matter to strong water movements down to at least 50 m. depth transferring such sediment to deeper water. The widespread occurrence of laminated clays however suggests they were deposited under very different climatic conditions to the present, perhaps with a winter ice cover restricting thermal gradients.

One core from Dores Bay taken in 21 m. of water was analysed for total halide content. Pennington et al. (1972) concluded that :

> "at no horizon is there a significantly higher halogen content than that found in the varved clays of the Lake District lakes so it seems unlikely that sea water was present in the loch during the formation of these clays" (p. 267)

However, there is one sample from 133 - 133.5 cm. taken from a stratum of grey clay with brown sand which has a halide content double that of the rest, a fact Synge and Smith (1980) think significant.

The other Dores Bay core was kindly given by F.M. Synge in order that a diatom analysis could be carried out. The stratigraphy consisted of (adapted from F.M. Synge, pers. comm.)

0 - 40.5 cm.	Bedded silt
40.5 - 92.0 cm.	Sand in silt in distorted beds
92.0 - 157.0 cm.	Laminated silt and fine sand
157.0 - 201.0 cm.	Over 215 laminations (varves?)
201.0 - 291.0 cm.	Laminated silt and fine sand
291.0 - 293.0 cm.	Plant remains (including Caryophyllaceae seed) in silt and fine sand
293.0 - 316.0 cm.	Red sand
316.0 - 329.0 cm.	Laminated fine sand and silt
329.0 - 332.0 cm.	Laminated fine sand and silt with sand lenses at top
332.0 - 356.0 cm.	Laminated silts
356.0 - 387.0 cm.	Slumps (large granite pebble 0.025 m. across)
387.0 - 393.0 cm.	Sand (base of laminated silts)
393.0 - 490.0 cm.	Fine silt

29 levels were sampled and slides prepared in the standard manner (Appendix II). A systematic scan across the slides revealed no diatoms or fragments of diatoms present in 27 of them. However, two levels at c 350 cm. revealed diatoms of fresh and fresh-brackish affinity (Tabellaria, Gomphonema and Eunotia spp. with Diploneis ovalis). More work needs to be undertaken on the core before definite statements can be made. No time control is available though the stratigraphy seems to split into two sets of laminates separated by a thin fine sand and silt layer including derived plant material. One interpretation could be that the two sets of laminates are related to ice sheet decay and the Loch Lomond Readvance with the plant remains attributable to zone II. If this were so, the diatoms would relate to a stage during ice sheet decay. If a marine incursion were to have occurred its effect on the diatom flora in Loch Ness with its great throughflow of fresh water added to by glacial meltwater is questionable in any case.

The effect of a jökulhlaup on the sedimentary sequence in Loch Ness is also questionable, the most probable indicator would be bands of sand showing erosive lower contacts as much of the heavier material would tend to be deposited at the Fort Augustus end of the loch. The situation remains speculative and very interesting. A concerted programme of research such as that carried out by Dickson et al. (1978) for Loch Lomond is needed.

2.3.5 Conclusion

A critical review of the data relating to ice limits and contemporary marine accompaniment reveals many inconsistencies in the area. One major problem is the lack of time control. From Teindland at 28,140 B.P. to Loch Droma at 12,810 B.P. both geographically and chronologically there is a distinct lack of dated sites. This means that relative dating by inference from superposition of landforms and successive events is the only method of providing an interpretation. It must, therefore, be remembered that the scheme of glacial retreat stages outlined by J.S.Smith (1977) and that of Synge (1977a) for Late Devensian sea-levels has no chronological base and the correlation of glacial limits and shorelines over large distances (as in fig. 2.5) when the intervening areas have not been studied and mapped in detail is but one interpretation that can be placed on the evidence.

CHAPTER 3

FLANDRIAN SEA-LEVEL CHANGES

3.1 Introduction

The two informal methodologies that have been used to study sea-level change in Scotland are in reality little different. Both shoreline studies and those involving sea-level curves are essentially concerned with the determination of the altitude and age of features related to former sea-levels, the difference is essentially one of emphasis. Shoreline diagrams, especially the more commonly used shoreline-distance diagram show the change in altitude with distance (gradient) of a single shoreline or groups of shorelines normal to the proposed isobases. The method has been well used in Scotland and many of the problems associated with it have been discussed by Gray (1975) and Gemmell (1976). Major difficulties arise with the dating of raised shorelines, especially on open coasts since here there is generally a lack of organic material in situ. However the relationship between age and gradient of shorelines has been used by Andrews and Dugdale (1970) to date the earlier East Fife shorelines.

Sea-level curves are constructed with index points taken from former tidal flat and lagoonal environments. It is in areas such as these, at the heads of estuaries or embayments that the measurement of present and past tidal range can be greatly in error.

However the distinction between types of site used is not a clear one. Sissons and Brooks (1971) and Cullingford et al. (1980) working in the western Forth valley and lower Strathearn respectively have used the shoreline sequence produced for each area as a geomorphological constraint on the time control given by the ^{14}C dated index points.

Nine published sea-level curves from Scotland are shown in fig. 3.1

Fig. 3.1 Published sea-level curves for Scotland.

Sources: 1. Sissons and Brooks 1971

2,3. Jardine 1975

4. Peacock *et al*. 1978

5. Peacock *et al*. 1977

6. Cullingford *et al*. 1980

7. Paterson *et al*. 1981

8,9. Donner 1970

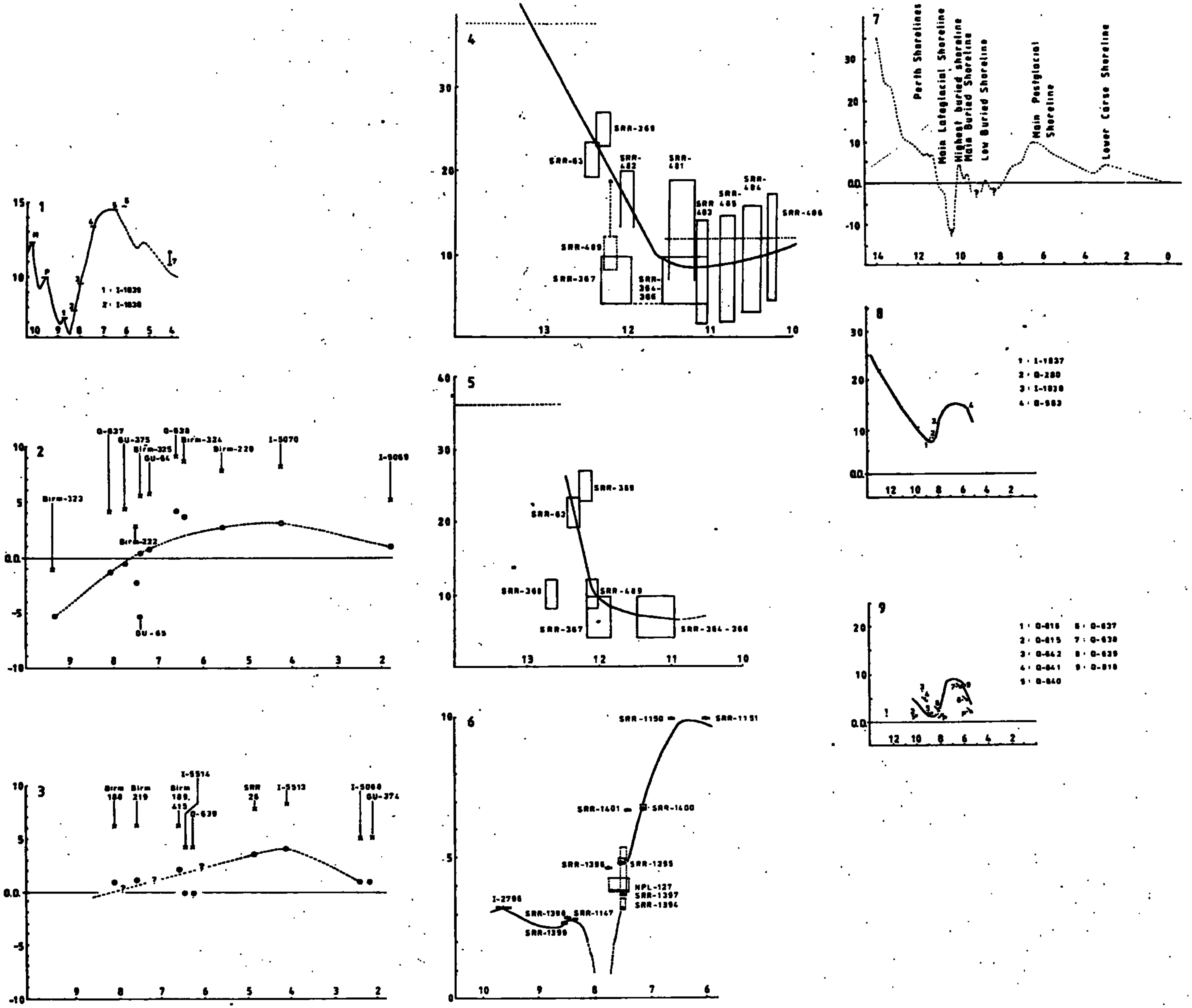
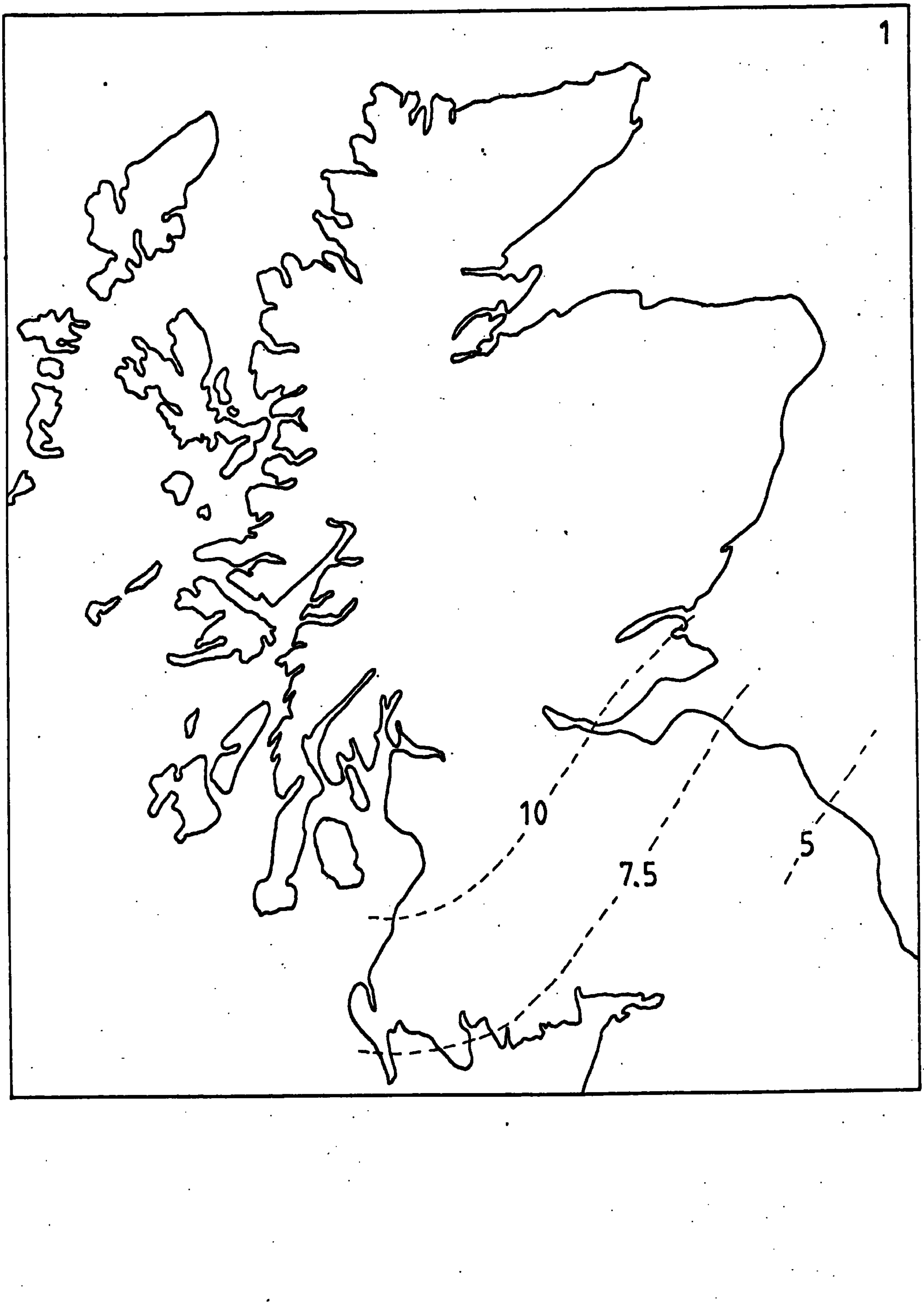

1
15
10
10
9
8
7
6
5
4
1 : I-1839
2 : I-1838
2
3
4
5
6
7
8
9
10
4
30
20
10
13
12
11
10
SRR-369
SRR-63
SRR-482
SRR-481
SRR 483
SRR-485
SRR-484
SRR-486
SRR-489
SRR-367
SRR-384-386
7
30
20
10
0.0
-10
14
12
10
8
6
4
2
0
Perth Shorelines
Main Lateglacial Shoreline
Highest buried shoreline
Main Buried Shoreline
Low Buried Shoreline
Main Postglacial Shoreline
Lower Carse Shoreline
2
10
5
0.0
-5
-10
9
8
7
6
5
4
3
2
Q-637
GU-375
Birm-325
GU-64
Q-638
Birm-324
Birm-220
I-5070
I-5069
Birm-323
Birm-322
GU-65
5
40
30
20
10
13
12
11
10
SRR-369
SRR-63
SRR-368
SRR-489
SRR-367
SRR-384-386
8
30
20
10
0.0
12
10
8
6
4
2
1 : I-1837
2 : Q-280
3 : I-1838
4 : Q-983
9
20
10
0.0
12
10
8
6
4
2
1 : Q-816
2 : Q-815
3 : Q-642
4 : Q-841
5 : Q-840
6 : Q-637
7 : Q-638
8 : Q-639
9 : Q-818
3
10
5
0.0
-5
-10
9
8
7
6
5
4
3
2
Birm 188
Birm 219
Birm 189, 415
I-5514
Q-639
SRR 26
I-5513
I-5068
GU-374
6
10
5
0
10
9
8
7
6
SRR-1150
SRR-1151
SRR-1401
SRR-1400
SRR-1398
SRR-1395
NPL-127
SRR-1397
SRR-1394
I-2796
SRR-1399
SRR-1147
SRR-1396

Fig. 3.2 Provisional isobases for the 'Post-glacial 25-foot beach' Donner (1963). Isobases in metres.

Fig. 3.3 Provisional isobases for the Main Postglacial Shoreline (Sissons 1976). Isobases in metres.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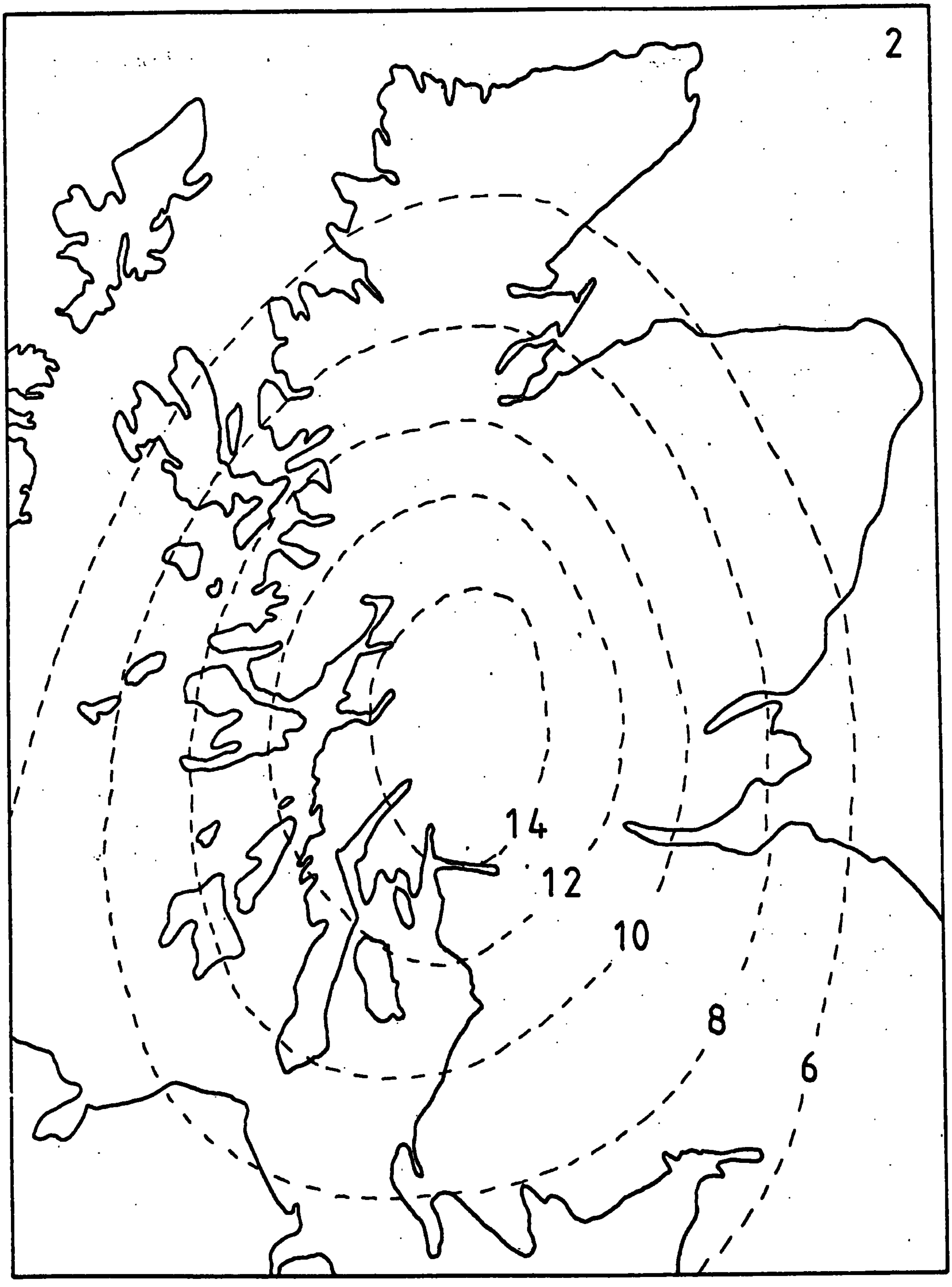

2
14
12
10
8
6

(Sissons and Brooks 1971, Jardine 1975, Peacock et al. 1977, Peacock et al. 1978, Cullingford et al. 1980, Donner 1970 and Paterson et al. 1981). Only those using index points of Flandrian age will be considered. The seven remaining curves (fig.3.1, 1, 2, 3, 6, 7, 8 and 9) effectively summarize knowledge of relative sea-level movement in the Forth, Tay and Solway Firth areas.

W.B. Wright was perhaps the first to produce a generalized map and statement of the extent - or zero isobase - and nature of the '25 foot' raised beach (Wright 1911). In this work he clearly owes a debt to Jamieson (1865) who was one of the first to recognize and explain the height variation in Scottish raised shorelines.

Provisional isobases for the Main Postglacial shoreline shown in fig.3.2 and fig.3.3 (Sissons 1976, Donner 1963) describe an elliptic uplift dome centred on the Rannoch Moor area. If this was the general form of uplift all the relative Flandrian sea-level curves for Scotland should be broadly similar in shape though differing in detail on the chronology and maximum extent of transgressions and regressions. Clearly the two curves for the Solway Firth area are different in shape. This could either be because the differences are real, the cause being a differential isostatic history coupled with regional eustasy,or the differences are apparent ones.

In this chapter the data for sea-level change during the Flandrian in Scotland will be reviewed using the sea-level curves as a basis but also using shoreline or raised beach studies where necessary.

3.2 The Forth area

Over the past twenty years the Forth valley has become the most intensively studied area for sea-level change in Scotland (Sissons 1962, 1963, 1969, 1972, 1976 , Sissons and Brooks 1971, Sissons et al. 1965, Sissons et al. 1966, Sissons and Rhind 1970, Sissons and Smith 1965 , D.E. Smith 1968, Smith et al. 1978, Kemp 1975) and the sequence of sea-level changes defined there has become accepted as an informal model with which to compare other areas of Scotland. Much of the work undertaken has been the identification of shorelines and gradients.

The succession outlined for the Forth during the Flandrian will be discussed using the sea-level curve for the western Forth valley (Sissons and Brooks 1971) as a basis. It is based on data from seven sites five of which provide seven radiocarbon dates. The curve is shown in fig.3.1,1.

Immediately outside the Menteith moraine - formed at the maximum of the Loch Lomond Readvance - lies the earliest of a suite of buried beaches. Termed the High Buried Beach (Sissons 1966) it is a continuous feature running some 3 km. in an east-west direction with no discernible gradient. Often the pink sands of the beach are overlain by a thin peat layer. Pollen analysis of the thin peat suggests a hiatus in deposition between beach formation and peat initiation and therefore the beach can only be dated with respect to its stratigraphic position. The pink sands partly overlie fluvioglacial material associated with the moraine but do not occur within it. Sissons (1966) concludes that the beach must have been formed shortly after c. 10,300 B.P. while ice stood at the Menteith moraine - strictly therefore it is a Late Devensian feature. The first index point shown in fig. 3.1, 1 is consequently based on stratigraphic evidence alone and shows a rise to 12.1 m. followed by a fall.

The horizontal expression of the High Buried Shoreline is unexpected because later shorelines do show a measurable gradient. Sissons (1972) suggests this is due to local circumstances such as the availability of fluvioglacial material from the west during beach formation. An additional factor could be the inability to make meaningful measurements further east due to the poor development and subsequent erosion of the beach.

Sissons (1966) however also notes that the pink sands of the beach which were penetrated to a maximum of c. 4 m. often show distinct laminations which could represent varves. If this is true and a strict definition for varve is applied then a non-marine origin may be assumed for at least part of the beach deposits. No laboratory analysis of the pink High Buried Beach deposits has been undertaken.

The altitude of the second index point is the average of sixteen measurements on the Main Buried Shoreline immediately east of the Menteith moraine (9.9 m.). This Main Buried Beach formed later than the High Buried Beach since it occurs both inside and outside the Menteith moraine and is at a lower altitude. Composed of light grey silts and clays it is said to be dislocated in two places by neotectonic faulting (Sissons 1972). The age of the feature is inferred from pollen analysis of the upper levels of the beach deposit and the overlying peat layer (Durno 1956, Newey 1966, Brooks 1971). No hiatus in deposition is suggested and peat initiation is considered to have begun immediately after the withdrawal of marine conditions. An age of c. 9600 B.P. is assumed with reference to the Godwin zone IV/V boundary at Scaleby Moss and a date of 9640 ± 140 B.P. (I 2796) on a comparable feature at Carey in lower Strathearn.

The third index point has been ^{14}C dated. It is on the lower contact of the thin peat layer overlying the Low Buried Beach - the lowest in a staircase of buried features - at Kippen and has an age of 8690 ± 140 B.P. (I - 1839). Pollen analysis (Newey 1966) shows the contact at 7.2 m. to be transitional in nature and again peat initiation is regarded as reflecting the removal of marine conditions from the site.

Kemp (1975) and Smith <u>et al</u>. (1978) have found essentially the same pattern of buried beaches, of assumed similar age, on the north side of the Forth and in the Teith valley. The evidence from the buried beaches of the Forth taken together, shows an intermittent fall in sea-level of c. 5 m. between c. 10,300 B.P. and c. 8800 B.P.

The rapid rise of sea-level, some 0.7 m./100 years, started at c. 8500 B.P. bracketed by the regressive and transgressive contacts of the thin peat layer at Kippen, the transgressive contact having a date of 827 0 ± 160 B.P. (I 1838) and an altitude of 7.68 m. Further radiocarbon dated index points at South Flanders, 9.5 m. and 8010 ± 130 B.P. and Easter Offerance, 13.3 m. and 7480 ± 125 B.P. on the transgressive contact at higher altitudes show the rapid nature of the transgressing sea.

The culmination of the Flandrian rise in sea-level is given by a date of 6490 ± 125 B.P. for the basal 10 cm. of the surface peat at West Flanders Moss, a date supported by pollen analysis. Subsequently sea-level fell intermittently to the present. D.E. Smith (1968) has identified three shorelines below the altitude of the Main Postglacial Shoreline of the Forth and one of these is shown schematically in fig.3.1, 1.

The curve for 'central parts of Scotland' (Donner 1970 and fig.3.1,8) includes two radiocarbon dated index points used by Sissons and Brooks (1971), from Kippen I 1838 and I 1839 and two index points - the age established by pollen analysis - from West Flanders Moss (Newey 1966). However, Donner's curve departs from that of Sissons and Brooks through the inclusion of index points from Airth Colliery, Flanders Moss and Garscadden Mains. Of these latter three points the Flanders Moss date (Q 553, 5492 ± 130 B.P. is from a sample of wood 10 - 12 cm. above the transition from the carse (4 on fig. 3.1, 8) and the age of the Garscadden index point is established by pollen analysis as late zone I. Garscadden is in the Clyde basin, an area that has a different isostatic history from the Forth and Donner overlooks evidence from the Forth of a low sea-level during the Loch Lomond Readvance which is considered to have cut the Main Lateglacial Shoreline. This early part of the curve is therefore unreliable.

3.3 The Tay and east coast of Scotland

A recent Flandrian sea-level curve for lower Strathearn (Cullingford et al. 1980 and fig. 3.1, 6) shows essentially the same shape as the western Forth valley curve but at a lower altitude reflecting less isostatic recovery. For example the altitude of the shoreline considered the equivalent to the Main Buried Shoreline of the Forth is 3.2 m. as opposed to 9.9 m. and the altitudes of the Main Postglacial Shoreline in the lower Tay estuary and the western Forth are c 10 m. and 14.4 m. respectively.

The lower Strathearn curve is based on 15 ^{14}c dates with supporting pollen and diatom evidence from six sites. The main difference between the curves occurs in the timing of the low point postdating the formation of the Low Buried Shoreline and the start of the rise to the Main Postglacial Shoreline. In lower Strathearn this low point is dated between 8370 ± 45 B.P. (SRR 1147) and 7525 ± 50 B.P. (SRR 1394) whereas in the western Forth valley the comparable minimum has an age between 8690 ± 140 B.P. (I 1839) and 8270 ± 160 B.P. (I 1838).

The age of the culmination of the Flandrian rise in sea-level is quite comparable - between 6679 ± 40 B.P. (SRR 1150) and 6083 ± 40 B.P. (SRR 1151) in the Glencarse area and at 6490 ± 125 B.P. in the western Forth. The lower Strathearn curve is not drawn through the Glencarse index points SRR 1150 and SRR 1151 (fig. 3.1, 6) since the Glencarse site lies some 5-6 km. north-east of the other sites used in the study.

A recent generalized sea-level curve for the Errol area (Paterson et al. 1981) shows many features in common with the lower Strathearn curve, indeed for the period the curves overlap it is based on much the same data. There are important differences however. The High and Main Buried Shorelines shown on fig. 3.1, 7 are based on data from lower Strathearn whilst the Low Buried Shoreline is based on data from the Carse of Gowrie.

As Paterson et al.(1981)admit the morphology of the buried terraces in this latter area have not yet been investigated in detail, the correlation between the two areas is purely chronostratigraphic. This may account for the difference in altitude between the Low Buried Shoreline in lower Strathearn at 2.8 m. and near Errol where it is close to Ordnance Datum.

A second important difference is the marked oscillation in the curve on the rise to the Main Postglacial Shoreline. This is derived from the presence of a sandy channel fill at Kingston in the Carse of Gowrie the upper parts of which are considered equivalent to the lower part of the 'carse deposits' elsewhere in the vicinity and interpreted as a minor transgressive episode. The third major difference is the schematic representation of a shoreline younger than the Main Postglacial Shoreline the age of which is not known for certain.

In theory the formation of a single shoreline in an area undergoing isostatic uplift, such as the Main Postglacial Shoreline should be time-transgressive, with the removal of marine conditions occurring earlier in areas where isostatic uplift is greater. Radiocarbon dates are now available from sites where the estuarine 'carse deposits' of the Main Postglacial Transgression of the Tay and east coast of Scotland wedge out in a landward direction. In table 3.1 only published dates are used and relate to the transgressive and regressive overlaps which bracket the culmination of the Main Postglacial Shoreline.

TABLE 3.1

Site	Details		Lab-code		Age (B.P)	Altitude (m)	
St.Michael's	RO	0.15 m.	St.	3062	5830 ± 110		(1)
St.Michael's	TO	0.15 m.	St.	3063	7605 ± 130		(1)
St.Michael's	RO	0.01 m.	SRR	1331	5890 ± 95	6.76	(2)
St.Michael's	TO	0.01 m.	SRR	1332	7310 ± 100	7.24	(2)
Hole of Clien	RO	0.02 m.	SRR	1510	6170 ± 90	10.04	(2)
Hole of Clien	TO	0.02 m.	SRR	1511	7500 ± 90	9.62	(2)
Glencarse	RO	0.01 m.	SRR	1151	6083 ± 40	9.82	(2)
Glencarse	TO	0.01 m.	SRR	1150	6679 ± 40	9.53	(2)
Fullerton	RO	0.01 m.	SRR	1148	6704 ± 55	6.34	(3)
Fullerton	TO	0.01 m.	SRR	1149	7086 ± 50	5.57	(3)
W.Flanders	RO	0.10 m.	-		6490 ± 125	14.4	(4)

Sources : (1) Chisholm (1971) (2) Morrison et al. (1981) (3) Smith et al. (1980) (4) Sissons and Brooks (1971)

RO = Regressive overlap TO = Transgressive overlap

The data for the western Forth, lower Strathearn and the more peripheral east coast sites do seem to suggest that the culmination of the Main Postglacial Transgression, defined as the transgression which led to the formation of the Main Postglacial Shoreline in eastern Scotland, was diachronous. The regressive overlap has dates of c. 6500 B.P. in the western Forth Valley, c. 6100 B.P. in the middle Tay estuary and c. 5850 B.P. in north east Fife. The date of 6704 ± 55 B.P. (SRR 1148) from Fullerton near Montrose interrupts the sequence however. Unpublished dates from areas north of Aberdeen, at Waterside and Philorth suggest the regressive overlap here has a date of c. 5700 B.P. (D.E. Smith, unpublished).

The anomalous dates from Fullerton may be due to local conditions. The stratigraphic diagram given by Smith et al. (1980 fig. 16.3) shows the maximum altitude reached by the 'carse' is at least 1-2 m. higher than the altitude of the landward limit of the carse. In other words the regressive overlap of the 'upper peat' at Fullerton shows a rise seawards. In such cases - the same type of occurrence can be seen at West Flanders Moss (Sissons and Smith 1965, fig.2) - the cause must either be subsequent compaction or an interplay between peat growth and marine deposition. If compaction can be dismissed then local sedimentation factors must predominate and the date may be only locally significant. Major problems arise here too in the definition of what constitutes the Main Postglacial Shoreline - is it the highest expression of Flandrian marine deposition? or the altitude of the landward limit?

A further reason for the apparent diachroneity could be that the same event has not been dated in each area. D.E. Smith (1968) identified three shorelines younger than the Main Postglacial Shoreline in the Forth and it may mean in some of the peripheral areas less affected by isostatic uplift it is a younger shoreline that has been dated. This argument is hard to disprove unless detailed morphological, stratigraphic and biostratigraphic evidence suggests a comparable feature. Each site must also be evaluated for a possible delay in resumption of peat growth which could also produce an observable diachroneity.

At certain sites prior to the culmination of the Main Postglacial Transgression a minor transgressive episode may have occurred. At Easter Offerance in the western Forth Valley (Sissons and Smith 1965), St. Michael's Wood in north east Fife (Morrison et al. 1981), Fullerton near Montrose (Smith et al. 1980) and perhaps Philorth near Fraserburgh (D.E. Smith unpublished) it is manifested by a thin - usually less than 20 cm. - silty sand layer often containing marine or marine-brackish diatoms, overlain by a thin peat in turn succeeded by the estuarine 'carse deposits' proper. In seaward sites the peat layer is absent and the sand layer forms a distinct unit within the 'carse deposits'. The Kingston Sand (Paterson et al. 1981) and a shelly sand layer in the Carse of Gowrie in a similar stratigraphic position could also correlate with this feature.

Published ^{14}C dates above and below this silty-sand horizon i.e. dates on the transgressive overlap of the lowermost peat and regressive overlap of the middle peat are shown in Table 3.2.

TABLE 3.2

Site	Details		Lab-code		Age (B.P)	Altitude (m)	
St.Michaels	RO	0.01 m.	SRR	1333	7050 ± 100	6.39	(2)
St.Michaels	TO	0.01 m.	SRR	1334	7555 ± 110	6.20	(2)
Fullerton	RO	0.02 m.	Birm	867	6880 ± 110	5.50	(3)
Fullerton	TO	0.02 m.	Birm	823	7140 ± 120	5.32	(3)

Sources : as for Table 3.1

Both these sites show an age inversion with depth within the 'middle peat' layer (the transgressive overlap dates for the 'middle peat' are given in table 3.1). In such cases the best approximation of age is given by a weighted mean and standard deviation using the formula of Olsson (1979) on both dates for the transgressive and regressive overlaps. This results in weighted means of 7180 ± 70 B.P. for St. Michael's Wood and 7050 ± 45 B.P. for Fullerton. The age brackets for the sand layer may now be considered as 7555 - 7180 B.P. at St. Michael's Wood and 7140 - 7050 B.P. at Fullerton. Unpublished data from the Forth Valley also indicates a comparable age of 6900 - 7000 B.P. for a similar sand layer (Sissons, unpublished).

3.4 The Ayrshire coast and Solway Firth

The only other Flandrian sea-level curves are from the Ayrshire and Solway Firth coasts. Three sea-level curves have been published (Donner 1970, Jardine 1975).

Donner's curve for 'marginal parts of Scotland' (1970, fig.3 and this vol. fig.3.1, 8) contains ^{14}C dated index points from such widespread areas as Irvine in Ayrshire and Redkirk Point in Dumfriesshire. Nevertheless the overall shape is similar to the western Forth and lower Strathearn curves with a pronounced minimum relative sea-level between c. 8000 B.P. and 9000 B.P. with the culmination of the main Flandrian rise in sea-level at an altitude of c. 9 m. and an age of c. 7000 B.P.

However of the nine ^{14}C dated index points only three are used to plot the curve, Q640, Q637 and Q818 (Godwin and Willis 1962, Godwin et al. 1965). Q818, 6244 ± 140 B.P. is from wood fragments in a lens of peat which is embedded in marine/estuarine deposits at Gatehouse of Fleet. Q637, 8135 ± 150 B.P. is a sample cut from a tree stump in situ at Redkirk Point. The tree rests on a peat layer 23 cm. thick overlain by c. 3.65 m. of 'carse' type deposits and its exact relationship to sea-level must be open to question. Q640, 9020 ± 150 B.P. is from Girvan, Ayrshire and dates wood fragments and peat overlying a sand and gravel layer, there is no supporting evidence to suggest this index point refers to a marine event. The curve is derived from data points from a wide area and the three points through which it passes are suspect. Other possibly more suitable points such as Q638, 6645 ± 120 B.P. which dates the basal 2 cm. of peat at Lochar Moss, Dumfriesshire are ignored in preference to less reliable ones e.g. Q818. Nichols (1967) considers the Lochar Moss date to be strongly supported by pollen analysis from the nearby Racks Moss.

Jardine's curves for the Solway Firth (figs. 3.1, 2 and 3.1,3) although charting the course of mean tide level as opposed to a high water mark implicitly assumed for the other curves still has a shape that is unlike any other for Scotland during the Flandrian Age. This has important repercussions for if the difference in shape is real it implies a different isostatic and perhaps eustatic history for the Solway Firth area. These curves, especially the curve for eastern Kirkcudbright and Dumfriesshire (fig. 3.1,2) will be studied more closely in an attempt to determine any real differences from apparent ones.

The curve for eastern Kirkcudbright and Dumfriesshire (Jardine 1975) is based on eleven ^{14}C dates and shows a rise of mean sea-level from -5.23 m. at 9390 ± 130 B.P. (Birm 323) to a maximum of 3.18 m. at 4290 ± 100 B.P. (I 5070). It also depicts a smooth curve with no short term low amplitude oscillations characteristic of curves from the western Forth and lower Strathearn.Jardine (1975) states:

> "it is acknowledged that this feature probably is due in large measure to the incompleteness of the data available on the area covered by the curve. It is questioned, however, whether the addition of more detailed information leading to the construction of a curve showing minor oscillations would do more than indicate local changes in coastal configuration accompanied perhaps by adjustments in the tidal range" (pp.192-3)

The curves are unsupported by pollen evidence as an independent means of age corroboration and there are no other micropalaeontological techniques used as an aid to the identification of unbroken succession over lithologic boundaries. The curves also have poor stratigraphic control. Rises and falls in sea-level are determined solely by the age and altitude of the derived index points and local indicators of a fall in sea-level are ignored. The only date to record a fall in sea-level on the eastern Kirkcudbright and Dunfriesshire curve is consequently the youngest at West Preston with an age of 1850 ± 95 B.P. (I 5069) and an altitude of 1.00 m.

Of the two curves published by Jardine only the first, for east Kirkcudbright and Dumfriesshire - considered the most reliable - will be studied further. The earliest index point is from the South Carse borehole (Birm 323, 9390 ± 130 B.P.). The sample is from an 0.15 m. thick layer of organic detritus above marine sands and probably contains material from both the transgressive and regressive contacts. The local stratigraphic setting is unknown since only one borehole was recorded and it is also unknown if peat accumulation began immediately after the withdrawal of marine conditions nor if the transgressive contact is erosional. The index point incorporated in the curve shows a rise in sea-level, it could perhaps equally be interpreted as a fall.

The second index point is from Redkirk Point (Q637, 8135 ± 150 B.P.) and dates wood from a tree trunk growing in situ on organic detritus. The tree is interpreted as having been killed by the transgressing sea that subsequently covered the site. The provenance of the sample is unknown but if the dated material was from the centre rings of the tree it could be in error by a few hundred years. Similarly its exact relationship to sea-level is unknown.

At Newbie Mains (GU375, 7812 ± 131 B.P.) the index point comes from a 0.10 m. thick layer of organic detritus again dating both the transgressive and regressive overlaps and without regard to its local stratigraphic relations. Of three other dates from the nearby Newbie Cottages (Birm 222, 7540 ± 150 B.P. Birm 325, 7400 ± 150 B.P. and GU64, 7254 ± 101 B.P.) all from the same organic detritus layer overlying a podzolic soil formed on fluvioglacial deposits only the latter two are included on the curve. The first, Birm 222, is not included on the curve because it does not "lie on the general line of such a curve" (Jardine 1975, p.191), a circular argument.

Two seemingly suitable dates at Nether Locharwoods and Midtown

(Q638, 6645 ± 120 B.P. and Birm 324, 6470 ± 280 B.P.) on the basal layers of a peat overlying brackish-water deposits and supported by pollen evidence from the nearby Racks Moss (Nichols, 1967) are ignored. Instead tidal differences caused by the configuration of the Lochar Gulf are proposed as causing errors in the altitude adjustment to the best fit mean sea-level curve.

The final points on the curve are dates from allochthonous wood fragments from Newbie Cottages (Birm 220, 5630 ± 116 B.P.) and the basal 0.07 m. of the 0.4 m. thick peat in which the wood was located (I 5070, 4290 ± 100 B.P.). Both are essentially components of the same contact and both points are plotted, one showing a rise in sea-level, the other denoting the culmination of the Flandrian rise in sea-level. The West Preston date (I 5069, 1850 ± 95 B.P.) is from the basal 0.05 m. of a 1 cm. thick surface peat layer and is the only index point to record a fall in sea-level.

Alternative interpretations can be placed on the basic data. The South Carse index point could equally be taken to indicate a fall of sea-level followed by a rise. If true this would be approximately the age of a fall in sea-level during the Boreal period to a low sea-level quite comparable with the Forth and Tay. Omitting Q637, the date on the tree trunk from Redkirk Point and the allochthonous wood fragments of the Sandyknowe Bridge date (GU65) and including Birm 222, the Newbie Cottages date omitted because it did not lie on the curve, results in an increased rate of sea-level rise between c. 7500 and 7000 B.P. The inclusion of the two index points from the Lochar Gulf at Midtown and Nether Locharwoods gives a culmination of the Flandrian rise in sea-level at 6645 ± 120 B.P. and c. 9.15 m. O.D. very comparable to other areas of Scotland.

The argument of Jardine (1975) that the Lochar Gulf dates do not represent the end of the Flandrian marine transgression in the Solway Firth area is also open to alternative interpretation. He argues that the presence of a baymouth bar "admittedly seen only to be partially blocking the entrance to the Gulf" (pl. 83) may have been the cause of the exclusion of the sea from the Lochar Gulf. Much more stratigraphic control is needed until firm conclusions can be made.

Using supporting evidence, he suggests that continued marine penetration east of the Lochar Gulf is recorded after this time. At Newbie Cottages east of the Lochar Gulf the 'carse deposits' characteristically contain abundant molluscs, foraminiferids, ostracods and echinoids, the later 'carse deposits' only contain rare occurrences. In the Lochar Gulf all 'carse deposits', predominantly of sand, contain a rich fauna indicating it correlates with the earlier unit at Newbie Cottages and hence that the Lochar Gulf, unlike Newbie Cottages, was cut off suddenly from marine conditions.

Jardine argues that the siting of a mesolithic settlement at Barsalloch dated 6000 ± 110 B.P. on top of a cliff instead of at the base suggests the sea was very close to or actually at the cliff foot - again suggesting marine penetration east of the Lochar Gulf after c. 6600 B.P. An alternative explanation could be that the cliff top site was favoured initially by mesolithic peoples because of the natural advantages of such a site.

Radiocarbon evidence for the continued marine penetration after c. 6600 B.P. east of the Lochar Gulf is based on the two samples from Newbie Cottages. The peat date (I 5070, 4290 ± 100) may simply relate to a stage in the general fall in sea-level from the maximum as shown on fig. 3.1, 2. In addition, it is not knownif there was a delay in resumption of peat growth following the removal of marine conditions.

Evidence is given of a continued rise in sea-level after 6600 B.P. west of the Lochar Gulf at the head of Wigtown Bay. Dates at Palnure for the peat matrix and wood fraction (Birm 415, 6540 ± 120 B.P., Birm 189, 6240 ± 240 B.P.) give a weighted mean of 6480 ± 117 B.P. However, Jardine argues that two dates at Carseminnoch (I 5514, 6325 ± 120 B.P.) and 3.5 km. west of Palnure (Q639, 6159 ± 120 B.P.) are evidence for the persistence of estuarine conditions after the beginning of peat growth at Palnure. Both dates are on allochthonous wood and all four are indistinguishable at the 95% level.

The curve for Wigtown Bay (fig. 3.1,3) shows the culmination of the Flandrian rise in sea-level between 4746 ± 50 B.P. and 4000 ± 100 B.P. (SRR 26 and I 5513 respectively). The former Muirfad Flow date is from twigs in the basal 0.05 m. of the surface peat layer and the latter is from wood fragments from the basal 0.05 m. of the surface peat at Moss of Cree.

The dates are from derived material and show that the date of 4746 ± 50 B.P. is not likely to give reliable age estimate for the culmination of the Flandrian rise in sea-level in Wigtown Bay.

In summary many of the differences between sea-level curves for the Western Forth and lower Strathearn and the Solway Firth can be explained through differences in the use and application of the ^{14}C dated material to sea-level studies and the interpretations inherent in the different approaches used. It is proposed that the Solway Firth area can be looked upon as similar in isostatic and eustatic reponse to other areas of Scotland and differences between the areas are more apparent than real. Much more rigorous work needs to be undertaken in peripheral areas with a lower rate of isostatic recovery if real differences are to be detected between curves.

3.5 Other areas of Scotland

There is abundant published evidence relating to peat layers beneath present high water mark or beneath later marine deposits from all parts of Scotland (Sissons 1967). Very little detailed work has been done on buried peats outside the areas so far discussed. Many ideas have been invoked to explain the presence of such peats though it was Jamieson (1865) who was the first to realize that the majority of such peat layers give evidence for a period of lower sea-level. The buried peats are certainly not members of a single population and vary greatly in age and in mode of initiation. The oldest buried peat, 12, 290 ± 250 B.P. from Redkirk Point (Q816, Godwin et al. 1965) lies on a grey carbonaceous silts of a stream deposit cut into till and is overlain by grey silts and fine sands of marine origin (Bishop and Coope 1977). The buried peats of the Forth lie on a suite of buried beach forms dated from c. 10300 B.P. to c.8800 B.P. and are covered by carse deposits. Finally, Sissons (1967) states that peat that is still growing at the present time is being submerged in the outer islands.

The main point to be made here is that many buried peats probably started to accumulate during the early Flandrian either in response to a regressing or transgressing sea and were covered by later marine and estuarine deposits during the main Flandrian rise in sea-level.

Flandrian raised shorelines have also been studied in other areas of Scotland - in the Oban area (Gray 1974), the Firth of Lorne to Loch Broom (McCann 1966), Wester Ross (Kirk et al. 1966) and northern Scotland. Published gradients for these areas and those already discussed include -

TABLE 3.3

West Coast	0.075 m./km.	(McCann 1966, Synge and Stephens 1966)
Oban area	0.05 m./km.	(Gray 1974)
Forth	0.076 m./km.	(Sissons 1976)
Tay	0.09 m./km.	(Cullingford 1972 in Gray 1974)
Easter Ross	0.09 m./km.	(J.S. Smith 1966)

Because of the different approaches adopted in some of the studies, for example in field methods and sampling stategy, it is not known if all the results are strictly comparable. In addition it is not known if the measurements of altitude relate to the same shoreline, or if some studies use points on more than one shoreline. Problems of definition and interpretation mean no specific conclusions can be reached other than that all methods do show a gradient normal to the proposed isobases of c. 0.05-0.1 m/km.

3.6 The Moray Firth area

Little or no previous work explicitly dealing with sea-level change has been published for the Moray Firth area during the Flandrian Age. This is surprising since Ogilvie (1923) states that the area

> "includes some of the finest and most complex examples of raised beach at several levels" (p.377)

Ogilvie's monograph is however primarily a morphological study concerned with the changing shape of the coast between Golspie and Port Gordon. It is perhaps indicative of the quality of Ogilvie's work, coupled with the lack of research since 1923, that Sissons (1967, 1976) and Steers (1973) continue to use Ogilvie's work extensively. It contains a fine description of the variety of beach forms encountered in the Moray Firth area from the high fault-controlled cliffs of the Black Isle to the flat 'carselands' of the inner Beauly Firth, the wide sand and shingle foreland of the Culbin Sands and the composite spits of Dornoch Point and Cuthill Links but it pays little attention to stratigraphy and offers nothing in time control.

Evidence for sea-level change is often implicit in the published literature and there is no synthesis available. Certain lines of evidence point to a period of low sea-level during the early Flandrian. At a number of sites peat is found beneath later, marine deposits. Wallace (1883,1896) recordslocal memory of an extensive peat bed covering the floor of Burghead Bay; the rights of turbary were the subject of a law suit in 1787. The peat layer was apparently much more extensive than now; present occurrences are sporadic. However in places beneath the compact peat layer are occurrences of blue silty sand containing abundant shell fragments.

Eyles et al. (1946) provide information of a buried peat layer in the Spynie depression. A brick-clay pit, worked until 1939 near Loch Spynie, c. 5 km. north of Elgin contained a peat layer 38 cm. thick, 570 cm. from the surface overlain by a shell bed and blown sand and underlain by c. 45 cm. of light blue clay and over 600 cm. of dark clay. Jamieson (1865) recorded the presence of Scrobicularia plana da Costa, a mollusc that favours muddy estuarine conditions. The stratigraphic position of the find is unreported however.

Smith and Mather (1973) described a peat layer which outcrops on or at the back of the fringing beach of the Morrich More, Ross and Cromarty. The peat is suggested to predate the Flandrian transgression and underlies much of the ridge and slack system.

J.S.Smith (1968) recorded a thin layer of peat in field drains close to Delny church. The site is on the fringe of an extensive area mapped as a lagoon of Flandrian Age (Ritchie et al. 1967). Notes on the original 6" Geological Survey maps record the discovery of a peat stratum containing Alnus and Betula twigs and seeds of Menyanthes sp. near Lower Kincraig.

Some morphological forms too have been used as evidence for a lower sea-level. J.S. Smith (1963) in a short note calls attention to the well-developed gullies between Cromarty and Jemimaville on the southern shore of the Cromarty Firth. The gullies are incised into higher beach deposits and are graded to a level below that of the Flandrian raised beaches in the area. There are no debris cones at or below their point of debouchement onto the raised beach indicating that the gullies are older forms. Smith favoured an early Atlantic age c. 5,000 B.P. Sissons et al. (1965) criticized the paper and described similar forms in the Forth and Tay area that are older and were in existence at least 8,000 to 8500 B.P.

The only detailed stratigraphic record with independent age corroboration pertaining to Flandrian sea-level change is that given by Peacock et al. (1980) for the Cromarty Firth borehole C2. Using all borehole data three informal lithologic units have been described : from the base up, the Findon beds, Ardullie beds and Cromarty beds. Many problems of interpretation exist but it is proposed that only the Cromarty beds are exclusively of Flandrian Age though perhaps the Ardullie beds span the transition from Late Devensian to Flandrian. There are three radiocarbon dates from the lower Cromarty beds, SRR1068, 8748 ± 80 B.P. dating plant debris and two dates on shells, SRR1069 at 7326 ± 360 B.P. and SRR 1070 at 8156 ± 150 B.P. All dates have been normalized with respect to the P.D.B. standard. The lower Cromarty beds therefore probably accumulated during the early Flandrian

If the marine shell dates are to be questioned then the lower Cromarty beds accumulated c. 8750 B.P. at the time of the relative low sea-level recorded in the Forth. The lower Cromarty beds have a high proportion of very shallow water species and the stratigraphy contains possible channel lag deposits. If the age quoted above is correct, an altitude of -6 m. O.D. for the contemporary sea-level is reasonable (Peacock et al. 1980).

If the plant debris date is to be questioned and shell dates accepted then the lower Cromarty beds accumulated between 8000 B.P. and 6500 B.P. at the time of the rise in sea-level to the Flandrian maximum in the Forth. The shallow water fauna could then be explained through downward translocation of shallow water and intertidal species.

The fauna of the Upper Cromarty beds indicate deposition in deeper water which may relate to the culmination of the Flandrian transgression and subsequent events.

Flandrian raised beaches have been described by the field officers of the Geological Survey (Horne and Hinxman 1914, Peach 1912, Read et al. 1925, Read et al. 1926) by Ogilvie (1923) and Steers (1937) though accurate height measurements and overall synthesis are lacking. Smith (1966) notes two Flandrian raised beaches,the higher one rises from 8.22 m. at Kessock to 9.14 m. at Tarradale, a gradient of c.0.09 m./km. The lower beach is at 3.9 m. O.D. but accurate height determination was impossible due to disturbance by road building.

The present state of knowledge concerning Flandrian sea-level change in the inner Moray Firth area is fragmentary. There is no adequate time control given by radiocarbon dating and little accurate altitude information. The data that are available are fragmentary and often implicit rather than explicit, nevertheless it does suggest a relatively low sea-level during the early Flandrian followed by a rise to produce the well developed raised beach at c. 9-10 m. in the inner Firths.

3.7 A method of representing Flandrian coastal sequences

It is not known when the term 'carse' - first referenced in semi-Gaelic form in 1143 (Grant and Morrison 1929 - 76) and defined as a stretch of flat land bordering a river estuary - came to include a lithostratigraphic connotation with the addition of the word clay. Nor is it certain when the chronostratigraphic and genetic connotation of being formed during the main Flandrian rise and fall in sea-level in Scotland came into being, though Jamieson (1865) certainly uses the term 'carse clay' with all three uses implicit. Stemming from the use of the term 'carse clay' has been the adoption by some workers of the term 'sub-carse peat' referring to the widespread thin peat layer occurring on beaches of different ages and subsequently buried by the transgression that deposited the 'carse clays' (e.g. Newey 1966, Paterson et al. 1981). Paterson et al. (1981) have also used the term 'post-carse' estuarine deposits which refers to a number of terraces formed below the level of the Main Postglacial Shoreline "as a result of fluctuating sea-level fall". (p.21). Whether the term also includes a lithostratigraphic connotation is not clear.

At Fullerton near Montrose (Smith et al. 1980) and other sites on the east coast of Scotland (Morrison et al. 1981) the Flandrian rise in sea-level probably involved at least two marine transgression episodes. In places there are three peat layers in the coastal peat mosses separated by two marine clastic horizons. Subsequent to the Main Postglacial Shoreline of the Forth and Tay there are lower beaches, the product of minor transgressions or stillstands during a general fall in sea-level (e.g. D.E. Smith 1968). Hence the 'carse clay' is composed of several episodes encompassing proposed rises and falls in sea-level. It is also comprised of several different lithologies and is clearly unsatisfactory for the process of correlation.

The use of a newly developed system for the description and lithological classification of Flandrian coastal sequences is therefore proposed (Barckhausen et al. 1977). Developed specifically for coastal sedimentary sequences it is an hierarchical scheme based on the vertical succession and lateral interfingering of clastic sediments and peat. There are three levels in the hierarchy, complexes, sequences and facies units. Each level contains a number of profile types.

Complexes contain 3 profile types:-

- clastic (X) types : a body of clastic sediments without intercalated peat layers. Peat may occur at the base or top of the complex.

- interfingering (Y) types : a body of coastal deposits in which clastic sediments are intercalated by peat layers.

- peat (Z) types : a body of peat and limnic deposits. Thin layers of clastic sediments can either be intercalated in the peat complex or can occur at the base or on top of the peat complex.

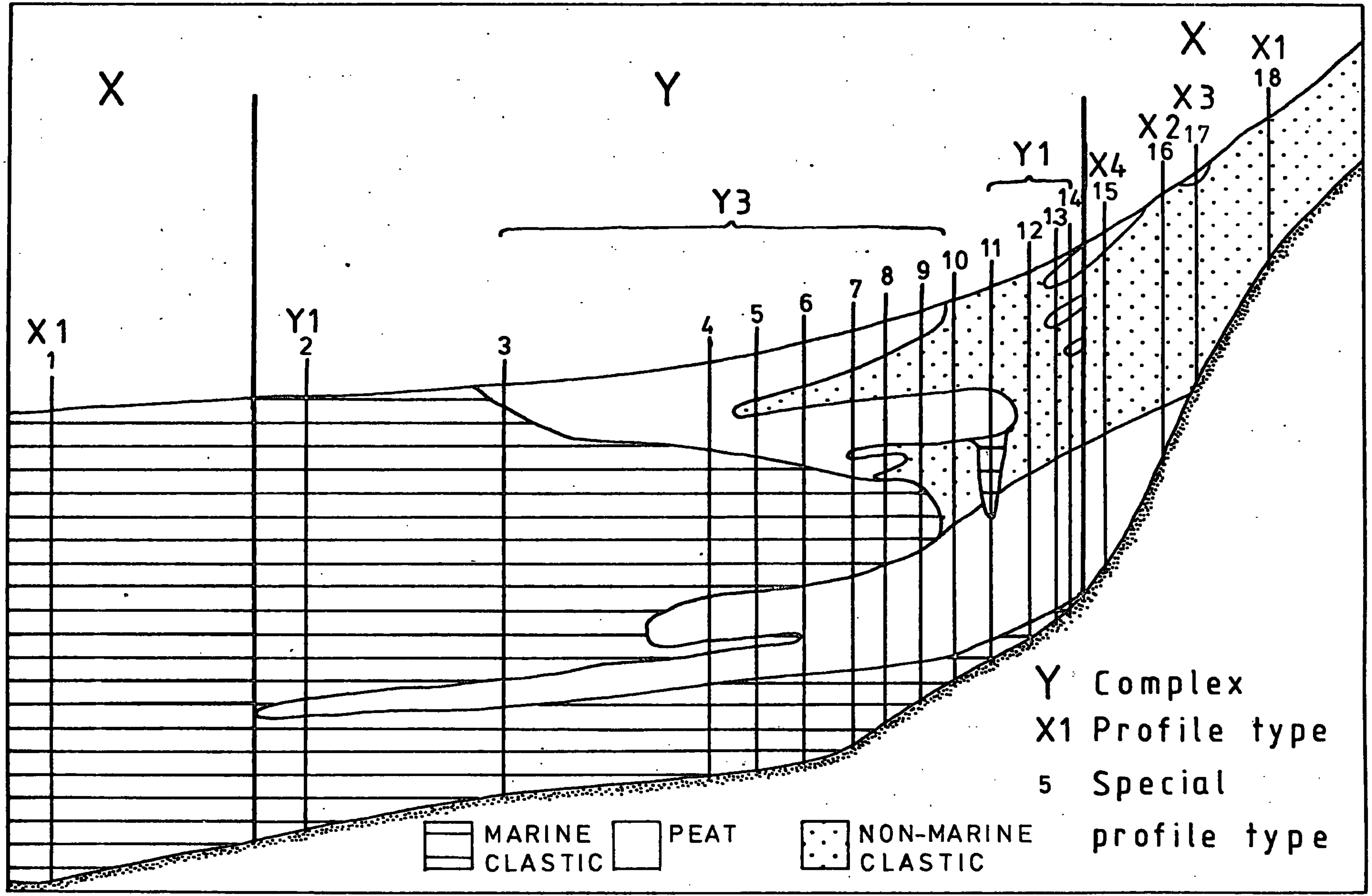
Sequences are subdivisions of the complexes and consist of one or more facies units. Streif (1978) outlines ten sequences characteristic of the clastic, interfingering and peat complexes and a description of these is given in Appendix V. In a coastal context there are a finite number of interrelationships these ten sequences can hold. Streif (1978, fig.1) outlines twelve subordinate profile types (X1, Y1, Z etc.) and these are shown diagrammatically in Appendix V.

Facies units, the lowest division of the hierarchy have a variable number of special profile types which are defined individually with regard to specific objectives such as geological, engineering or resource potential. In this study the use of special profile types is specifically aimed at isolating terrestrial clastic (or non-marine) sequences from marine clastic sequences especially where they interfinger with peat layers. They are defined as far as possible on lithologic properties with stratigraphic relationships and micropalaeontological analyses also considered. A schematic diagram of the most common special profile types encountered in this study is given in fig.3.4 and are described in Appendix V.

The advantage of such a system is that it avoids the confusion of terms such as 'carse-clay', 'sub-carse peat', 'post carse estuarine deposits' which have come to include a lithostratigraphic, chronostratigraphic and genetic meaning. This loose use of terminology leads to difficulty in correlation between areas.

The scheme can be linked to a chronostratigraphic system based on

Fig. 3.4 Schematic section showing most commonly encountered profile types in the inner Moray Firth coastal area following the scheme of Barckhausen _et al_. (1977).


X
Y
X
X1 1
Y1 2
3
Y3
4
5
6
7
8
9
10
11
12
13
14
Y1
X4 15
X2 16
X3 17
X1 18
MARINE CLASTIC
PEAT
NON-MARINE CLASTIC
Y Complex
X1 Profile type
5 Special profile type

radiocarbon dates to provide a flexible method of explaining coastal development in a palaeogeographic sense through time and space. However, the validity of lithostratigraphic correlation depends on the scale of the investigated area. In the first instance this is taken to represent the site scale. Because by its very nature a transgressive episode for example is time transgressive the lithological classification and chronostratigraphic scheme must be regarded as two independent methods to be used in conjunction if clarification of coastal development is the aim.

The scheme has many practical applications such as the ease of incorporation into data bank management systems. The new type of geological map for Emden West (Barckhausen and Streif 1978) contained information from 650 boreholes, 10,000 m. of sedimentary cores and 25,000 individual layers all processed from original field data capture using the scheme.

There are some basic differences in applying the scheme to coastal sequences in eastern Scotland. The method is universal but the underlying model of coastal development is different. Inherent in the scheme as applied to the southern North Sea are certain situations that do not transfer. In the southern North Sea the basal unit often consists of a sandy deposit with podzol formation and is widely regarded as Late Weichselian or early Flandrian. Upon this sloping surface the marine deposits and peat were laid down under conditions of a slowly rising sea-level, perhaps with short term low amplitude oscillations after c.7000 B.P. This has resulted, with the continued geological subsidence of the southern North Sea, in a basic tripartite succession, the X, Y and Z complexes.

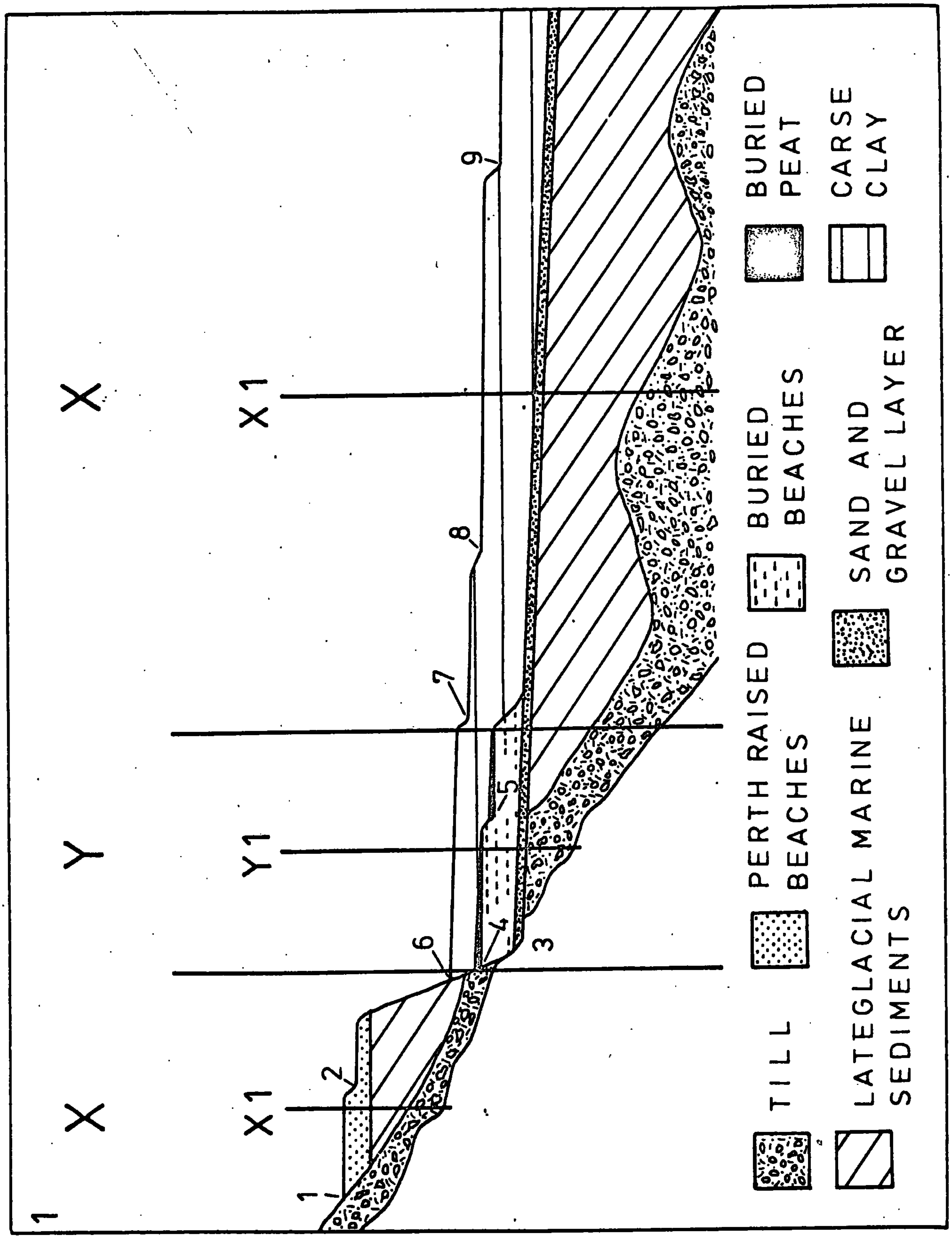
In eastern Scotland the effects of glacial isostasy and eustatic sea-level movements mean that often the local basal deposits comprise glacial units or bedrock. Above these Late Devensian marine clays and silts are sometimes preserved. In its application to this study therefore

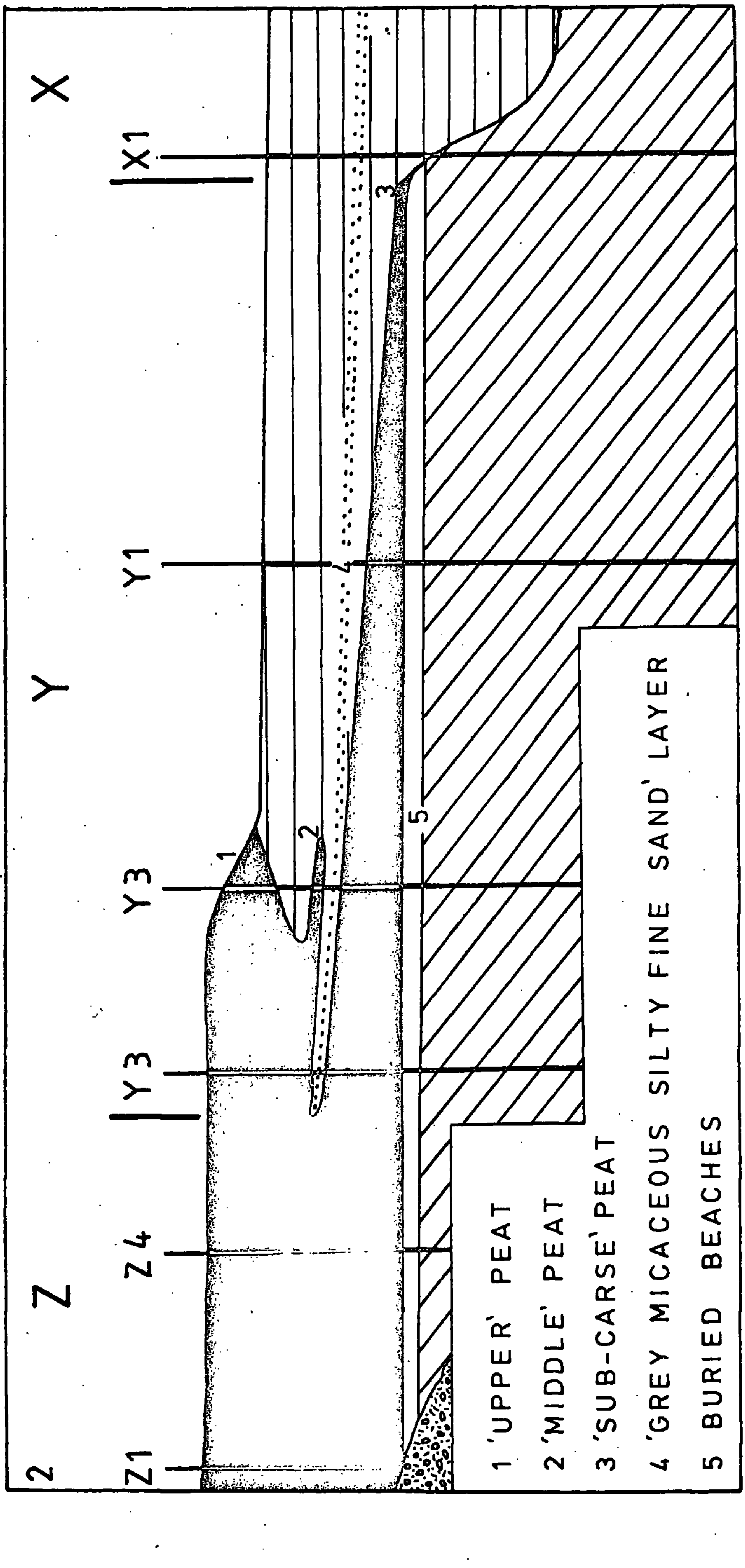
Fig. 3.5 Diagrammatic section of the Grangemouth-Airth area (mid Forth Valley) showing main elements of the stratigraphy (Sissons <u>et al</u>. 1966).

1 = Main Perth Shoreline
2 = Lower Perth Shoreline
3 = Main Lateglacial Shoreline (Sissons 1976)
4 = Main Buried Shoreline
5 = Low Buried Shoreline
6 = Main Postglacial Shoreline
7, 8, 9 = Later Flandrian Shorelines

Diagram also shows the application of the scheme of Barckhausen <u>et al</u>. (1977) showing its equivalence in complex and subordinate profile type.

Fig. 3.6 Diagrammatic section of the Upper Forth Valley (Sissons and Smith 1965). Symbols as for fig. 3.5 except the buried beaches are unshaded. Diagram also shows the application of the scheme of Barckhausen <u>et al</u>. (1977) giving the equivalent in complex and subordinate profile type.


1
X
X1
Y
Y1
X
X1
1
2
3
4
5
6
7
8
9
TILL
PERTH RAISED BEACHES
BURIED BEACHES
BURIED PEAT
LATEGLACIAL MARINE SEDIMENTS
SAND AND GRAVEL LAYER
CARSE CLAY


2
X
X1
Y
Y1
Y3
Y3
Z
Z4
Z1
1
2
3
4
5
1 'UPPER' PEAT
2 'MIDDLE' PEAT
3 'SUB-CARSE' PEAT
4 'GREY MICACEOUS SILTY FINE SAND' LAYER
5 BURIED BEACHES

the basal units are considered to be of glacial origin or bedrock and this means an extension of the scheme into the Late Devensian.

Geological inheritance and relative sea-level changes in eastern Scotland mean that large flat areas equivalent to the coastal plains of the southern North Sea are not available for marine sedimentation.

Fig. 3.5 shows a model sequence for the mid-Forth Valley including common terms used for sequences (Sissons 1976, Newey 1966, Brooks 1971). Their equivalent in the scheme of Barckhausen et al. (1977) is also shown. For instance a borehole through the carse clays, sub-carse peat, buried beach and till would essentially record a Y1 profile with an upper clastic sequence (qhKO) a splitting-up sequence comprising only one peat layer (qhA) and a lower clastic sequence (qhKU).

Fig. 3.6 shows a model sequence for the Upper Forth Valley (Sissons and Smith 1965) and the equivalent profiles and subordinate profile types of the new scheme.

CHAPTER 4

TECHNIQUES OF ANALYSIS

4.1 Introduction

The need for accurate and reliable data is the prerequisite for all further analysis and the foundation of all subsequent interpretation. The techniques outlined below are standard and have been used extensively in research on sea-level changes in the Netherlands (Jelgersma 1961), the Fenland (Godwin 1940a, Shennan 1980) and eastern Scotland (Smith et al. 1980, Morrison et al. 1981). It is regarded as essential that procedures adopted for data collection should be presented to enable independent evaluation of any subsequent interpretation. Accordingly the seven techniques used to study the nature and age of sea-level changes in the Moray Firth area are outlined below.

4.2 Levelling

All boreholes and sampling sites were instrumentally levelled to Ordnance Datum (Newlyn) using a Kern GK-1A level. Benchmark heights were taken from Ordnance Datum Benchmark Lists derived from the Third Geodetic Levelling of Great Britain (1951/59). All levelled transects were closed, the highest compound closing error being 0.23 m. for Moniack 1 → 7, however the majority of surface altitudes are considered accurate to 0.05 m. There is also an error inherent in the use of O.S. Benchmarks. Eady (1976) states that:

> "within a distance of 0.5 km. their maximum relative error should not exceed 1 cm. However, at this stage it is not yet possible to guarantee that the published heights in relation to Mean Sea Level at Newlyn are any more accurate than about 15 cms. in England and Wales and about 20 cms. in Scotland."

4.3 Field sampling

Three different types of sediment sampler were used for the reconnaissance of stratigraphy and sampling for further laboratory examination. Initially a gouge sampler provided rapid results. The sampler comprised a 1 m. half-chamber and 1 m. extension rods compatible with a percussion drill and jack attachment. Boreholes of up to 10 m. depth were easily achieved by one person in all sediment types save for compact sand and gravel.

Problems were encountered with contamination in wet, non-cohesive peats and organic clays. Shennan (1980) has shown that shearing of adjacent sediments through a core using such a gouge sampler could mean an error on peat/clay boundaries of up to 0.02 m. This makes the confident identification of thin peat bands difficult in some circumstances and in addition the small amount of sediment retrieved presents difficulty in accurate sediment description.

A Russian sampler compatible with the percussion drill and jack attachment enabled half-cores of 0.5 m. to be taken with little contamination or shearing of adjacent sediments. At Moniack 4B the use of multiple shots enabled a complete core to be retrieved for further micropalaeontological examination and to provide material for ^{14}C analysis. In this case the sampler was cleaned between samples and the sediment transferred to plastic guttering in 0.5 m. lengths and sealed in polythene.

The third sampler used comprised a modified Livingstone corer (Merkt and Streif 1970) also compatible with the percussion drill and jack attachment which provided undisturbed cores 1 m. in length and 0.048 m. in diameter. Some trouble was experienced in using two adjacent boreholes to provide overlap and ensure contamination-free sampling since vibration during the down stroke caused early sampling. In such cases, as at BY 14B, only one borehole was continued with resulting loss of an overlapping sequence of samples, the possibility of slight contamination at the top of each sample and small gaps in the sequence. Extrusion of the cores provided another source of error, the compression of the sample. This error, while affecting different materials in different ratios is unidirectional since compression always occurs from above and will result in measured depths being slightly deeper than actual.

4.4 Stratigraphic analysis

Stratigraphy was described in the field according to the scheme proposed by Troels-Smith (1955). It is considered essential that generalization of stratigraphic description should begin at a secondary stage. If, for example, an intercalated peat layer is described initially as a single unit the possibility of establishing information regarding tendency of water-level movement from evidence within such layers as shown by Tooley (1974) is denied. Similarly if a minerogenic layer is considered a single entity in a coastal context it denies the possible recognition of discrete events such as storm surges which although common have left little trace in the sedimentary record, a fact remarked upon by Walcott (1975). All changes in stratigraphy have significance and only additional work can differentiate the scale on which they operate.

This leads to a related point of objectivity. Stratigraphic subdivision and description must be undertaken without reference, implicit or explicit, to any model of formation. The dangers of only finding evidence to support such schemes or models are obvious here.

The Troels-Smith system for characterizing unconsolidated sediments (Troels-Smith 1955) is a procedure with widespread applicability since it is based on the assumption that each basic unit of stratigraphy or stratum, once designated, is a mixture of a limited number of elements (deposit components) which can be described and summed to arrive at a simple characterization. It has gained increasing acceptance as a descriptive technique and was recommended in 1974 for use by I.G.C.P. Project no.61 and more recently for I.G.C.P. Project no.158.(Aaby 1979).

There are problems, however, with its application principally in the characterization of the matrix of totally humified microscopic organic material which surround the recognizable macroscopic remains in a peat deposit or is in association with minerogenic components in an organic clay. Troels-Smith gives two main alternatives : Substantia humosa (Sh) consists of completely disintegrated and decomposed organic matter without macroscopic structure. The term can be used in a descriptive sense when the origin of the material cannot be stated with certainty. Limus humosus (Ld^4) is similarly made up of microscopic particles of organic material but results from sedimentation in water. This is a genetic interpretation, however, and departs from the original intention to provide an objective descriptive scheme. Obviously a gyttja or organic lake mud formed entirely of material produced from primary productivity within a lake ecosystem may have a matrix including Ld^4. However, Troels-Smith does not define the depth or type of water body in which Ld^4 is envisaged as being deposited. At the other extreme it could be applied to mean organic deposition almost in situ in a few centimetres of an ephemeral water body. This raises questions over the transition from Sh to Ld^4 and to avoid confusion Substantia humosa has been used to describe the totally humified organic matrix of any given deposit without regard to its origin.

The signatures used in the stratigraphic diagrams have the same meaning as originally proposed though their arrangement has been altered. Trace elements are omitted and the stratigraphic column is divided into four, each symbol representing ¼ presence in the deposit. This refinement is simply to reduce the time-consuming and difficult practice of drawing the symbols to the original specification and to provide a consistency with the computer-drawn diagrams.

In addition to field stratigraphic analysis, a supplementary technique has been the analysis of material retained on 180 μu sieves during preparation for pollen analysis. Though not carried out in such a formal or quantitative sense as proposed by Berglund (1979) each level was assessed on a 4 point scale for deposit components and interesting plant macrofossils extracted, many of which were kindly determined by Dr. P.A. GreatRex

4.5 Pollen Analysis

Preparation of samples followed established procedures (Appendix I). Prior to chemical treatment, however, Lycopodium tablets were added to a known volume of sediment allowing the pollen concentration technique of Stockmarr (1971) to be used. Routine counting was carried out on a Zeiss photomicroscope at a magnification of 625x with critical identification under oil-immersion possible up to 2500x. The standard pollen keys of Faegri and Iversen (1964) and Moore and Webb (1978) were used in conjunction with an extensive type-slide collection.

The counting procedure adopted involved the systematic traversing of each slide until 200 Lycopodium spores had been registered (400 at BY3B). The basic pollen and spore data for each site are tabulated in Appendix I.

The following should be noted :

- Corylus and Myrica pollen were not differentiated and are grouped accordingly under Coryloid.

- Cerealia type is taken to represent Gramineae-type pollen with a diameter over 45 μu.

- Betula nana pollen was not differentiated from Betula as suggested by Birks (1968) though a number of grains suggestive of Betula nana encountered at the lower levels at Arcan Mains and Barnyards.

- Typha angustifolia type includes Typha angustifolia and Sparganium.

Many attempts have been made to quantify the relationship between sediment lithology and pollen deterioration (Havinga, 1964, 1967, Sangster and Dale 1961, 1964). Differential pollen preservation is an important question to which attention must be given if one of the goals of pollen analysis is held to be the reconstruction of past vegetation assemblages. Most pollen studies attempting to describe the various forms of deterioration and their relationship to depositional environment have tended to focus on the Late Devensian (Birks, H.J.B. 1970, Cushing 1967, Lowe and Walker 1977) and in fully marine sediments (Stanley 1966). None have concentrated on coastal environments showing intercalations of peat on marine silts and clays.

All pollen grains encountered, save those from Arcan Mains, were classified as determinable or indeterminable. The determinable category was then identified and counted as normal, though registered as either corroded, degraded, broken, folded or well-preserved. Where one grain exhibited more than one aspect of deterioration a subjective decision was taken regarding the more important form. Unknown grains formed a subset of determinable grains. The indeterminable grains were also listed separately as corroded, degraded, broken, folded and concealed.

Indeterminable and unknown pollen grains are represented at the right hand side of each pollen diagram, whilst the determinable group is included separately in the summary diagram for each site. It must be noted, however, that while a relationship between sediment lithology and pollen preservation is intuitively obvious it has rarely been convincingly demonstrated perhaps, in part, due to the variety of factors operating on a pollen grain _en route_ to deposition and subsequent to deposition. The multitude of depositional environments through time and space in a coastal area exhibiting a migrating coastline, together with differential susceptibility of different pollen types to different forms of degradation, must mitigate against such a simple relationship.

Correction factors ('R' values) first described by Iversen (1947 in Andersen, 1973) and also by Davis (1963) have often been used in an attempt to correct for differential pollen productivity and dispersal to facilitate the use of pollen frequencies in reconstructing past vegetation assemblages and their change through time (Andersen 1970, Birks 1977 in Tooley 1981). Most work has been undertaken in mixed woodland using present day measures of vegetational area and surface pollen frequencies. Several problems are encountered here when applying such factors to fossil pollen spectra :

- with a range of possible pollen source strengths and a range of possible distances from the sampling site, the same recorded frequencies can be made up of an infinite number of combinations of pollen source, strength and distance. This means, in effect, that unless the distance and strength of a pollen source are known, correction factors cannot strictly be used to convert pollen frequency recorded at the sampling site into a measure of the abundance of the taxon which produced it in the contemporary vegetation (Oldfield 1970).
- in reality little such work has been accomplished and the replicability of such correction factors in other geographic areas and different environments, especially those which gave rise to peat layers intercalated with marine facies in low-lying coastal areas must be questioned. Accordingly, no correction factors are used in this study.

All pollen counts were processed using the computer program NEWPLOT developed at Durham by Shennan (1980). Various options are available to calculate and draw 95% confidence limits for taxa within and without a basic sum, a factor which itself can be varied. This enables a wide range of possible combinations. In addition, pollen concentration values are calculated again with upper and lower 95% confidence limits.

Moore and Webb (1978) have shown the need to be aware of the importance of choosing the basic pollen sum with respect to the problem in question. The use of pollen analysis in this study is threefold :

- as an independent age determination to supplement and verify ^{14}C dating.
- as an indicator of continuous sedimentation, any hiatus in deposition may be represented by a marked change in the pollen spectra.
- to outline the environmental changes shown by vegetation communities consequent upon transgression and regression.

The first use relies implicitly on the age connotations of the regional pollen rain whilst the third needs a treatment that will emphasize the predominantly local and extra-local component.

In a coastal environment which has not been continuously wooded during the Flandrian Age since it comprises an ecotone alternately favouring the extremes of marine and terrestrial regime, a basic sum is needed that will not over-emphasize the local component when the regional arboreal component is small. A sum based on total pollen - in this case total land pollen + group (%TLP + Group) - is therefore proposed. With pollen concentration forming another line of evidence it is felt that sufficient material is available to attempt to answer questions posed by the use of pollen analysis in this study.

In certain parts of Scotland it has become accepted that the pollen zones defined by Godwin (1940) for England and Wales do not apply. Connotations of synchroneity, climatic equivalence and a parallelism in vegetation development inherent his scheme became established underpinnings contrary to the original intention. In order to consider more easily the obvious regional differences found in peripheral parts of the country and to avoid misleading correlation, R.G. West (1970) advocated the adoption and use of the Assemblage Zone in pollen stratigraphy. Based entirely on the presence and relative proportions of its constituent fossils it is independent of any of the assumptions that became inherent in Godwin's scheme. This method, now widely used, has been of great value in illustrating the patterns of regional difference in Flandrian vegetational history (Birks,H.H. 1970, 1972a, 1972b, Birks, H.J.B. 1973, Peglar 1979).

The approach provides a useful and flexible method of correlation. Local Pollen Assemblage Zones (LPAZ) defined solely with respect to locally derived pollen may be correlated with a Regional Pollen Assemblage Zone system (RPAZ) defined after inspection of other available pollen profiles from the area showing similar successions and comparable assemblages (Birks, H.H. 1970). A further stage in this biostratigraphic correlation is for Regional Pollen Assemblage Zones to be tied to a formally designated chronozone system comprising radiometrically dated pollen zone boundaries at a type site (Hibbert et al. 1971, Hibbert and Switsur 1976).

However, the use of chronostratigraphy has been questioned by Lowe and Gray (1980) who suggest the scheme does not adapt itself to the essentially time-transgressive nature of vegetational change since being isochronous surfaces, chronozone boundaries when traced laterally will be out of accord with times of significant environmental change, one of the original problems in Godwin's scheme. Similarly, there are problems in the representivity of type sites or reference sections over large areas.

The type of study proposed for the Moray Firth area differs in some respects to the ideal circumstances for pollen assemblage zone construction and correlation. The type of site investigated is different in behaviour with respect to pollen recruitment to the large lake and bog sites traditionally used to define Regional Pollen Assemblage Zones. In addition there have been few pollen sites studied in the Moray Firth coastlands which could provide a basis for the establishment of an RPAZ system. The procedure adopted here will be to define several LPAZ for each site incorporating changes in the whole pollen spectra since it is felt that the construction of a local-regional hierarchy for the Moray Firth is not merited at present. A Local Pollen Assemblage Zone system is seen as having certain advantages in that it is flexible and allows for local variations which may be expected in the area of diverse habitat under study.

The zones, described in the next chapter, are considered to be of local significance only and are numbered (not named) following H.H. Birks (1970). Zone boundaries are placed where simultaneous changes appear to be taking place in a number of pollen types. The program NEWPLOT (Shennan 1980) in calculating 95% confidence intervals provides an admirable tool for zonation in that two levels that exhibit no overlap of confidence intervals in any particular taxon (that is they are statistically different at the 95% level) are more likely to show real rather than random differences.

4.6 Diatom Analysis

Samples were treated with 30% warm hydrogen peroxide to remove organic matter. A random sample of distilled water and sediment were then dried on a No.1 22 x 22 mm. coverslip and mounted in Microps 163 mountant. The analyses were carried out on the same microscope as for pollen identification, routine counting was undertaken at 625x and critical identifications were carried out under oil immersion up to a magnification of 2500x. At least 200 valves were counted at all levels. No absolute diatom analyses were carried out.

The main references used for identification were Cleve-Euler (1951-5), Hendey (1964), Hustedt (1927-62) and van der Werff and Huls (1958-74) with nomenclature following Cleve-Euler unless otherwise stated.

It is recognized that classification of species into life form classes and especially salinity groupings will in some cases be arbitrary. There is no general agreement on such classification, in many cases authors are at variance concerning specific allocations. Overall there is a shortage of information on the ecological tolerances and preferences of most taxa even though there have been great advances in the numbers of autecological studies (Battarbee 1979).

There are two salinity classifications in use at present. Hustedt (1927-62) developed the Halobian system in which there are five groupings ranging from polyhalobous through mesohalobous, halophilous, oligohalobous indifferent to halophobous. The salinity classification proposed by van der Werff and Huls (1958-74) has been used for this study. They identified seven groupings according to the chloride ion concentration in water -

Marine (M)	>17,000 mg. Cl^-/l
Marine-Brackish (MB)	10,000 - 17,000 mg. Cl^-/l
Brackish-Marine (BM)	5,000 - 10,000 mg. Cl^-/l
Brackish (B)	1,000 - 5,000 mg. Cl^-/l
Brackish-Fresh (BF)	500 - 1,000 mg. Cl^-/l
Fresh-Brackish (FB)	100 - 500 mg. Cl^-/l
Fresh (F)	< 100 mg. Cl^-/l

Diatom frequencies can be expressed as a percentage of the total valves counted or special sums can be constructed as in pollen analysis, for example Kjemperud (1981) uses total valves - Fragilaria spp. as a basis for calculations. Since all fossil diatoms exhibit the property of thanatacoenosis and are essentially allochthonous, having been transported and redeposited subsequent to death, there is perhaps some merit in constructing a basic sum of benthonic valves in the underlying hope that this will more readily reflect the environmental conditions of deposition.

Eronen (1974), among others, has noted that the large fluctuations in individual curves may well represent many factors, including primary productivity, differential deposition and survival and perhaps also reflect the mosaic of microhabitats that are potentially available on a salt marsh surface within a very limited area. Stress is therefore to be laid on the interpretation of overall changes in the assemblage rather than on individual curves.

Van der Werff and Huls (1958-74) have proposed a qualitative approach based on the number of species present within each salinity class and represented as a percentage of total species in an attempt to overcome irregularities in individual diatom curves. This method gives no weighting to frequency of occurrence of individual species as once a species has been identified, further occurrences are ignored.

There is no agreed method of representing either individual species or classes of species. Shennan (1980) has drawn attention to the variety of ways information can be enumerated and presented in a qualitative or quantitative way. In sea-level studies diatom analyses have often provided evidence for succession or retrogression in assemblages consequent upon an increase or decrease in the marine effect. When so little is known about the autecology and community ecology of littoral and marine diatoms and so many permutations of representation are available, great care must be taken in the objective presentation and interpretation of diatom data.

In this study several different methods of representing diatom counts will be used. All diatom counts are given in Appendix II. The computer-drawn diagram shows individual species calculated as a percentage of total valves with unknown valves and species outside the sum. The species are arranged from left to right following the seven salinity classes of Van der Werff and Huls and within each class according to life form class i.e. benthonic, epithytic and planktonic. Within each of these secondary classes the taxa are arranged alphabetically. In addition, a summary diagram is presented for each site showing diatom data in six ways. The first four sections show taxa according to salinity class with a basic sum calculated as % total valves, % benthonic + epiphytic valves, % species and % benthonic + epiphytic species. The latter two show taxa summed according to life form class with a basic sum calculated as % total valves and % total species respectively. This departs from the treatment given by Shennan (1980) since it is considered that removal of the planktonic element only will give a better approximation to environmental conditions during deposition of the sediment. Zonation of the diatom diagrams has been carried out in exactly the same manner as for pollen.

4.7 Grain size analysis

The procedure adopted involved standard dry sieving and sedimentation techniques as described in the British Standards Institution Handbook (BS 1377:1967). The technique tends to amplify the amount of coarse silt in the fraction since it is determined by subtraction from the amount of material retained on sieves above 0.075 mm. (fine sand + coarser material) added to the amount of medium silt + finer material calculated by sedimentation. In reality this means it encompasses the size range 0.02-0.075 mm.

The amount of material needed, 30-50 g. may also mask important changes, for example sampling a laminated sediment is of little use due to the averaging effect.

The data are shown in simple percentage frequency - depth diagrams incorporated in the site summary diagrams.

4.8 Radiocarbon Dating

It is probably the case that not enough attention has been paid in sea-level research to the errors involved in radiocarbon dating and the inferences that can and cannot be drawn from the final date. This section will consider the uncertainties in radiocarbon dating and in particular their effect on sea-level index points.

4.8.1. Variations in $^{14}C/^{12}C$ ratio

Variations through time and space in the proportions of ^{14}C to ^{12}C in atmospheric carbon dioxide first suggested by de Vries (1958) are now well established as fact. Traditionally the method used to determine the character of the changes in ratio which cause calculated radiocarbon years to deviate from calendar years has been to date samples of known age such as those provided by a fixed tree-ring time scale. Suess (1970) provided a calibration curve that exhibited an oscillating course, though as in sea-level studies there is an alternative school of thought that consider the 'wiggles' can be covered by experimental error, their amplitude often being smaller than the limits of error of many laboratories. Clark (1975) for instance suggests that the relationship between specific ^{14}C activity and calendar years is best described by a smooth curve. The direction and rate of change in the relationship is still not agreed upon. Pearson et al. (1977) state that although -

> 'it is 19 years since the de Vries report there is still no satisfactory experimentally-derived calibration curve that can be used unambiguously to convert radiocarbon ages to calendar dates' (p. 25).

Their precise and exhaustive work on a 1,200 yr. section of a 2,990 yr. floating tree ring chronology derived from sub-fossil oaks in Northern Ireland does not show any of the 'wiggles' predicted by Suess for the time period investigated. Suess (1980) has recently confirmed the existence of short-term low amplitude oscillations in specific ^{14}C activity with time and using Fourier analysis suggested there were cyclic, non-random features to the variation, including a 200 yr. component. In addition, the oscillations were found to exhibit a steeper rise (c. 1% in 20 yrs.) than fall (c. 1% in 40 yrs.) and to be largely independent of geographic location.

The causes of secular change in specific ^{14}C activity have also been under intensive study and work has tended to concentrate on two main aspects, variations of the rate of ^{14}C production in the atmosphere and reservoir changes within the global carbon cycle. Stuiver and Quay (1980) suggest that modulation of the cosmic ray flux arriving in the upper atmosphere by changes in the magnetic properties of the solar wind and the interaction closer to earth of the incoming cosmic ray flux and the earth's geomagnetic field can between them best explain changes in the atmospheric ^{14}C record - with climatic change having only a secondary effect. Siegenthaler et al. (1980) however emphasized the influence of changes in the global carbon cycle, prompted by climatic change, to explain the variations in the ^{14}C record. The three main carbon reservoirs of the ocean, atmosphere and biosphere have undoubtedly been greatly affected by climatic change on the glacial-interglacial scale. They conclude that during phases of rapid climatic variation, such as during the Late Devensian - Flandrian transition, rates of change of ^{14}C in the atmosphere of the order of 1% per century may have been caused by rapid changes in the ocean circulation pattern. During more stable times, however, other changes in the carbon reservoir system are unlikely to explain fluctuations such as the Suess 'wiggles'.

Empirical evidence, for example, by Oescheger et al. (1980) provides supporting evidence in that detailed ^{14}C analyses from peat profiles in the Wachseldorn area of Switzerland point to a compression of the ^{14}C time scale during the Younger Dryas caused perhaps in part by variation in the $^{14}C/^{12}C$ ratio. Similarly, the dating of the Late Devensian - Flandrian boundary in Scotland has shown a great variation in ages even from such a small geographical area as Rannoch Moor (Lowe and Walker 1980) in spite of a consistent sampling strategy again suggesting a contributory factor may well have been variations in the $^{14}C/^{12}C$ ratio.

In sea-level studies few dates have been determined for the period

18,000 B.P. to 10,000 B.P. and changes in specific ^{14}C activity through time have rarely been taken into account. However, for Flandrian index points, where close sampling of radiocarbon dates indicates an age inversion, then perhaps in addition to the many other possible causes, variation in the $^{14}C/^{12}C$ ratio may be a factor. In eastern Scotland at least two sites, Fullerton near Montrose (Smith _et al_. 1980) and Silver Moss, East Fife (Morrison _et al_. 1981) dating of the 'middle' peat layer above a marked grey silty fine sand layer and below the traditional 'carse clays' has shown age inversion with depth on closely spaced samples. While accepting the views of Pearson _et al_. (1977) above, it is interesting to note that the computer-drawn diagram of Suess (1980, fig. 3) showing variations in the atmospheric ^{14}C level during the past 8,000 years has a pronounced maximum at c. 7250 B.P. falling to a minimum at c.6750 B.P. with oscillations at c.7075 B.P. and c. 6850 B.P., the absolute change of which appears to be as great as any since, save for the recent man-induced variations such as the Suess effect. The age of the inverted determinations lies between 6880 ± 110 B.P. and 7310 ± 100 B.P. and the effect of such a rapid fall in ^{14}C content during this period would be to make older samples younger and younger samples older.

4.8.2. Isotopic Fractionation

The different isotopes of carbon have different masses, ^{14}C has a mass 15% greater than ^{13}C (Ogden 1977) and will therefore be absorbed differentially by living matter so that most living tissue is deficient in ^{14}C with respect to the atmosphere. Using the ratio of ^{12}C to ^{13}C in the PDB limestone standard, most terrestrial material is deficient in ^{13}C by c.24-35‰ and knowing the relationship between ^{13}C and ^{14}C it is an easy matter to use a correction factor to account for differential isotopic fractionation. It is customary for dating purposes that all ages should be adjusted or normalized to a $\delta^{13}C$ value of -25‰.

In sea-level studies this normalization will mean a considerable adjustment. Olsson (1979) provides a table of $\delta^{13}C$ values for commonly dated samples and their mean age correction required. Marine shells need a correction factor of c. +400 years, foraminifera c.+380 years, brackish water shells c.+260 years, peat c.-30 years and gyttja c.-15 years. In addition, salt marsh plants such as Spartina sp. operate on a different carbon-fixation cycle (C_4) and will take up the heavier ^{14}C preferentially so that if dated the result could be too young by 150 to 300 yrs. compared to wood samples (Stuckenrath 1977).

Use has often been made of the stated $\delta^{13}C$ value to differentiate between aquatic and terrestrially synthesized carbon. The arguments of Sutherland (1980) are relevant in a coastal context. A $\delta^{13}C$ value of -27.2‰ as at Barnyards 3B (Hv 10.010) does not suggest a lack of carbon from salt marsh taxa. The value is an average and could include a proportion of salt marsh plants which would tend to produce a young age. Theoretically a dated index point could contain 50% terrestrial material with a $\delta^{13}C$ value of -34‰ and 50% salt marsh material at -15% which would give a $\delta^{13}C$ value of 24.5‰ which is well within that generally accepted for the range of terrestrial material.

4.8.3. The Reservoir Effect

Due to the slow mixing rate of the oceans, marine organisms fix carbon that can be up to 400 years old in the case of the North Atlantic. With marine molluscs it has often been suggested that the correction for isotopic fractionation (c.+400 yrs.) and the reservoir effect cancel each other out and should be ignored. This is a bad practice and as Olsson (1979) suggests the two corrections should be kept separate, although being roughly equal but in opposite senses.

In the context of a salt marsh peat the species that fix carbon through the C_4 cycle could also be drawing on carbon in water supplied by tidal inundation that has a slight reservoir effect. Dating an admixture of terrestrial and salt marsh peats could involve differential reservoir effects since once peat begins to form above the tidal range the plants that form it would use fresh water with little reservoir effect. In sampling material to produce index points, therefore, care should be taken not to sample across stratigraphic boundaries since these may incorporate material from different carbon exchange reservoirs.

4.8.4 Contamination

All obvious macro fossil contamination was removed from the samples and coring equipment was cleaned before each sampling run. The larger visible pieces of Phragmites and woody detritus were removed by hand sorting to minimize the risk of contamination by younger or allochthonous material. With Phragmites Streif (1972) has reported age differences of 845 ± 210 ^{14}C years between the rhizome and matrix fractions and van de Plassche (1980) has noted a similar younging effect of c.400 years.

Alternatively contamination by small amounts of very old carbon cannot be ruled out, especially when the sediment is to some extent inorganic. Baxter et al. (1980) indicate:

> 'the need to consider natural fossil carbon contamination as a potential and significant source of error in dating sediments'. (p. 36).

However, their work was carried out in the Clyde Sea area where many coal seams outcrop along the coast and in the catchment. The Moray Firth area is devoid of coal measures save for a small deposit near Brora.

Finally Sutherland (1980) has mentioned other sources of contamination that could affect ^{14}C determinations on index points, including sediment mixing, bioturbation, percolation of humic acids and the 'hard water' effect where submerged aquatics fix old carbon in a freshwater lake, the old carbon coming from calcareous groundwater seepage or simply the reservoir effect of a water body.

4.8.5 Thickness of sample

Sample thickness was kept to a minimum to reduce the averaging effect of including older with younger organic material. Sutherland (1980) has shown that since radiocarbon decay is exponential it tends to weight the 'average' age towards the younger end of the sample. Obviously the sedimentation rate of organic material is important here, the higher the rate the less the younging effect. Similarly, compaction may well affect this factor and will tend to weight the averaging effect to the older portion of the sample.

The maximum sample thickness used in this study was 0.06 m. which after removal of obvious contamination, younger roots and allochthonous material usually gave a wet weight of 50-75 g. While this is not recognized as ideal it must be noted that often the (praiseworthy) effort in achieving small sample thicknesses (Walker and Lowe 1979, Lowe and Walker 1976, 1980, Morrison et al. 1981) is not rewarded by a corresponding accuracy of result.

4.8.6 Laboratory error

Few laboratories quote errors other than those resulting from the random process of radioactive decay which usually includes the sum of background, standard and sample errors. Indeed Pardi and Marcus (1977) suggest that quoted standard deviations may underestimate the actual physical measurement errors quite considerably. Pearson et al. (1977) investigated and corrected for eight significant error sources in the physical determination and their 25 yr. standard deviation on all determined ages covered all errors in experimental procedure. Some errors such as background variation with barometric pressure could have caused an error of up to 100 years. Care should therefore be taken in accepting the standard deviation given with each date as a measure of the absolute accuracy of that date. One way to overcome this would be to use replicate sampling with different laboratories but the cost of such an exercise would be prohibitive.

CHAPTER 5

SITES INVESTIGATED

5.1 Barnyards

The Barnyards site is located at the head of the Beauly Firth 20 km. east of Inverness and 0.5 km. north of Beauly itself. It lies north-west of the Kirkhill ridge on the larger section of the Beauly carse which rises from the Beauly river at c.2 m. to c.10 m. at which altitude the Flandrian marine deposits wedge out against a marked break in slope. No detailed work has been published on the Flandrian stratigraphy of the area. Wallace (1883) reported the discovery of mussels and other marine molluscs in gravels at Wester Lovat and behind the schoolhouse at Beauly. Eyles et al. (1946) made reference to a trial pit excavated for brick clay in the Beauly area on Barnyards Farm. The stratigraphy was recorded as follows:-

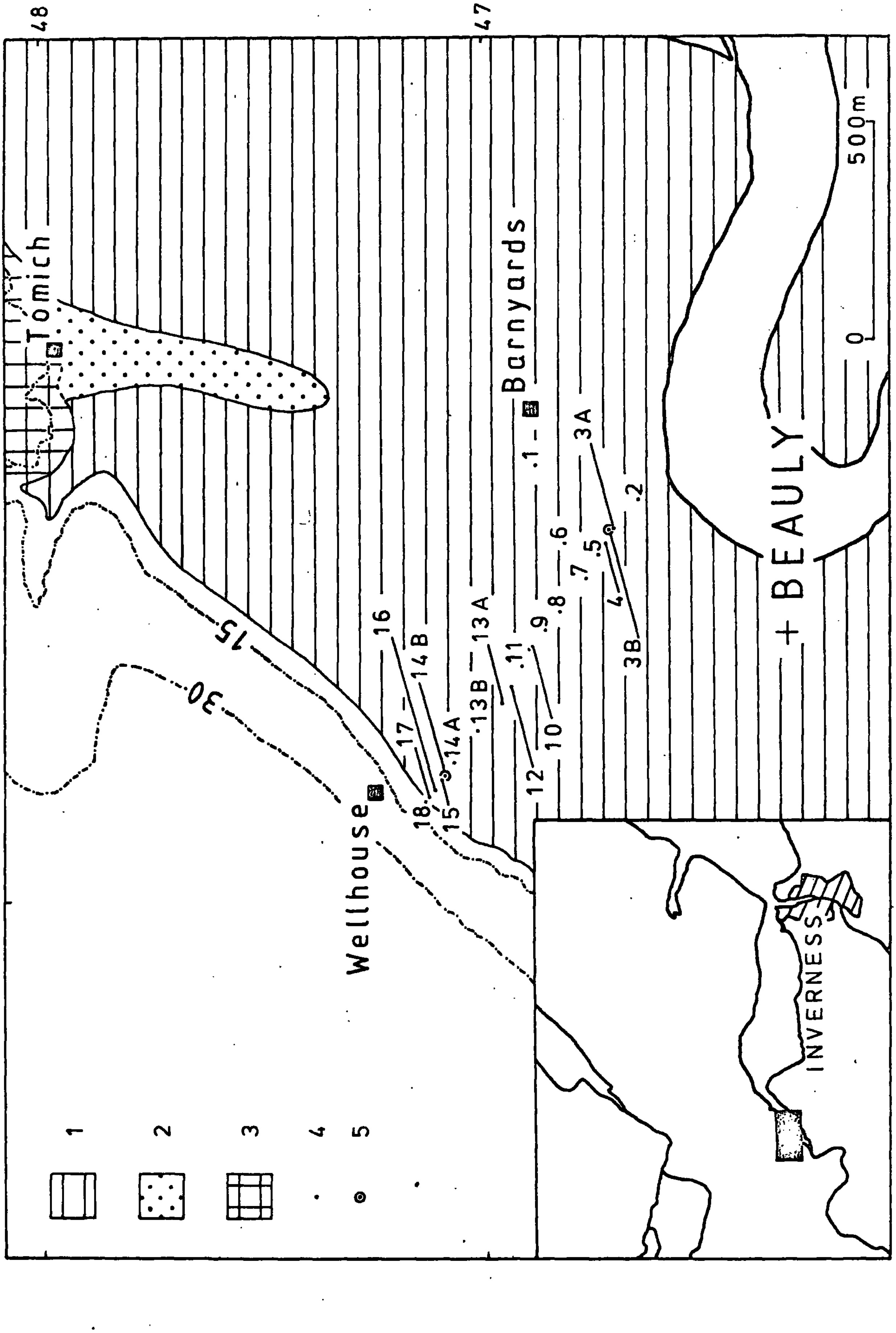
Brown clay (including topsoil)	c	6 ft. (1.83 m.)
Grey clay	c	5 ft. (1.52 m.)
Peat	c	1 ft. (0.3 m.)

To the north lies the Muir of Ord outwash terrace mapped by Ogilvie (1923) and J.S. Smith (1968) which terminates to the south and east between Tomich and Tarradale in a prominent erosional notch, the backslope of which rises in altitude from c 10 m. to c 23 m. Exposures in the terrace prove its distal end to be comprised mainly of sand, and a relict sand bar, presumably derived from the outwash projects southwards from Tomich towards Beauly reaching a maximum altitude of c.9 m.

To the south at Balblair an impressive delta is graded to a sea-level at c. 26-28 m. Exposures of foreset bedding capped by topset bedding in Balblair Quarry, together with an ice contact slope to the south west in Balblair wood,suggest an ice marginal delta prograding into the Beauly Firth at an altitude of 26-28 m. and fed by a glacier flowing

Fig. 5.1 Barnyards site map

1. Beauly carse
2. Relict sand spit
3. Fluvioglacial outwash
4. Borehole
5. Sampling sites


48
47
53
52
Tomich
Barnyards
Wellhouse
+ BEAULY
INVERNESS
0
500m
15
30
.1
.2
3A
3B
4
.5
.6
.7
.8
.9
10
.11
12
13A
.13B
.14A
14B
15
16
17
18
1
2
3
4
5

down the Beauly gorge (Synge and Smith 1980).

The Beauly Firth itself is a complex estuary. The dominant feature to the east is the outflow of the river Ness which not only flows eastwards to the sea, but also westwards, at flood tide, into the inner Beauly Firth. West of a line from Charlestown to the outlet of the Caledonian canal the estuary has a reversed water circulation with upper water moving westwards and deep water moving slowly eastwards (Craig and Adams 1969). Freshwater input to the Beauly Firth is therefore quite considerable and can be from two directions.

The configuration of the firth is also important to tidal movements. At the Kessock narrows the constriction can often produce surface tidal streams of 4 knots on ebb and flood tides. Tidal range measured at Inverness is 4.1 m. (springs) and 1.9 m. (neaps) with MHWS reaching 4.8 m.O.D. (Admiralty Tide Tables 1981). It is not known if tidal range increases eastwards towards Beauly. In the Tay estuary, for example, a fall in tidal range is recorded in the inner estuary (Williams and Nassehi 1980).

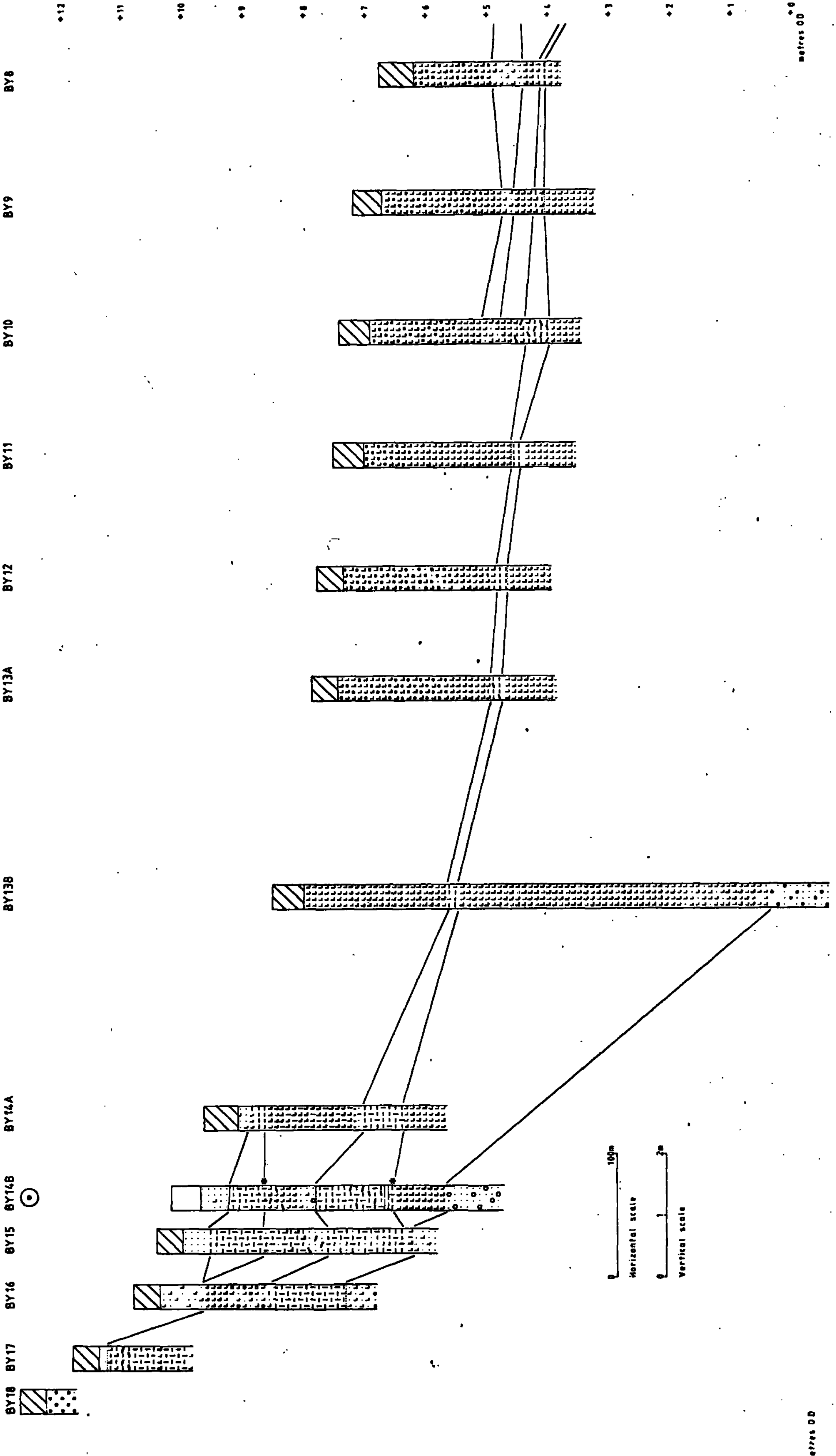
5.1.1 Barnyards stratigraphy

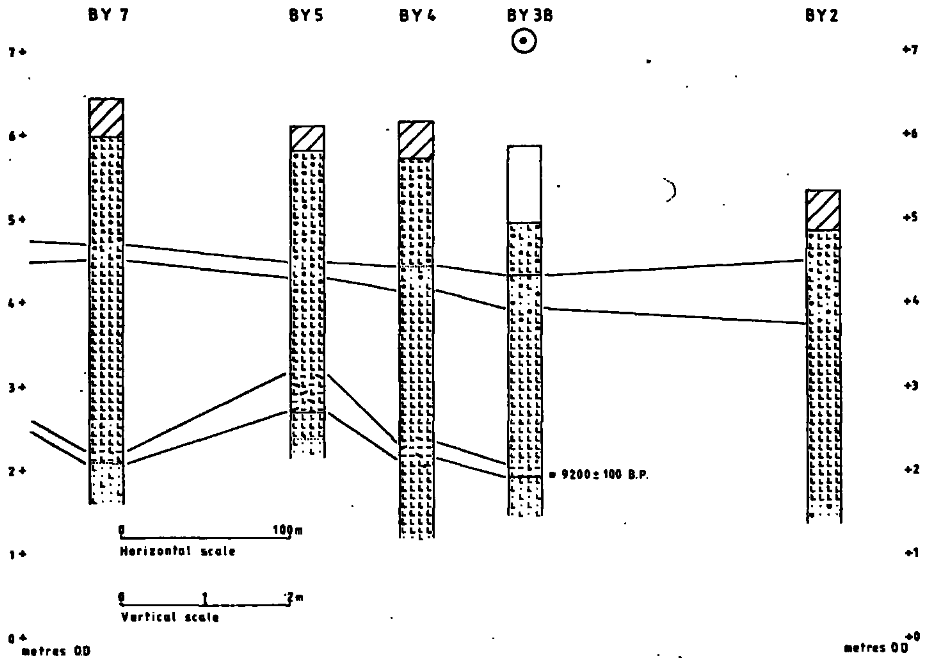
21 boreholes were put down, all except two, BY1 and BY6 in a transect normal to the break in slope and 0.8 km. in length. The locations of the boreholes are given in figs. 5.1 and the stratigraphy is shown diagrammatically in figs. 5.2 and 5.3. The majority of the transect shows a Y1,2 profile with a lower marine clastic sequence overlain by a splitting-up sequence capped by an upper clastic sequence. BY14A, BY14B and BY15 show a Y1, 11 profile, BY16 a Y1,12, BY17 a Y1,10 and BY18 an X1,18 profile. It is not known however if part of the clastic cover sequence in BY16 or the intercalated silty clay layer in BY17 relate to a marine event.

In 5 boreholes, BY13B, 14B, 15, 16 and 18 the basal deposit encountered comprises pink silt, sand and gravel, some gravel being quite

Fig. 5.2 Barnyards stratigraphy. Boreholes BY 8 to BY 18

Fig. 5.3 Barnyards stratigraphy. Boreholes BY2 to BY7


BY8
BY9
BY10
BY11
BY12
BY13A
BY13B
BY14A
BY14B
BY15
BY16
BY17
BY18
+12
+11
+10
+9
+8
+7
+6
+5
+4
+3
+2
+1
+0
metres OD
12+
11+
10+
9+
8+
7+
6+
5+
4+
3+
2+
1+
0+
metres OD
0
100m
Horizontal scale
0
1
2m
Vertical scale


BY 7
BY5
BY4
BY3B
BY2
7+
6+
5+
4+
3+
2+
1+
0+
metres OD
+7
+6
+5
+4
+3
+2
+1
+0
metres OD
9200±100 B.P.
0
100m
Horizontal scale
0
1
2m
Vertical scale

coarse - up to 40 x 25 x 20 mm. at BY14B. It is considered to represent the surface layers of a till deposit, the colour and composition of which are derived from the local Old Red Sandstone conglomerate. The till surface slopes sharply south-eastwards away from the break in slope with a gradient of 39.6 m./km. (based on only 4 boreholes). If projected this would result in a depth of the boulder clay surface of c -25 m. O.D. at BY2.

Overlying the till is a complex series of grey marine clays, silts and sands up to 5 m. thick in BY13B. In this borehole the sequence comprises three units, 67 cm. of light grey silty clay overlain by 72 cm. grey silty sand and succeeded by 361 cm. of grey silts and clays, a finer → coarser → finer succession that is repeated elsewhere in the area (e.g. at Moniack). Above the till at BY14B, 15 and 16 only the latter two units are represented, the coarser grey silty sands with the finer grey silts and clays succeeding them. Boreholes BY2 to BY13A only penetrate the upper unit of the succession. More detailed analysis of the stratigraphy at BY3B including particle size analysis revealed a grey sandy silt with laminations of lighter grey silty sand. It is not known if such laminations are present elsewhere at Barnyards within this unit since the method of sampling precludes the confident identification of thin laminae because the gouge sampler tends to destroy finer structures.

Above the qhKU sequence rests a widespread layer of peat encountered in all boreholes except BY1, 2 and 18. In general it thickens in a landward direction ranging from 4 cm. at BY5 to 129 cm. at BY14B and BY15, while the altitude of the regressive overlap varies from 1.94 m. at BY3B to 8.76 m. at BY14B, a slope of 6.32 m./km. (based on 17 boreholes). The composition of the peat layer also varies along the transect and an ecological gradient is apparent. At BY3B where the layer is 17 cm. thick it comprises a well-stratified Phragmites peat with little internal variation. At BY14B the peat layer is 129 cm. thick and comprises three distinct units, a lower monocotyledonous peat 10 cm. thick overlain by a well humified peat including woody detritus of 68 cm. in turn overlain by another monocotyledonous peat 52 cm. thick. It is usual for the transition zone between the underlying grey marine sequence and the lower peat to be extremely thin. At BY3B the transition is marked over 1cm, however at BY14B the zone is more gradual with an intermixed peat and silty clay stratum (stratum 5) perhaps representing a reworked peat ball (Greensmith and Tucker 1973) beneath the lower peat proper.

The transgressive overlap has a gradient of 7.43 m./km. (based on 17 boreholes) though this is undoubtedly affected by a number of erosion contacts. Evidence for erosion of this peat layer can be seen in a number of boreholes. At BY7 the peat layer is c. 1 m. lower than surrounding boreholes and has the character of a mixed organic and minerogenic deposit, perhaps representing the fill of a small channel. Supporting evidence comes from BY5, 6 and 8 which shows a marked thinning of the peat layer to 6, 4 and 6 cm. respectively with an increased minerogenic component within the peat at BY6. The existence of a former channel in the area of these boreholes is inferred. At BY14B the top of the lower peat is clearly eroded with a large piece of gravel, 55 x 40 x 26 mm. resting unconformably on the peat surface. As this borehole is near the shoreline of the clastic deposit between the lower and upper interfingering peat layers, increased erosive activity is expected.

The altitude of the transgressive overlap varies from 2.11 m. at BY3B to 7.88 m. at BY14B, a rise of 5.77 m. As the peat layer exhibits a marked decrease in thickness seaward a linear regression for both transgressive and regressive overlaps was performed with distance from BY18 as the independent variable.

The solution of the equation for the limit of biogenic sedimentation when $T = R$ is +2.18 m. O.D. at a distance of 744 m. from BY18. BY3B, the site chosen for further analysis is 750 m. from BY18 and the thin peat layer is at 1.94 - 2.11 m. O.D. close to the extrapolated limit of biogenic sedimentation. The regression equations comprised:-

$$TC = 7.708 + -0.00743\ \text{Dist} \quad r = -0.98 \quad n = 17$$

$$RC = 6.883 + -0.00632\ \text{Dist} \quad r = -0.98 \quad n = 17$$

$$BC = 8.25 + -0.0396\ \text{Dist} \quad r = -0.99 \quad n = 4$$

Overlying the lower peat and underlying the upper peat at Barnyards is a succession of marine clays, silts and occasionally sand. The succession is characteristically divided into three facies units at Barnyards. Directly above the lower peat, apart from localities eroded by later channelling and wave activity are grey silts and clays which range in thickness from 57 cm. at BY13B to 199 cm. at BY7. Particle size analysis at BY3B (fig. 5.8) shows them to be composed of c. 50% coarse silt, 15% medium silt, 10% fine silt and 25% clay. The second unit of these interfingering clastic deposits is found only in boreholes BY2, 3A, 3B, 4, 5, 6, 7, 8, 9 10 and perhaps 12 (figs. 5.2 and 5.3) where coarser sandy silts and silty sands overlie the finer greyer silts and clays. Whether this unit represents an erosive event is difficult to ascertain since the gouge samper used makes the identification of erosion contacts difficult, however, the upper and lower boundaries do show a markedly gentler gradient rising from 4.73 m. at BY2 to 6.27 m. at BY12.

Above this coarser layer lie finer orange and yellow iron-stained silts. This iron-stained unit can be up to 220 cm. thick as at BY3B and often contains iron concretions of fine gravel size. It is interesting to note that where an upper peat overlies the marine clastic sequence in boreholes BY14A, 14B, 15 and 17 there is no trace of iron-staining which suggests that a condition of permanently high groundwater levels occurred. The division of this marine clastic sequence into an upper orange-brown iron-stained layer and a lower grey unoxidized layer suggested by Eyles et al. (1946) above has also been reported from the carse clays of the Forth Valley (D.E. Smith 1968).

In three boreholes BY14A, 14B and 15 an upper peat layer overlies the marine clastic deposits and completes the qhA sequence in these boreholes. The peat layer varies in thickness from 22 cm. at BY14A to 122 cm. at BY15, the altitude of the regressive overlap varying from 8.65 m. at BY14A to 8.70 at BY15. In BY14B there is a lower monocot. peat with Phragmites of underlying a woody detrital peat and overlain by a monocotyledonous peat. The layer is not present in BY16, here a dark grey silty sand and gravel is overlain by a dark grey silty clay which may point to the total erosion of the peat by channelling. It is not known if these minerogenic units forming the upper clastic sequence relate in whole or part to a marine event. Similarly the thin silty clay unit interfingering with peat layers at 10.5 m. in BY17 is of unknown origin though for the present it has been classed as terrestrial which makes the profile a Y1,10 type.

Above the upper peat in boreholes BY14A to 17 and lying unconformably on it is a colluvial deposit. This unit is variable in composition though comprising orange and brown silty sand and gravel up to 95 cm. thick at BY14B.

5.1.2 Barnyards 3B

The Barnyards 3B site was chosen for further micropalaeontological analysis since it is situated near the seaward limit of lower peat accumulation. A large diameter core of 48 mm. was retrieved using a modified Livingstone sampler and levels were selected for pollen, diatom, particle size, loss on ignition and radiocarbon analyses. The stratigraphy of the core comprised

	cm.	m.O.D.	Description
	0 - 92	4.95 - 5.87	Not sampled.
9.	92 - 120	4.67 - 4.95	Yellow brown sandy silt with iron-staining. Ag2 Ga1 Lf1 nig. 1 strf. 2 elas. 0 sicc.3.
8.	120 - 155.5	4.315- 4.67	Yellow brown silt with iron-staining Ag3 Lf1 Ga+ As+ nig.1 strf. 2 elas. 0 sicc.3.1.s.0.
7.	155.5 - 191	3.96 - 4.315	Yellow brown silty sand with iron-staining Ga2 Lf1 Ag1 As+ Lf+ nig. 1 strf. 2 elas.0 sicc.3. 1.s.4.
6.	191 - 220	3.67 - 3.96	Yellow brown and grey silt with iron-staining. Ag2 Lf1 Ga+ As1 nig. 2 strf. 2 elas. 0 sicc.2.1.s.0.
5.	220 - 248	3.39 - 3.67	Grey silt with occasional iron-staining. Ag3 As1 Lf+ nig.2 strf. 2 elas. 0 sicc.2 1.s.0.
4.	248 - 376	2.11 - 3.39	Grey silt. Ag3 As1 Dh+ Ga+ nig.2. strf. 2 elas. 0. sicc. 2 1.s.0.
3.	376 - 393	1.94 - 2.11	Well humified dark brown peat. Sh 3 Th^2 (Phra.) 1 Ag+ As+ nig. 3 strf. 3 elas. 1 sicc. 3 1.s.0.
2.	393 - 402	1.85 - 1.94	Grey sandy silt. Ag3 Ga1 As+ Dh+ nig. 2 strf. 2 elas. 0. sicc. 2 1.s. 3/4.
1.	402 - 440	1.47 - 1.85	Laminated sands and silts with occasional root channels. Ag2 Ga2 Sh+ As+ Th^2+ Dh+ nig.2. strf. 2 elas.0 sicc. 2 1.s.0.

5.1.2.1. BY3B Pollen

35 levels were analysed for pollen between 355 and 430 cm. at 1 cm. intervals throughout the 17 cm. thick peat layer and into the clastic layers above and below at 5 and 10 cm. intervals. Low numbers of pollen grains were encountered in stratum 2, the grey sandy silt directly beneath the peat layer. However, these levels are included in the pollen diagrams (figs. 5.4 and 5.5) since the large 95% confidence intervals on the counts are indicative of the uncertainty involved. The diagrams have been divided into 5 local pollen assemblage zones, numbered from the base upwards and with the prefix BY3B.

Pollen counts are tabulated in Appendix I.

Zone BY3B1 430 - 393.5 cm.

The pollen of Betula and Gramineae dominate the zone with Betula rising to 49.7% at 420 cm. Gramineae is characterized by a continuous curve of c. 15% with no significant changes throughout the zone. The mean value of Pinus rises from 0.7% at 430 cm. to 12.5% at 395 cm. though again there is no significant change. Coryloid, Salix and Cyperaceae are present in low percentages and Filicales rises throughout the zone from 11.2% at 430 cm. to 58.9% at 394 cm. The sporadic occurrence of Ulmus, Picea, Alnus and Myriophyllum alterniflorum points to reworking under marine conditions. Concentration values are uniformly low, the total being higher in the lower three levels but never exceeding 50 grains x $10^3/cm^3$. The upper boundary is placed at the significant rise in Gramineae from 19.6 to 34.2% and a significant fall in Filicales from 58.9% to 8.2% and with increases in the concentration of Betula, Pinus, Coryloid, Salix, Gramineae and Cyperaceae pollen.

Zone BY3B2 393.5 - 391.5 cm.

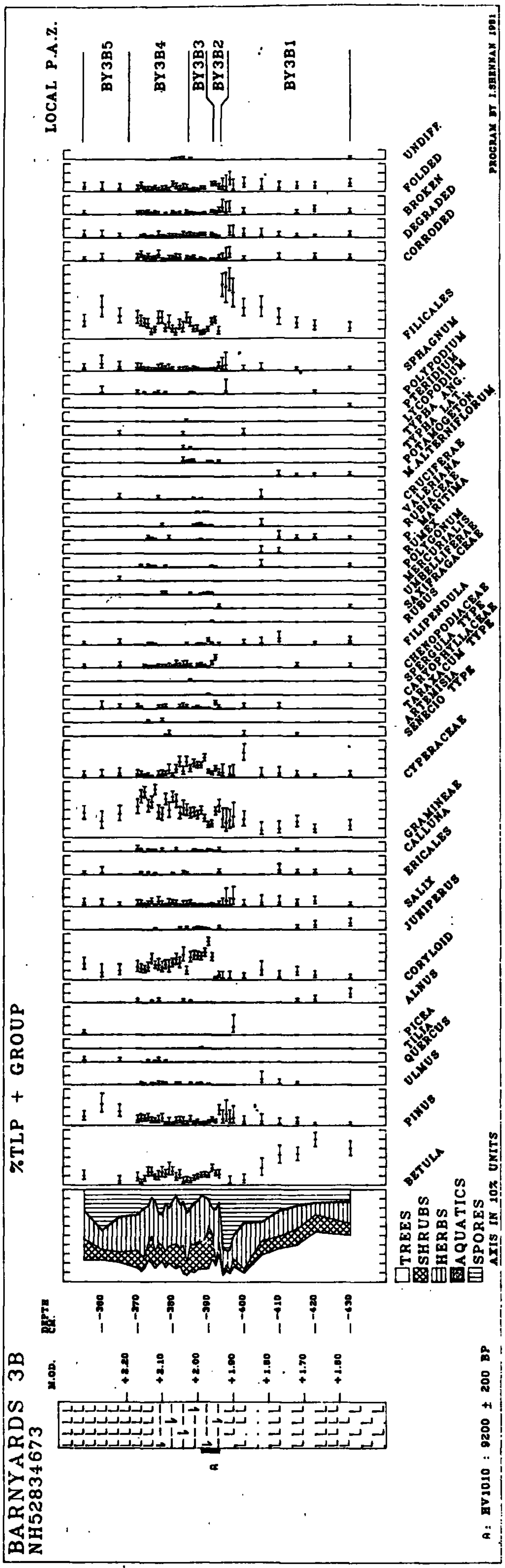
Gramineae, Betula and Pinus are the dominant taxa with a high Chenopodiaceae value of 11.3% at 392 cm. Gramineae reaches 34.2% at 393 cm. Total concentration increases through the zone from 49.9 to 122.2 grains x $10^3/cm^3$. The upper boundary is placed at the rational limit of the Coryloid pollen curve, a significant rise from 2.2% to 25% and from 12.3 to 100.0 grains x $10^3/cm^3$.

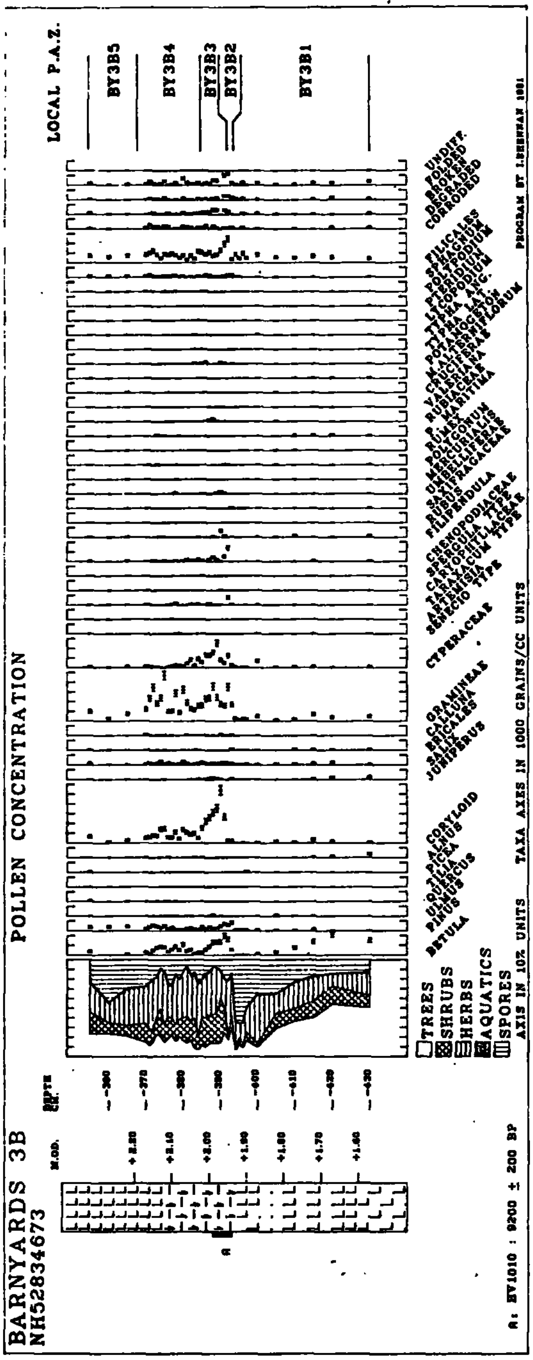
Zone BY3B3 391.5 - 384.5 cm.

Coryloid and Gramineae pollen are the most abundant taxa in the zone. Coryloid values reach 41.9% at 390 cm. and then fall throughout the zone to 24.9% at 385 cm. The Gramineae curve undergoes a complementary rise from 14.9% at 391 cm. to 26.2% at 385 cm. but with no significant change from level to level. The concentration of Coryloid falls throughout

Fig. 5.4 Barnyards 3B, %TLP + Group

Fig. 5.5 Barnyards 3B, Pollen concentration.
Horizontal scale should read 'Taxa Axes in 10 x 10^3grains/cm^3 units'


BARNYARDS 3B
NH52834673
M.OD.
DEPTH CM.
+2.20
+2.10
+2.00
+1.90
+1.80
+1.70
+1.60
-360
-370
-380
-390
-400
-410
-420
-430
a
%TLP + GROUP
LOCAL P.A.Z.
BY3B5
BY3B4
BY3B3
BY3B2
BY3B1
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
BETULA
PINUS
ULMUS
QUERCUS
TILIA
PICEA
ALNUS
CORYLOID
JUNIPERUS
SALIX
ERICALES
CALLUNA
GRAMINEAE
CYPERACEAE
SENECIO TYPE
ARTEMISIA
TARAXACUM TYPE
CARYOPHYLLACEAE
SPERGULA TYPE
CHENOPODIACEAE
FILIPENDULA
RUBUS
SAXIFRAGACEAE
UMBELLIFERAE
MERCURIALIS
POLYGONUM
RUMEX
P. MARITIMA
RUBIACEAE
VALERIANA
CRUCIFERAE
M.ALTERNIFLORUM
POTAMOGETON
TYPHA LAT.
TYPHA ANG.
LYCOPODIUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
UNDIFF.
a: HV1010 : 9200 ± 200 BP
PROGRAM BY I.SHENNAN 1981


BARNYARDS 3B
NH52834673
POLLEN CONCENTRATION
LOCAL P.A.Z.
BY3B5
BY3B4
BY3B3
BY3B2
BY3B1
M.O.D.
+2.20
+2.10
+2.00
+1.90
+1.80
+1.70
+1.60
DEPTH CM.
-360
-370
-380
-390
-400
-410
-420
-430
a
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
BETULA
PINUS
ULMUS
QUERCUS
TILIA
PICEA
ALNUS
CORYLOID
JUNIPERUS
SALIX
ERICALES
CALLUNA
GRAMINEAE
CYPERACEAE
SENECIO TYPE
ARTEMISIA
TARAXACUM TYPE
CARYOPHYLLACEAE
SPERGULA TYPE
CHENOPODIACEAE
FILIPENDULA
RUBUS
SAXIFRAGACEAE
UMBELLIFERAE
MERCURIALIS
POLYGONUM
RUMEX
P. MARITIMA
RUBIACEAE
VALERIANACEAE
CRUCIFERAE
M. ALTERNIFLORUM
POTAMOGETON
TYPHA LAT.
TYPHA ANG.
LYCOPODIUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
UNDIFF.
TAXA AXES IN 1000 GRAINS/CC UNITS
a: HV1010 : 9200 ± 200 BP
PROGRAM BY I.BRENNAN 1981

the zone from 54.0 to 15.2 grains x $10^3/cm^3$ between 390 cm. and 385 cm. Pinus, Salix, Cyperaceae, Chenopodiaceae and Filicales are present in consistent, if low, percentages. The upper boundary is placed where Coryloid concentration falls from 15.2 to 5.2 grains x $10^3/cm^3$.

Zone BY3B4   384.5 - 367.5 cm.

Gramineae pollen rises from 29.7% at 384 cm. to 49.2% at 372 cm. but fluctuates markedly from level to level. Coryloid falls more evenly from 27.6% to 14.1% between 383 cm. and 370 cm. The upper boundary is placed at a rise in Pinus pollen from 5.9% to 15.6% between 370 cm. and 365 cm.

Zone BY3B5   367.5 - 355 cm.

Gramineae, Pinus and Coryloid are the dominant taxa with Pinus recording a maximum of 23.8% at 360 cm. Salix is present in low percentages.

5.1.2.2. BY3B Diatoms

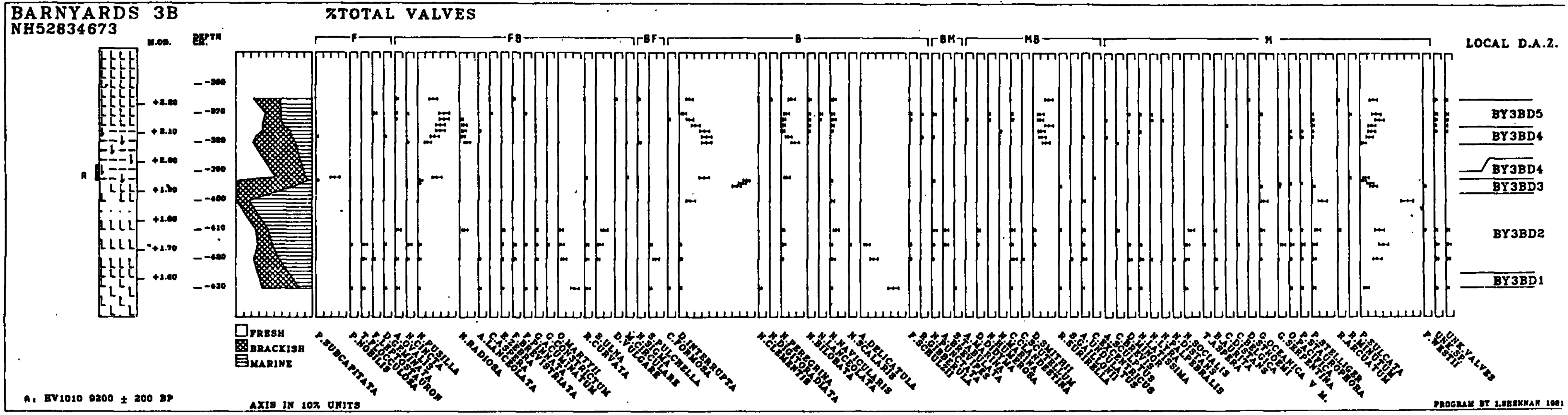
16 levels were prepared and counted for diatoms between 365 cm. and 430 cm. The sampling interval comprises 5 and 10 cm. intervals in the lower minerogenic layer, 1 cm intervals from 395 to 392 cm. and 2 cm. intervals into the upper minerogenic layer. The diagram produced (fig.5.7, see also the summary diagram fig. 5.8) was divided into six local diatom assemblage zones. Diatom counts are tabulated in Appendix II.

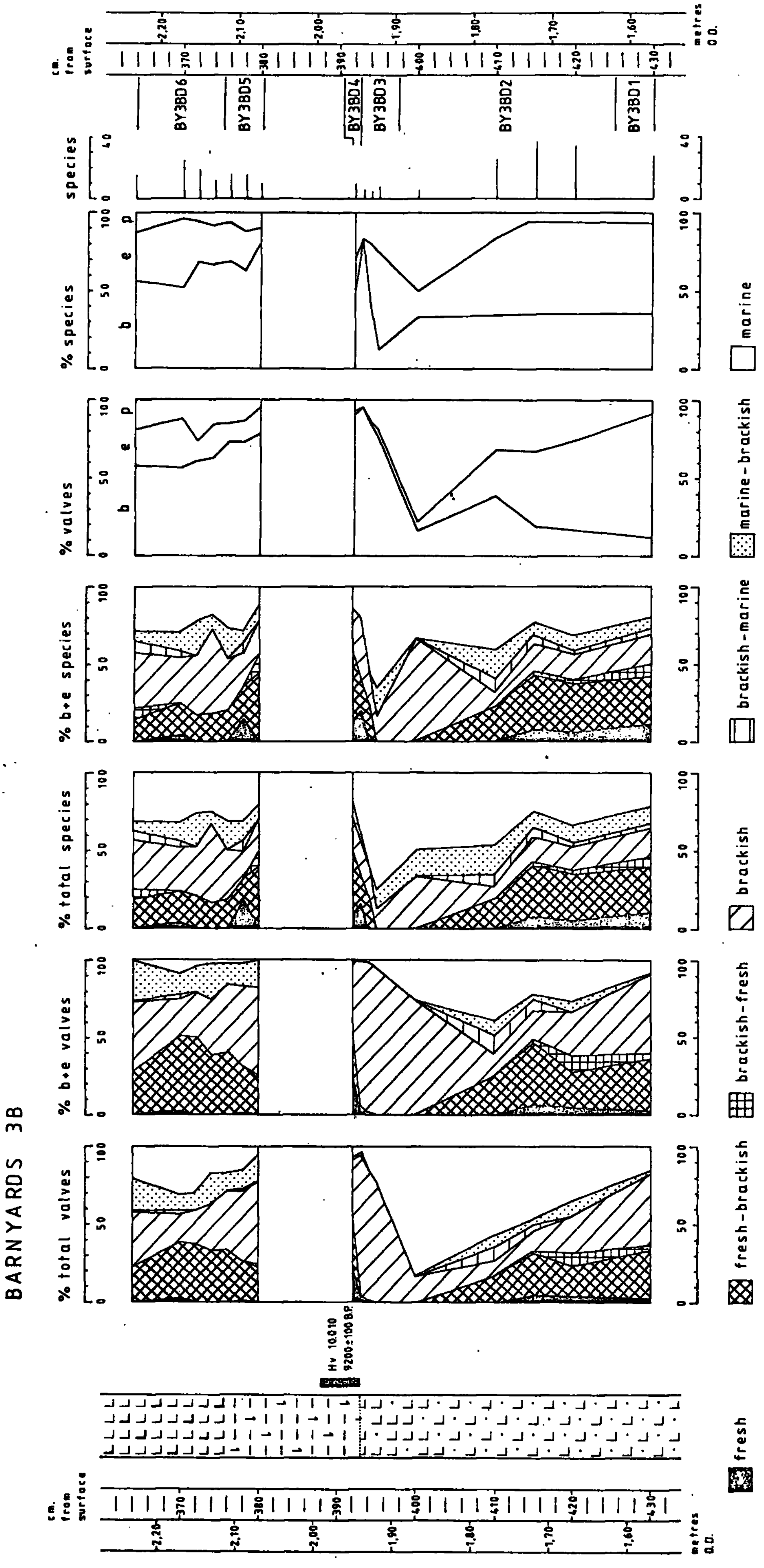
Zone BY3BD1   430 - 415 cm.

The zone comprises only one level and it is dominated by Achnanthes delicatula, 43.6% and Opephora martyii (21.5%). The upper boundary is placed at a significant fall in both these taxa and a rise is Paralia sulcata from 7.7% at 430 cm. to 22.4% at 420 cm. The zone is characterized by fresh-brackish and brackish water taxa.

Fig. 5.6 Barnyards 3B Diatoms, %Total Valves

Fig. 5.7 Barnyards 3B Diatom summary diagram


BARNYARDS 3B
NH52834673
M.OD.
DEPTH CM.
+2.20
+2.10
+2.00
+1.90
+1.80
+1.70
+1.60
-360
-370
-380
-390
-400
-410
-420
-430
A
%TOTAL VALVES
F
FB
BF
B
BM
MB
M
LOCAL D.A.Z.
BY3BD5
BY3BD4
BY3BD4
BY3BD3
BY3BD2
BY3BD1
FRESH
BRACKISH
MARINE
P.SUBCAPITATA
P.NOBILIS
T.FLOCCULOSA
F.LEPTOSTAURON
D.GEMINATA
A.OVALIS
N.CINCTA
N.PUSILLA
N.RADIOSA
A.LANCEOLATA
C.ASPERA
E.ZEBRA
F.BREVISTRIATA
P.PINNATA
G.ACUMINATUM
G.CONSTRICTUM
O.MARTYII
R.CURVATA
S.ULNA
D.VULGARE
M.CIRCULARE
N.SIGMA
S.PULCHELLA
C.FORMOSA
D.INTERRUPTA
N.CLEMENTIS
N.DIGITORADIATA
N.PEREGRINA
N.BILOBATA
N.LANCEOLATA
N.NAVICULARIS
N.SCALARIS
A.DELICATULA
F.SCHULZII
R.GIBBERULA
N.PUNCTATA
A.BREVIPES
S.TABULATA
A.MARINA
D.DIDYMA
N.HUMEROSA
N.MARINA
C.CLANDESTINA
C.SCUTELLUM
D.SMITHII
R.SURIRELLA
S.GAILLONII
A.UNDULATUS
C.EXCENTRICUS
A.SCULPTUS
C.BREVIS
D.MINOR
N.LATISSIMA
N.LYRA
N.PALPEBRALIS
N.DISTANS
N.SOCIALIS
T.ASPERA
B.AURITA
C.DISTANS
C.BELGICA
D.STROEMI
G.OCEANICA V M.
G.SERPENTINA
O.PACIFICA
P.STAUROPHORA
P.STELLIGER
R.ARCUATUM
R.MINUTUM
P.SULCATA
P.WESTII
UNK.SP.
UNK.VALVES
A: HV1010 9200 ± 200 BP
AXIS IN 10% UNITS
PROGRAM BY I.SHENNAN 1981


BARNYARDS 3B
% total valves
% b+e valves
% total species
% b+e species
% valves
% species
species
b
e
p
0
50
100
40
cm. from surface
metres O.D.
370
380
390
400
410
420
430
-2,20
-2,10
-2,00
-1,90
-1,80
-1,70
-1,60
BY3BD6
BY3BD5
BY3BD4
BY3BD3
BY3BD2
BY3BD1
Hv 10.010
9200±100 B.P.
fresh
fresh-brackish
brackish-fresh
brackish
brackish-marine
marine-brackish
marine

Zone BY3BD2 415 - 397.5 cm.

Paralia sulcata rises throughout the zone from 22.4% to 63.4% at 400 cm. Opephora martyii and Achnanthes delicatula disappear from the spectrum and Podosira stelliger increases to 13.8% at 400 cm. The zone is dominated by marine-brackish and marine taxa. The upper boundary is placed where there is a significant rise in Diploneis interrupta a brackish benthonic species from 14.5% at 400 cm. to 76.5% at 395 cm. There is also a significant fall in both P. sulcata and P. stelliger at the same level.

Zone BY3BD3 397.5 - 392.5 cm.

D. interrupta dominates the zone,characteristically brackish and low in species diversity. It reaches 89.9% of total valves at 393 cm. P.sulcata continues to fall throughout the zone and at 393 cm. the fresh and fresh-brackish taxa Pinnularia subcapitata and Navicula pusilla appear. The upper boundary is placed at a significant fall in D. interrupta from 89.9% to 32.8% and a complementary rise in P.subcapitata from 1.0% to 24.7% and N.pusilla from 3.0% to 24.7%.

Zone BY3BD4 392.5 - 392 cm.

The zone comprises only one spectrum dominated by P.subcapitata, N.pusilla and D. interrupta. Navicula peregrina also reaches 7.0%. The zone is predominantly fresh and fresh-brackish.

Zone BY3BD5 380 - 375 cm.

N. pusilla rises through the zone to 29.1% at 376 cm. though with no significant change from level to level. D. interrupta and Diploneis smithii are constant at c. 34% and c. 13% respectively while P.sulcata rises from 4.9% at 380 cm. to 15.3% at 376 cm. The zone contains taxa attributable to fresh,brackish and marine forms in the ratio of 28 : 46 : 26. Although there are no significant changes in taxa the upper boundary is located where the curve for D. interrupta falls and N. pusilla and P.sulcata rises.

Zone BY3BD6 375 - 365 cm.

N. pusilla reaches a value of 34.5% at 372 cm. and is the most abundant taxon of the zone with P. sulcata reaching 26.3% at 372 cm. D. interrupta and D. smithii are consistently present and again it is a mixed zone containing fresh, brackish and marine forms.

5.1.2.3 BY3B Particle size

Nine samples bulked from 5 cm. lengths of core were prepared for particle size determination and are shown diagrammatically in fig. 5.8. Twelve loss-on-ignition determinations were carried out below and above the peat layer and are also shown in fig. 5.8. The results of both analyses are given in Appendix III.

Particle size analysis showed a tendency for field observation using the Troels-Smith scheme to overemphasize the presence of sand. For instance between 420 cm. and 395 cm. the largest sand fraction was 10.3% at 400-405 cm. Stratum 1 however has been described as Ga 2 Ag 2 implying 50% presence of sand. Overall the particle size analysis shows the minerogenic layers to be dominated by the silt sized fraction with clay content increasing towards the regressive overlap. An interesting note is that in BY3B the qhKO or upper clastic sequence, strata 4 - 9 the equivalent of the traditionally term 'carse clays' contains only 24% clay at 365-370 cm, the remainder made up of the silt fraction.

Loss on ignition results show the lower marine deposits to be deficient in organic content, the %loss only reaching above 2% at 393-5 cm. The upper marine clastic sequence however shows a loss of 12.5% at 365-370 cm.

Fig. 5.8 Barnyards 3B Summary Diagram.

Pollen preservation curve,

A = Corroded

B = Degraded

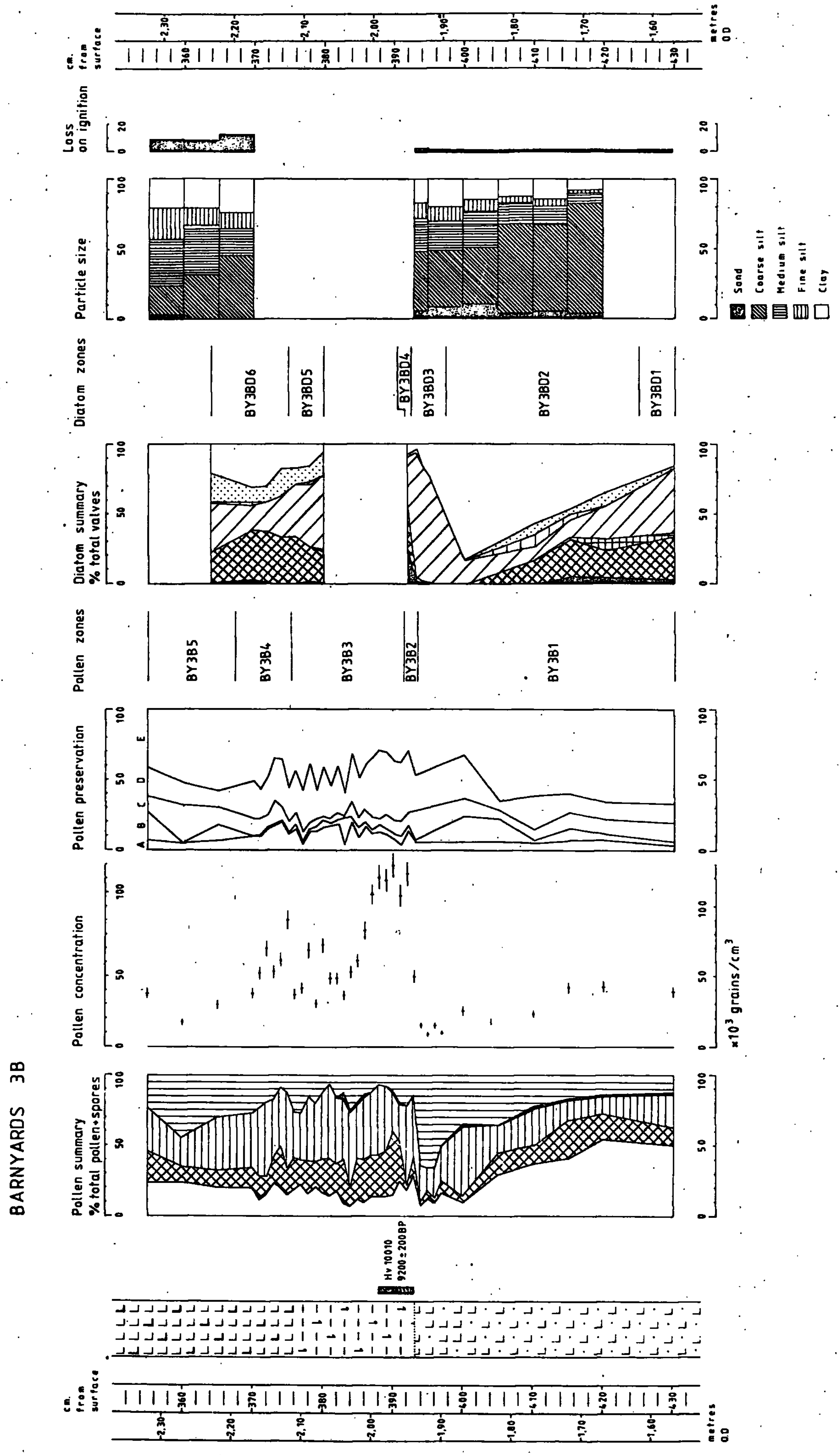
C = Broken

D = Folded

E = Well Preserved

Diatom summary curve, shading as for fig. 5.7

Pollen summary curve, shading as for fig. 5.4.


BARNYARDS 3B
cm. from surface
360
370
380
390
400
410
420
430
metres OD
2,30
2,20
2,10
2,00
1,90
1,80
1,70
1,60
Hv 10010
9200±200BP
Pollen summary
% total pollen+spores
0
50
100
Pollen concentration
x10^3 grains/cm^3
Pollen preservation
A
B
C
D
E
Pollen zones
BY3B5
BY3B4
BY3B3
BY3B2
BY3B1
Diatom summary
% total valves
Diatom zones
BY3BD6
BY3BD5
BY3BD4
BY3BD3
BY3BD2
BY3BD1
Particle size
Loss on ignition
0
20
Sand
Coarse silt
Medium silt
Fine silt
Clay

5.1.2.4 BY3B ^{14}C Dating

A 0.05 m. thick sample of Phragmites peat from the regressive overlap was submitted for ^{14}C assay. Full details are given on I.G.C.P. sea-level computer forms in Appendix IV. The most relevant data comprised however -

Lab. code		Hv. 10010
Depth	-	388 - 393 cm.
Altitude	-	1.94 - 1.99 m. O.D.
Age		9200 ± 100 B.P.

5.1.3 Barnyards 14 B

A second site was chosen at Barnyards near to the break in slope where Flandrian marine deposits wedge out. In addition the upper peat is sporadic in occurrence on the Beauly carse. At BY14B the upper peat is 51 cm. thick and the lower peat 129 cm. thick. Even though the transgressive overlap of the lower peat is clearly eroded it was felt that further analysis of the site could give information on the initiation of the 'Boreal period' regression and the culmination of Flandrian marine deposition in the area. A borehole was put down using a modified Livingstone sampler and a 48 mm. diameter core was retrieved. The stratigraphy, as described in the laboratory, comprised:-

cm.	m. O.D.	Description
0 - 48	9.74 - 10.22	Not sampled.
20. 48 - 58	9.64 - 9.74	Brown sand and gravel, small patches of iron mottling, some organic content, roots, Ga4, Gg (maj.)+ Sh+ Lf+ Ag+ Th^2+ nig. 3 strf. 0 elas. 0 sicc. 3.
19. 58 - 74	9.48 - 9.64	Mottled brown and yellow silty sand. Sand lamination at 64-65 cm. Upper boundary diffuse. Ga3 Ag1 Sh+ Lf+ nig. 2 strf. 1 elas. 0 sicc. 3 l.s.0.
18. 74 - 92	9.30 - 9.48	Brown-yellow laminated micaceous sand, siltier towards upper boundary. Small pieces of organic material, possibly charcoal. Ga4 Ag+ Lf+ Sh+ nig. 2-strf. 2 elas. 0 sicc. 3 l.s.0.

	cm.	m.O.D.	Description
17.	92 - 93 (5)	9.20 - 9.30	Yellow-grey silty clay. Small diagonal band over 1 cm. Some material reworked from peat below. As3 Ag1 Sh+ Lf+ nig. 2- strf. 3 elas. 0 sicc.3 l.s.0.
16.	93(5) - 114	9.08 - 9.29	Dark brown well humified monocot. peat with traces of sand. Upper boundary an erosion contact, diagonal and sharp over 0.5 mm. Sand lamination at 110 cm. Sh3 Th^{3}1 Ga+ nig.3 strf. 2 elas. 1 sicc. 3 l.s.4.
15.	114 - 141	8.81 - 9.08	Dark brown well humified monocot. peat with some included woody detritus. Sh2 Th^{2}2 DC+ nig. 3 strf. 1 elas. 1 sicc. 2+ l.s.0.
14.	141 - 146	8.76 - 8.81	Dark brown well humified monocot. peat. Some included silt and *Phragmites* rhizomes. Sh2 Th^2 (Phra.)1 Th^2 1 Dh+ Dl + Ag+ nig. 3 strf.2 elas. 1 sicc. 2 l.s.0.
	146 - 158	8.46 - 8.76	Not sampled.
13.	158 - 183	8.39 - 8.64	Mid grey organic clayey silt with herbaceous detritus. Dark banding of totally humified organic material (or perhaps FeS?) Upper boundary not sampled. Ag2 As1 Dh1 Sh+ nig. 2 strf.2 elas. 0 sicc.2+ l.s.0.
12.	183 - 199	8.23 - 8.39	Mid grey organic clayey silt with included herbaceous detritus and traces of micaceous sand. Coarse silt / fine sand lamination 2 mm. thick overlain by thin band of totally humified organic material at 191 cm. Ag2 As2 Sh+ Dh+ Ga+ nig. 2 strf. 2 elas. 0 sicc.2+ l.s.0.
11.	199 - 222	8.00 - 8.23	Light grey micaceous silty sand with included herbaceous detritus. Upper boundary diffuse Ga3 Ag1 As+ Dh+ nig.2 strf. 1 elas. 0 sicc.3- l.s.0.
10.	222 - 234	7.88 - 8.00	Light grey micaceous sand and gravel. Some included herbaceous detritus. One piece of coarse gravel 55 x 40 x 26mm. resting unconformably on peat surface. Ga3 Gg (maj.)1 As+ Dh+ nig.2 strf.1 elas. 0 sicc.3 l.s.0.
9.	234- 286	7.36 - 7.88	Dark brown well humified monocot. peat. Upper boundary an erosion contact. Sh3 Th^{2}1 nig.3+ strf. 0 elas. 1 sicc.3 l.s.4.

	cm.	m.O.D.	Description
8.	286 - 346	6.76 - 7.36	Dark brown well humified monocot. peat with woody detritus. Upper boundary diffuse. Sh2 Th^{2}1 Dl1 nig.3+ strf.0. elas 1. sicc. 3 l.s.0.
	346 - 352	6.70 - 6.76	Not sampled.
8.	352 - 354	6.68 - 6.70	As 286 - 346.
7.	354 - 363	6.59 - 6.68	Dark brown well humified monocot. peat. Upper boundary diffuse. Sh3 Th^{2}1 Dl+ nig.3 strf.0 elas.1 sicc.2+ l.s.0.
6.	363 - 375	6.47 - 6.59	Light grey silty clay with traces of included herbaceous detritus. Upper boundary sharp over 1 cm. As 3Ag1 Dh+ nig.1+ strf.2 elas. 0. sicc.2+ l.s.1.
5.	375 - 382	6.40 - 6.47	Intermixed peat and silty clay. Has the appearance of reworked material. Sh2 Th^{2}1 As1 Ag+ nig.3- strf.0 elas. 1 sicc.2+ l.s.0.
4.	382 - 446	5.76 - 6.40	Light grey sticky clayey silt, Upper boundary diffuse. Ag3 As1 nig.2- strf. 2 elas.0 sicc.2+ l.s.0.
3.	446 - 463	5.59 - 5.76	Light grey sand and fine gravel. Gravel subrounded → subangular. Ga3 Gg (maj.)1 nig.2- strf.0. elas.0 sicc.2 l.s.0.
2.	463 - 483	5.39 - 5.59	Light grey sand and traces of fine gravel. Upper boundary diffuse. Ga4 Gg(maj.)+ nig.2- strf. 0 elas.0 sicc. 2 l.s.0.
1.	483 - 538	4.84 - 5.39	Pink sand and gravel, including quartz. Coarse gravel 40 x 25 x 20 mm. at 502-504 mm. Ga3 Gg(maj.)1 nig.2 strf.0. elas.0 sicc.2 l.s.0.

5.1.3.1 BY14B Pollen

36 levels were counted for pollen between 525 and 80 cm. 3 levels, 525, 485 and 445 cm. contained virtually no pollen. The pollen diagrams (figs. 5.9, 5.10) and summary diagram (fig.5.11) have been divided into 10 local pollen assemblage zones numbered from the base upwards. Because of a low pollen count, the spectrum counted at 405 cm. has not been included in the zonation scheme. On the pollen diagrams (fig.5.9,5.10) Corylus should read Coryloid.

Zone BY14B1   380 - 362.5 cm.

Coryloid, Gramineae, Cyperaceae and Betula are the most abundant taxa though each fluctuates throughout the zone. Total pollen concentration is low at c. 27 x 10^3 grains / cm^3 for the zone. The upper boundary is placed at a significant increase in total concentration to 45.0 grains x $10^3/cm^3$ at 362 cm. Although most taxa show change through the zone boundary, none is significant at the 95% level.

Zone BY14B2   362.5 - 335 cm.

The pollen of Cyperaceae, Gramineae and Betula are the most abundant taxa. Cyperaceae reaches 31.1% at 355 cm. but fluctuates above and below this level. Gramineae remains constant at c.20% throughout the zone. Juniperus reaches a maximum of 19.0% at 360 cm. but falls to 3.9% at the boundary which is placed at a significant increase in Betula from 3.9% at 340 cm. to 38.7% at 330 cm. and a similar increase in concentration from 1.7 to 29.8 grains x $10^3/cm^3$. Cyperaceae falls from 20.9% to 9.2% and Gramineae from 13.1% to 4.2%.

Zone BY14B3   335 - 305 cm.

Coryloid and Betula dominate the zone. Coryloid pollen rises from 17.6% to 31.8% through the zone while Gramineae and Cyperaceae do not occur above 10%. Total concentration fluctuates from 77 to 11.4 to 63.3 grains x $10^3/cm^3$. The upper boundary is located where there is a significant fall in the Betula curve from 24.8% to 3.3% and a complementary rise in Coryloid from 31.8% to 61.7%.

Zone BY14B4   305 - 246 cm.

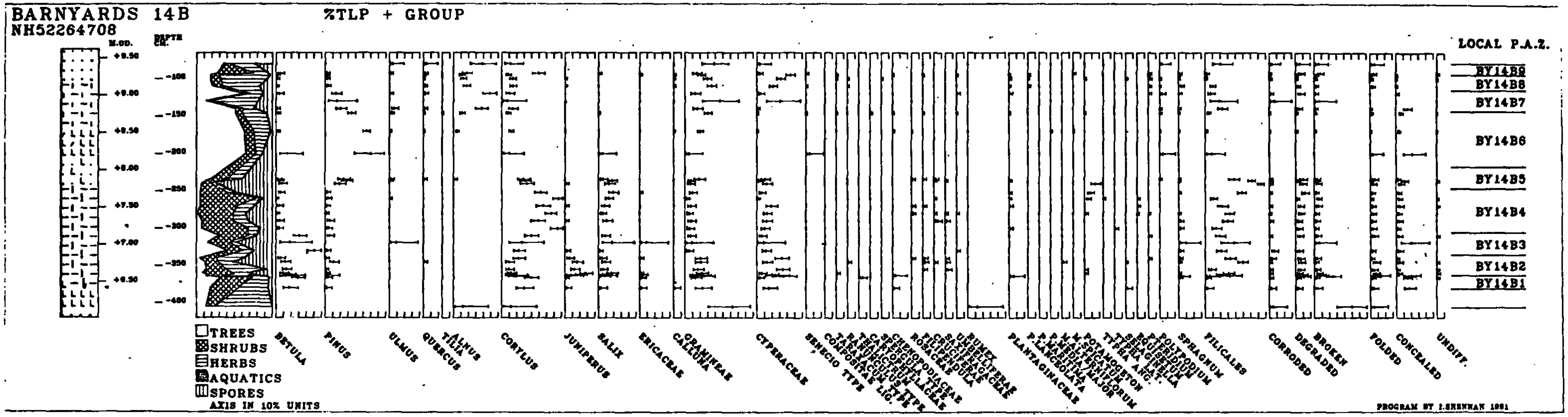
The zone is characterized by high frequencies of the pollen of Coryloid (c.33-63%). Betula declines and does not rise over 4%. Gramineae, Cyperaceae and Salix are present in small percentages. The upper boundary

Fig. 5.9 Barnyards 14B, %TLP + Group

N.B. Corylus should read Coryloid

Fig. 5.10 Barnyards 14B, Pollen concentration.

Horizontal scale should read 'Taxa Axes in 10 x 10^3 grains/cm^3units'.


BARNYARDS 14B
NH52264708
%TLP + GROUP
M.OD.
+9.50
+9.00
+8.50
+8.00
+7.50
+7.00
+6.50
DEPTH CM.
-100
-150
-200
-250
-300
-350
-400
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
CORYLUS
JUNIPERUS
SALIX
ERICACEAE
CALLUNA
GRAMINEAE
CYPERACEAE
SENECIO TYPE
COMPOSITAE LIG.
TARAXACUM TYPE
RANUNCULUS TYPE
THALICTRUM
CARYOPHYLLACEAE
SPERGULA TYPE
CHENOPODIACEAE
ROSACEAE
FILIPENDULA
CRUCIFERAE
SAXIFRAGACEAE
UMBELLIFERAE
RUMEX
PLANTAGINACEAE
P.LANCEOLATA
P.MARITIMA
P.MEDIA/MAJOR
M.ALTERNIFLORUM
M.SPICATUM
POTAMOGETON
TYPHA ANG.
TYPHA LAT.
SELAGINELLA
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
CONCEALED
UNDIFF.
LOCAL P.A.Z.
BY14B9
BY14B8
BY14B7
BY14B6
BY14B5
BY14B4
BY14B3
BY14B2
BY14B1
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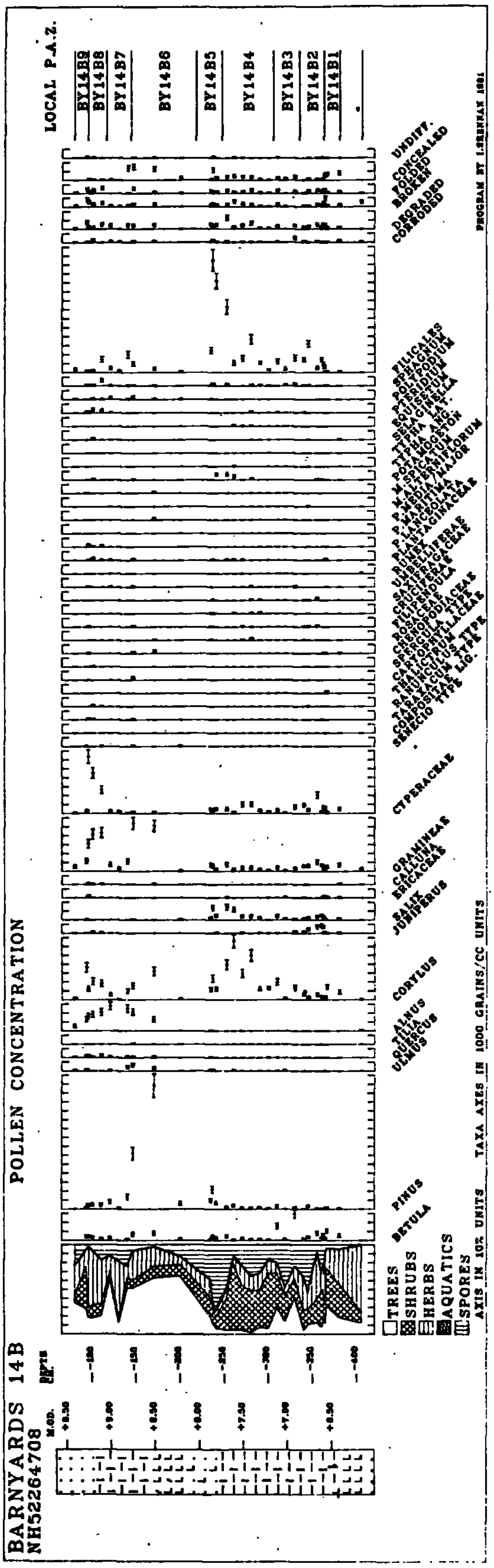
BARNYARDS 14B
NH52264708
M.OD.
+9.50
+9.00
+8.50
+8.00
+7.50
+7.00
+6.50
DEPTH CM.
100
150
200
250
300
350
400
POLLEN CONCENTRATION
LOCAL P.A.Z.
BY14B9
BY14B8
BY14B7
BY14B6
BY14B5
BY14B4
BY14B3
BY14B2
BY14B1
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
TAXA AXES IN 1000 GRAINS/CC UNITS
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
CORYLUS
JUNIPERUS
SALIX
ERICACEAE
CALLUNA
GRAMINEAE
CYPERACEAE
SENECIO TYPE
COMPOSITAE LIG.
TARAXACUM TYPE
RANUNCULUS TYPE
THALICTRUM
CARYOPHYLLACEAE
SPERGULA TYPE
CHENOPODIACEAE
ROSACEAE
FILIPENDULA
CRUCIFERAE
SAXIFRAGACEAE
UMBELLIFERAE
RUMEX
PLANTAGINACEAE
P.LANCEOLATA
P.MARITIMA
P.MEDIA/MAJOR
M.ALTERNIFLORUM
M.SPICATUM
POTAMOGETON
TYPHA ANG.
TYPHA LAT.
SELAGINELLA
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
CONCEALED
UNDIFF.
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is located at a level where there is a significant decline in Coryloid pollen from 25.3% to 8.5%, at a significant rise in Filicales from 46.5% to 70.8% and 72.7 to 101.7 grains x $10^3/cm^3$ between 252 and 240 cm. The limit also records the rational limit of the Pinus curve where it rises from 1.4 to 4.7%.

Zone BY14B5 246 - 217 cm.

Filicales, Coryloid and Pinus are the main components of the pollen spectra with Filicales declining from 70.8% to 38.1% between 240 cm. and 234 cm. Pinus rises from 4.7% to 14.9% over the same interval and the Coryloid curve remains constant at c.15%. Pollen concentration reaches a maximum for the zone of 202.4 grains x 10^3 $/cm^3$ at 236 cm. of which Filicales represents 124.8 grains x $10^3/cm^3$. Gramineae, Cyperaceae, Betula and Salix are present in low percentages. The upper boundary is placed where a significant rise in Pinus occurs from 14.9% to 52.2%. Filicales falls from 38.1% to 8.7% and the Cyperaceae curve disappears.

Zone BY14B6 217 - 143 cm.

Pinus reaches a maximum of 53.2% and 138.3 grains x $10^3/cm^3$ at 170 cm. Gramineae rises from 4.3 to 28.3% through the zone and the Coryloid curve remains constant at c.10%. The empirical limit of Alnus occurs within the zone at 170 cm. The upper limit is placed where there is a significant rise in Alnus and Filicales and with a significant fall in the Pinus curve.

Zone BY14B7 143 - 115 cm.

The pollen of Pinus and Alnus dominate the zone with Pinus declining throughout to 12.3% at 120 cm. Alnus however reaches a maximum of 42.6% at 120 cm, its disappearance at 130 cm. may be seen as an artefact of a low count. The Gramineae curve reaches a peak of 37.5% at 130 cm. and Cyperaceae reappears as a continuous curve. The empirical limit of

Quercus lies in the zone at 120 cm. The upper boundary is located where there is a significant fall in Pinus and Alnus and a significant rise in Gramineae and Cyperaceae.

Zone BY14B8 115 - 94 cm.

Gramineae reaches 29.3% at 110 cm. and falls to 20.8% at 95 cm. while Cyperaceae rises in the same interval from 17.9% to 43.5%. The Alnus and Coryloid curves are constant at c.12.5% and c.10% respectively. Total pollen concentration is high reaching 151.9 grains x $10^3/cm^3$ at 100 cm. The upper limit of the zone is located at a significant rise in the Coryloid curve from 8.6% to 46.9% and a fall in Cyperaceae from 43.5% to 3.5%. Total pollen concentration also falls to 77.6 grains x $10^3/cm^3$.

Zone BY14B9 94 - 80 cm.

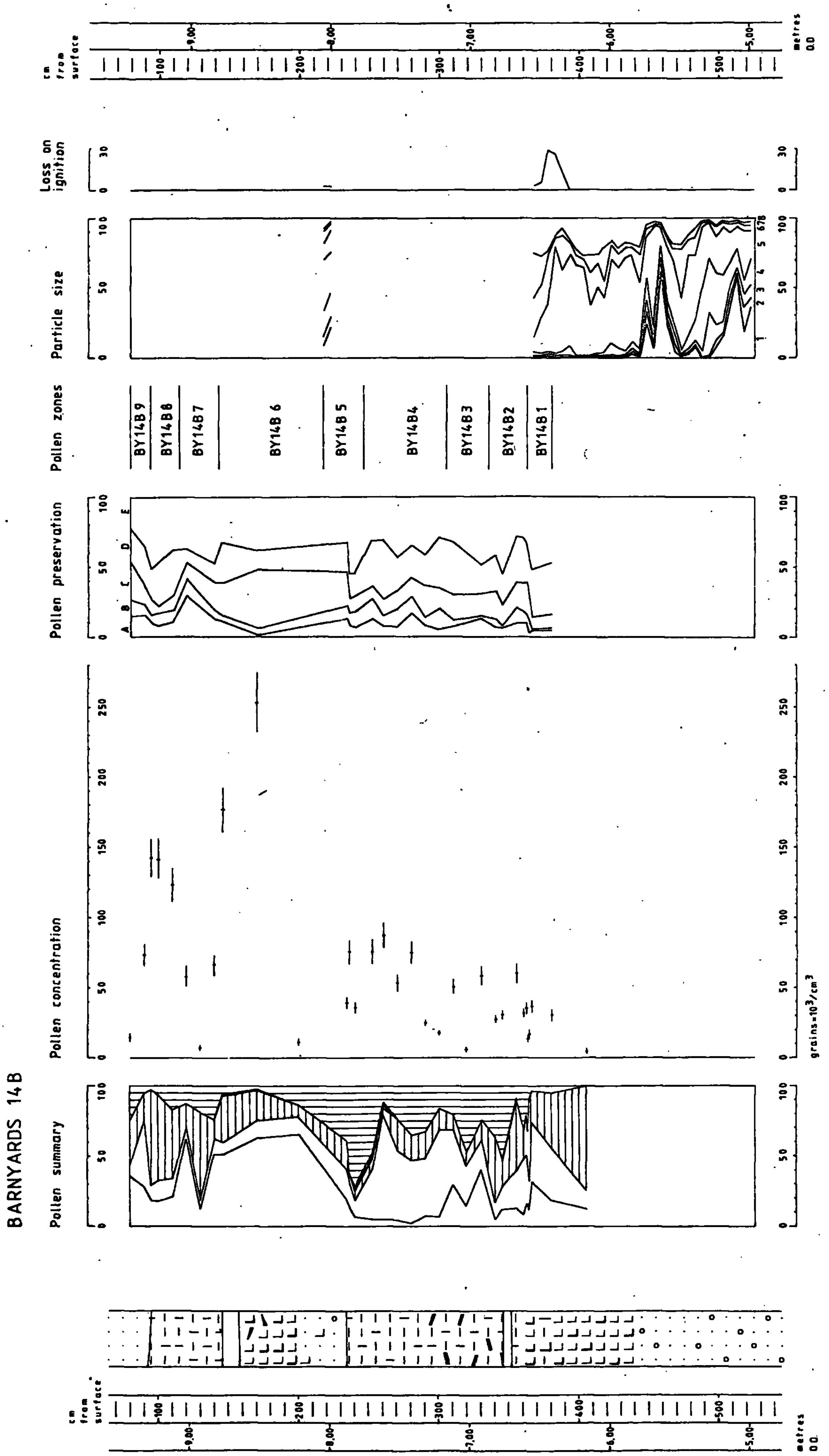
The pollen of Alnus, Coryloid and Gramineae dominate the zone with Alnus reaching 29.4% at 80 cm. and Coryloid 46.9% at 93 cm. Concentration values are low however with the total concentration at 80 cm. only 18.4 grains x $10^3/cm^3$.

5.1.3.2 BY14B Diatoms

14 samples from above and below the lower peat were prepared for diatom analysis. All those beneath the lower peat at 364, 370, 390, 410, 430, 450, 470, 490, 510 and 530 cm. contained no diatoms or fragments of diatoms. Similarly two samples above the the lower peat at 220 cm. and 230 cm. contained neither entire valves nor fragments of diatoms. At 160 cm. however the systematic traversing of the slide revealed only one diatom attributable to c.f. Asterionella formosa, a fresh-brackish water epiphyte, and at 234 cm. a similar procedure revealed only one valve attributable to c.f. Fragilaria lapponica, a fresh-water epiphyte. No further diatom analysis was carried out.

Fig. 5.11 Barnyards 14B, Summary Diagram.

Pollen summary curve shading as for fig. 5.8. Pollen preservation curve notation as for fig.5.8. Particle size summary 1 - Gravel, 2 - Coarse sand, 3 - Medium sand, 4 - Fine sand, 5 - Coarse silt, 6 - Medium silt, 7 - Fine silt, 8 - Clay.


BARNYARDS 14B
Pollen summary
Pollen concentration
grains×10³/cm³
Pollen preservation
A B C D E
Pollen zones
BY14B9
BY14B8
BY14B7
BY14B 6
BY14B 5
BY14B4
BY14B3
BY14B2
BY14B1
Particle size
1 2 3 4 5 678
Loss on ignition
cm from surface
metres 0.0
100
200
300
400
500
9.00
8.00
7.00
6.00
5.00
0
50
100
150
200
250
30

5.1.3.3 BY14B Particle size and loss on ignition

34 samples each usually bulked from 5 cm. lengths of core between 525 cm. to 365 cm. and 230 cm. to 220 cm. were prepared for particle size determination and are shown in fig.5.11. The results are tabulated in Appendix III.

Strata 1 to 3, 538 cm. to 446 cm. are predominantly sand and gravel though with a peak in the silt fraction between 460 cm. and 490 cm. Above 446 cm. strata 3 to 6 show a markedly different particle size distribution comprising the coarse silt to clay fraction. Stratum 5 has the appearance of an intermixed minerogenic and biogenic deposit, most probably a peat ball. Peat balls are more often found in association with transgressive overlaps, as at M4B though perhaps a renewed period of downcutting during a regressive phase may erode and rework peat growing on a recently abandoned surface elsewhere in the vicinity. Loss on ignition determinations for this stratum reach 28.5% between 375 cm. and 380 cm. Below 385 cm. the organic content is low, never exceeding 1% and above the 'peat ball' values fall again. Indeed the sample directly beneath the regressive overlap of the lower peat has only 3.29% organic content even though the medium and fine silt and clay fraction comprise 71% of the deposit.

Only two samples were analysed directly above the lower peat at 220-225 cm. and 225-230 cm. The particle size analyses show the gravel and fine sand fractions represent 70% to 75% of the deposit confirming the lack of a transition zone and the erosive nature of the transgressive overlap in this borehole. Organic content only reaches 2.25% and 2.19%

5.1.3.4 BY14B ^{14}C Dating

Two samples were submitted from BY14B to the University of Birmingham, Department of Geological Sciences for ^{14}C assay and the results are expected in November or December 1981. The stratigraphic relations of the samples are shown in fig. 5.2 and full details are given on I.G.C.P. sea-level comupter forms in Appendix IV. The more important data comprises -

Depth	-	141 - 146 cm.	358 - 363 cm.
Altitude	-	8.76 - 8.81 m.O.D.	6.59 - 6.64 m.O.D.
Thickness	-	0.05 m.	0.05 m.
Components	-	Sh2 Th^2(Phra.)1 $Th^2$1	Sh3 $Th^2$1 Dl+

The first sample 141-146 cm. was submitted to date the regressive overlap of the upper peat. The exact boundary was not sampled since 146 to 158 cm. was not retrieved in the core. The date may not be too much in error since the lowermost pollen spectrum in the upper peat at 146 cm. shows the presence of Chenopodiaceae and the stratigraphy has inclusions of silt and Phragmites rhizones.

The second sample submitted from 358 - 363 cm. is on the regressive overlap of the lower peat. Although no diatoms are present in the lower minerogenic layers and pollen preservation is bad, it is considered that at least strata 4 to 6 relate to a marine event since the characteristic fining upwards of grain size, presence of a peat ball and Chenopodiaceae pollen mitigate against a terrestrial origin.

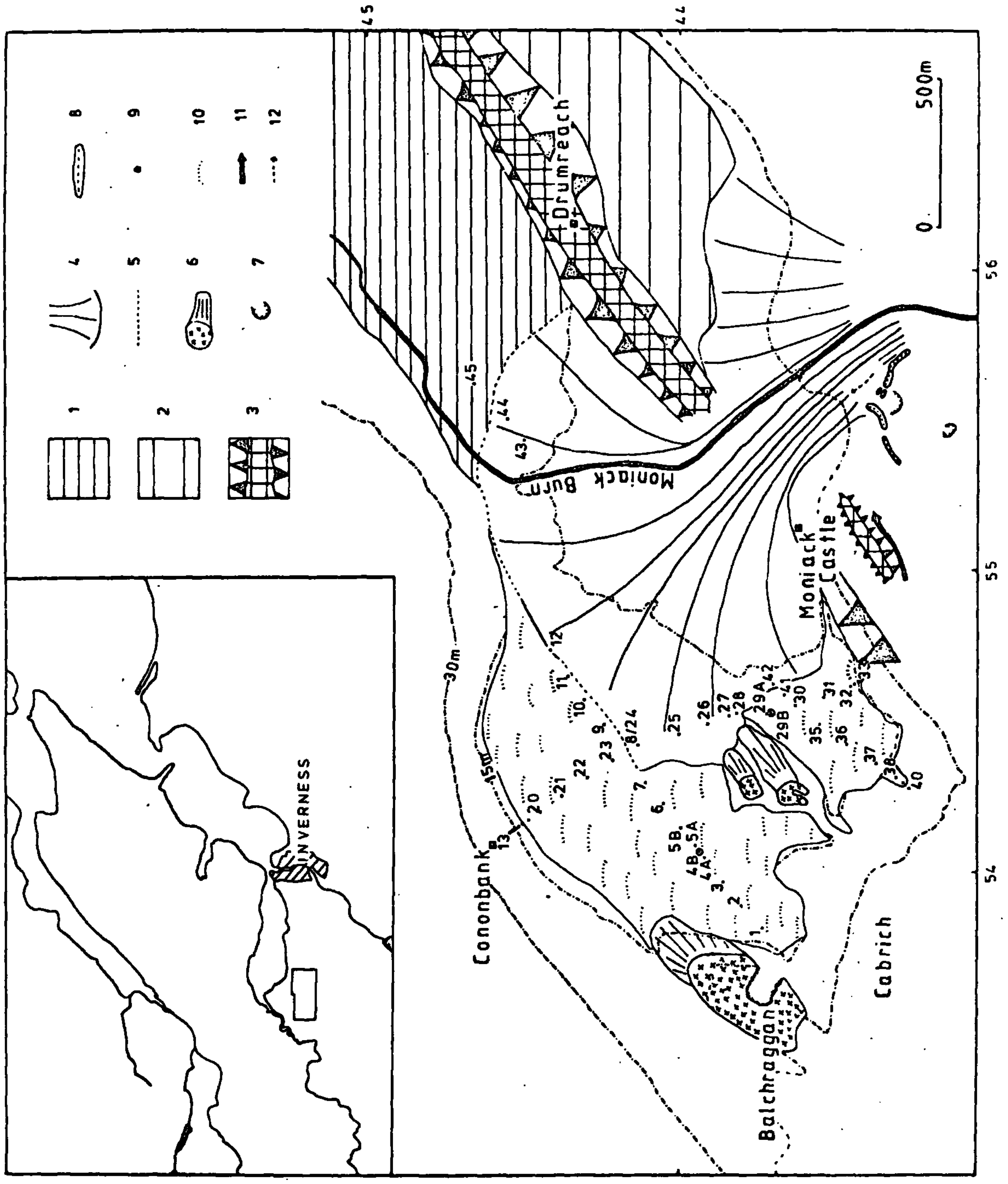
5.2 Moniack

The Moniack site is located to the south-east of the Kirkhill ridge 2 km. south-west of Kirkhill itself. Field mapping at a scale of 1 : 10,000 enabled the construction of fig. 5.12.

The most impressive morphological feature in the area is the large alluvial fan deposited by the Moniack Burn which falls from 41 m. south of Reelig House to 12 m. at the locality of borehole M12 and covers an area of approximately 1.1 km^2. 500 m. to the south-east of Moniack Castle there are a series of esker ridges and dead-ice hollows. The eastern esker is

Fig. 5.12 Moniack site map, showing location of boreholes

1. Beauly carse
2. Undifferentiated Late Devensian marine? deposits
3. Fluvioglacial ridge
4. Alluvial fan
5. Boundary of alluvial fan uncertain
6. Crag and tail features
7. Dead-ice hollows
8. Eskers
9. Sampling site
10. Surface peat
11. Meltwater channel
12. Small channel forms


1
2
3
4
5
6
7
8
9
10
11
12
INVERNESS
Drumreach
Moniack Burn
Moniack Castle
Cononbank
Balchraggan
Cabrich
30m
15m
0
500m
54
55
56
44
45
1
2
3
4A
4B
5A
5B
6
7
8/24
9
10
11
12
13
20
21
22
23
25
26
27
28
29A
29B
30
31
32
33
35
36
37
38
40
41
42
43
44
45

180 m. long and 10 m. high, its north-east side having been cut and sharpened by subsequent erosion of the Moniack burn. Two small exposures prove the fan to be composed predominantly of sand with some subrounded gravel and cobbles. The system can be traced south-westwards discontinuously for 250 m. to Knockbain Farm where a larger exposure confirms a composition of sand with some gravel.

Above Milifiach there is a linear ridge trending SW-NE which may be the continuation of the much larger ridge which runs from Easter Moniack through Drumreach to Drumchardine. Ogilvie (1923, 393) described this impressive linear ridge 1.5 km. long and 25-27 m. O.D. as a kame or drumlin "flattened by surf". One small exposure on the north-western side of the feature was recorded as showing a brown sandy till. To the east of the linear ridge and bounded by it is a depression which Ogilvie considers a drained lake. The fact that the Moniack fan terminates at the depression in a marked break slope does suggest a water body causing subsequent erosion.

To the west of the Moniack fan is an area of surface peat approximately 0.8 km^2 in extent divided into two separate basin forms by the eastern of two imposing crag and tail features. The western crag rises 40m. to reach 60 m.O.D. and sections in Balchraggan Quarry show it to be composed of a complex series of schists. The eastern crag is a smaller, more complex double feature rising 25 m. to 38 m.O.D. - here the schists contain intrusions of pegmatite.

5.2.1 Moniack stratigraphy

47 boreholes were put down, 44 in the two basins to the west of the Moniack fan and 3 to the east. Ogilvie (1923) suggested that:-

> "it is doubtful if the sea at the 25 to 30 ft. level passed the Moniack fan" (p.393)

yet the results, figs. 5.13, 5.14, 5.15 and 5.16 show a complex stratigraphic sequence of glacial and marine clastic, terrestrial organic and terrestrial clastic units, which suggests marine penetration to 10 m. O.D. in M1.

For ease of description the two sub-basins will be treated separately, the north-western one, less affected by the Moniack fan will be considered first.

Boreholes M1 to 12 and M19 to 25 (figs.5.13 and 5.14) show essentially a Y3 profile type with a lower clastic sequence, intercalated peat layer and upper clastic sequence overlain by an organic cover sequence. Problems are caused however by the intercalation of alluvial fan material in M6, 7, 8/24, 10, 11, 12, 25, 26 and 27. The correlation lines between boreholes should therefore only be seen as a preliminary attempt.

The basal clastic sequence in M5A, 9, 12, 20 and 25 usually consists of a grey silty sand, 31 cm. thick at M5A or a grey sand and rounded gravel, 168 cm. thick at M9. Above this coarser unit there is a finer facies of grey silty clay or clay silt, for example 30 cm. thick at M9. This may well correlate with the latter two stages in the internal variation found within the lower clastic sequence noted at Barnyards (finer → coarser → finer at BY13B) and elsewhere at Moniack (e.g. M36, fig. 5.15).

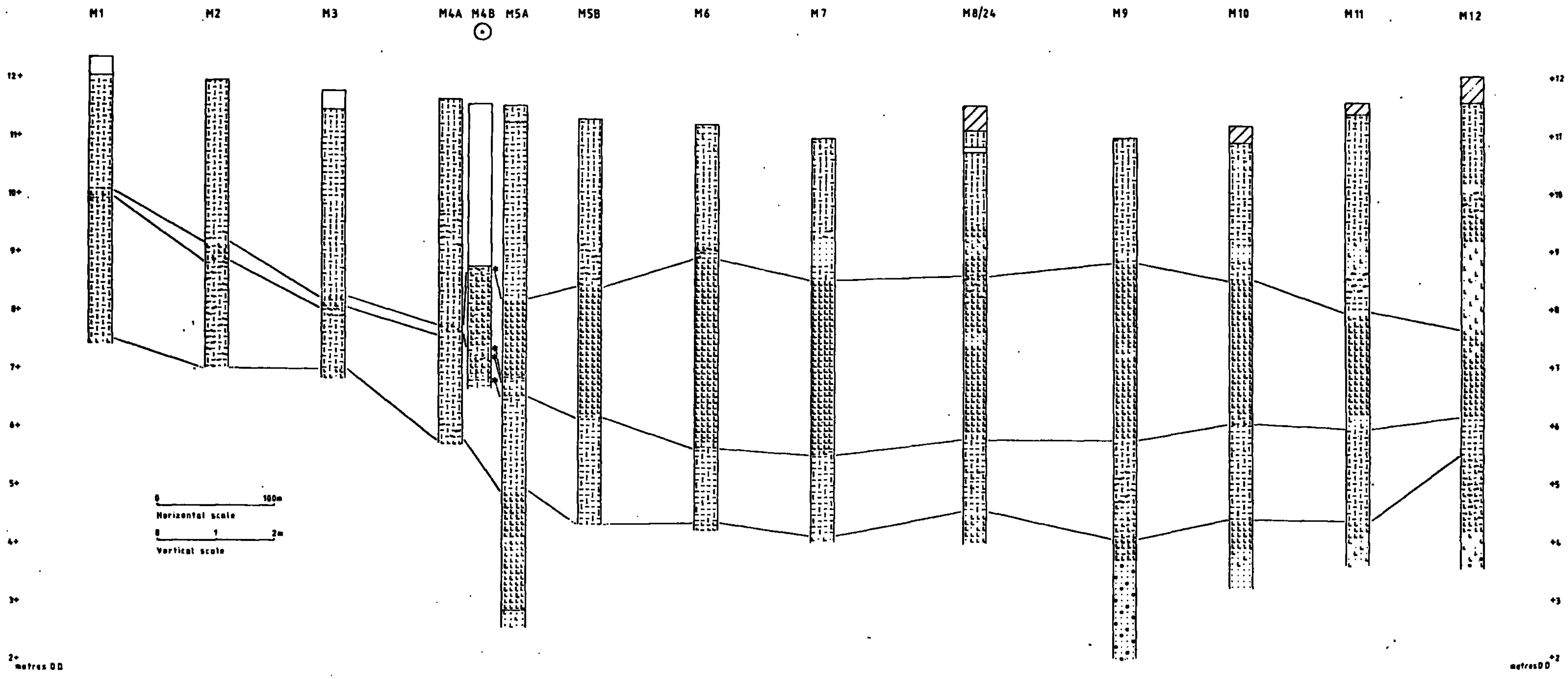
Above the lower clastic sequence is a widespread intercalated peat layer present in all boreholes save for M16, 17, 18, 26, 27 and 28. The lower, regressive contact shows a gradual slope seawards from 7.48 m.O.D. at M1 to 4.33 m. at M9, a distance of 0.88 km. although this masks marked undulations in the contact. The peat layer itself shows marked variation though probably more in response to local conditions than an overall regional ecological gradient. At M20 there is a basal layer of yellow-brown well humified bryophyte peat perhaps reflecting enhanced groundwater levels at the foot of a slope, At M 8/24 and M9 a small depression in the sub-peat surface suggests the possibility of organic deposition in a small basin form. Indeed within the peat at M8/24 there are two thin layers of

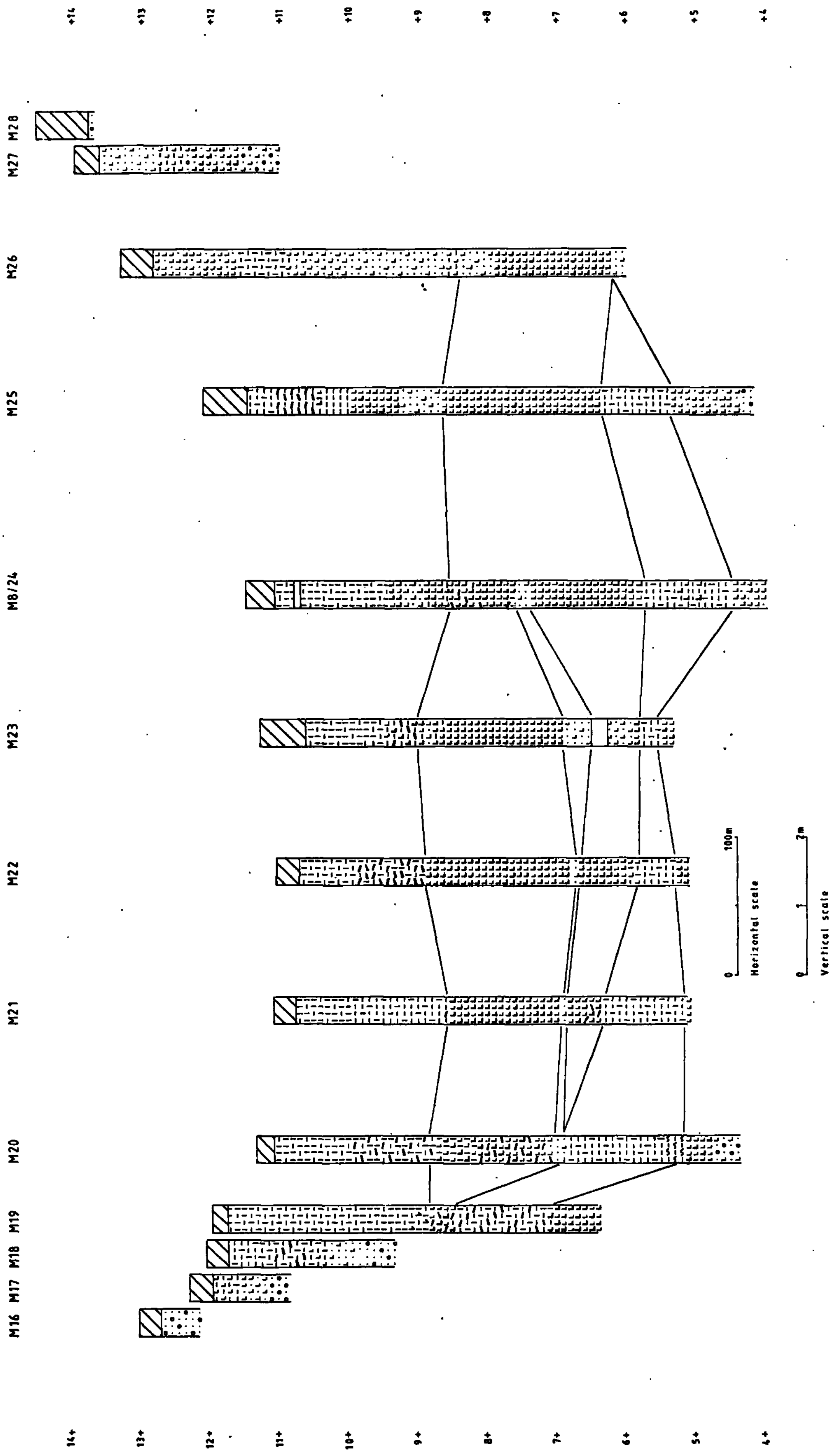
Fig. 5.13 Moniack stratigraphy, M1 - M12

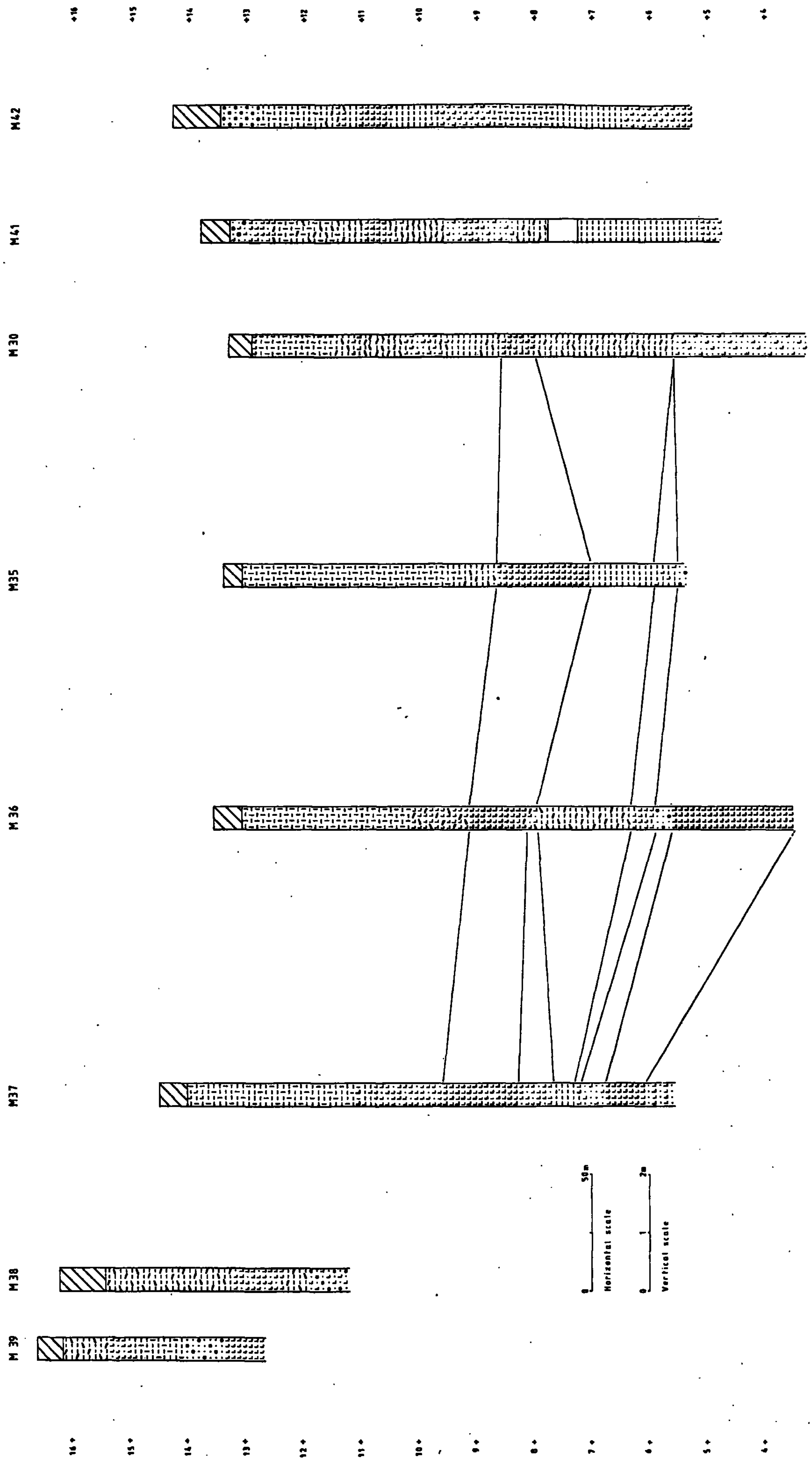
Fig. 5.14 Moniack stratigraphy, M16 - M28

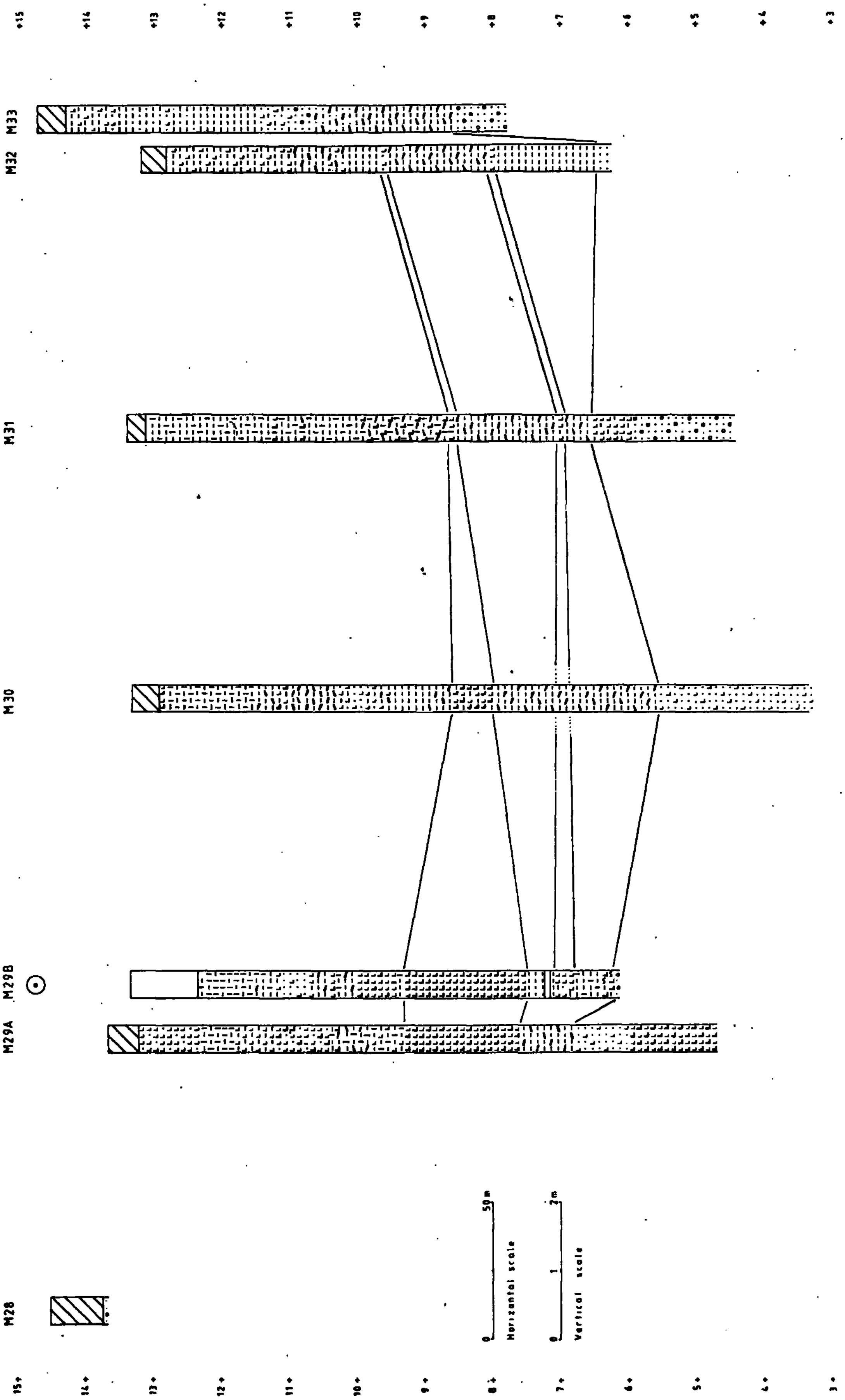
Fig. 5.15 Moniack stratigraphy, M39 - M42

Fig. 5.16 Moniack stratigraphy, M28 - M33


M1
M2
M3
M4A
M4B
M5A
M5B
M6
M7
M8/24
M9
M10
M11
M12
12+
11+
10+
9+
8+
7+
6+
5+
4+
3+
2+
metres OD
+12
+11
+10
+9
+8
+7
+6
+5
+4
+3
+2
metres OD
0
100m
Horizontal scale
0
1
2m
Vertical scale


M28
M27
M26
M25
M8/24
M23
M22
M21
M20
M19
M18
M17
M16
+14
+13
+12
+11
+10
+9
+8
+7
+6
+5
+4
0
100m
Horizontal scale
0
1
2m
Vertical scale


M42
M41
M30
M35
M36
M37
M38
M39
+16
+15
+14
+13
+12
+11
+10
+9
+8
+7
+6
+5
+4
0
50m
Horizontal scale
0
1
2m
Vertical scale


M33
M32
M31
M30
M29B
M29A
M28
+15
+14
+13
+12
+11
+10
+9
+8
+7
+6
+5
+4
+3
15+
14+
13+
12+
11+
10+
9+
8+
7+
6+
5+
4+
3+
0
50 m
Horizontal scale
0
1
2 m
Vertical scale

light brown organic silt, the result of deposition in a small water body at this location. They are present also in M23 but are too thin to be shown in fig.5.14. Woody detrital peat at M2 and M19 and M20 suggest more wooded habitats on the slopes surrounding the basin, supporting the idea of considerable lateral variation in habitat during the time of lower peat formation.

The transgressive contact of the lower peat falls from 9.95 m. at M1 to 5.53 m. at M7 though from M7 to M12 it rises again to 6.13 m. A simple least-squares linear regression was performed on the altitudes of the transgressive and regressive contacts in 12 boreholes with distance from a point 10 m. south-west of M1 as the independent variable. The regression equations were:-

$TC = 8.80 + - 0.00392\ D \qquad r = -0.85 \qquad n = 12$

$RC = 6.91 + - 0.00330\ D \qquad r = -0.86 \qquad n = 12$

and the solution for T = R, the point at which biogenic accumulation ceases was -3.19 m. O.D. at a distance of 3.049 km. seaward from M1. However, Moniack is a semi-enclosed site and the constriction afforded by the Moniack fan serves to decrease the overall gradients of the contacts. Indeed the seaward gradient for both overlaps is roughly half that for Barnyards, a more exposed site.

Above the lower intercalated peat layer is a single clastic sequence of blue-grey silty clays in boreholes M5B to M12 and M19 to M26. There is variation within this clastic sequence similar to that found at Barnyards. In M20, 21, 22, 23 and perhaps M8/24 (fig. 5.14) a prominent silty sand layer is recorded between 6.95 m. (M20) and 7.61 m.(M8/24). In the M1-12 transect (fig. 5.13) the altitudinal variation in the silty sand unit is greater and it is not knownif such coarser layers in M4B, M5A, M8/24, M9 and M11 relate to the same event.

In borehole M20 the silty sand unit provides an erosive contact with the lower peat. However, boreholes M4B and M5A form a Y3, 4 profile type with two interfingering clastic units separated by a thin peat layer. In both these boreholes the lower of these clastic deposits comprises the lateral equivalent of the silty sand unit found in M 20-24 above. The thin (c.16 cm.) interfingering 'middle peat' present is comprised of Phragmites rhizomes with other monocotyledonous rootlets in a matrix of totally humified material. Above the peat layer the blue-grey silty clay unit is present through M1 to M4A forming an upper clastic sequence in these Y3, 3 profile types. Made ground at Balchraggan Quarry (fig.5.12) denied the possibility of recording a Z type profile landward of M1.

Above the blue-grey silty clay unit is a widespread thick, peat layer. In boreholes M1 to M5B and M19 to M22 it forms an organic cover sequence (qhoD) and these boreholes exhibit Y3, 3 and Y3, 4 profile types. In boreholes nearer to the alluvial fan, from M6 to M12 and M23 to M27 clastic units of non-marine origin provide interfingering sequences within the upper peat. The transition from the underlying blue silty clay to the upper peat is gradual, over c. 50 cm. Woody detrital peats occur within the layer in boreholes M1, M2, M4A, M5B, M20 and M21. The maximum thickness is 355 cm. at M3.

Boreholes M6 to M12 and M23 to M27 are greatly affected by the intercalation of terrestrial clastic material which interfingers with organic units generally at altitudes above the marine blue-grey silty clay sequence. In M6, M7, M23 and M8/24 there is only one interfingering clastic sequence and these boreholes exhibit Y3, 6 type profiles. In M10, M12, M25 and M26 however there are two and these boreholes represent Y3, 7 and Y3, 9 profiles. In M12 and M25 the lower of the two terrestrial clastic layers, a grey-blue silty sand has completely eroded the peat layer that usually rests above the blue-grey silty clay sequence. Taken together, the evidence of intercalation of terrestrial alluvial fan material in the upper parts of many boreholes suggests renewed fluvial activity at or slightly after the culmination of the blue-grey silty clay sequence.

The second and smaller of the two basins is today entirely enclosed by the eastern crag and tail feature to the north-west, the Moniack alluvial fan to the east and the higher ground of Cabrich to the south-east and south-west. Surface altitudes in the central parts of the basin are generally 1-2 m. higher than the larger north-western basin (figs.5.15 and 5.16). Boreholes M33, M41 and M42 are Y1, 13 and 14 type profiles with multiple intercalations of terrestrial clastic and organic layers while M38 and M39 are X4, 15 type profiles. The remainder show intercalations of marine clastic sequences and peat while boreholes nearer to the Moniack alluvial fan also contain terrestrial clastic interfingering sequences at altitudes above the position of the marine units.

The lower clastic sequence (qhKU) seems to exhibit a succession of finer and coarser units as in boreholes M29A, M36 and M37. The upper, finer grey silty clays and clay silts that predominate as the upper unit in the lower clastic sequence of the north-western basin (figs. 5.13 and 5.14) are not distinguishable in the secondary basin. The lowermost stratum recorded in M37 comprises a blue-grey silty clay with laminations of grey-white sand indicating a rhythmic deposition. Above this unit is a tenacious blue-grey silty clay, the correlative of a similar unit at M29A and M36. This silty clay unit is extremely stiff and compact, difficult to penetrate even with a percussion drill attachment. In M29A comminuted shell fragments of undetermined origin were recovered from stratum 2. Above this unit there is generally a coarser deposit of grey silty sand and sometimes gravel, 225 cm. thick and containing shell fragments in M30 but also found in M29A, M29B, M30, M31, M32, M35, M36, M37, M41 and M42 - reaching a maximum altitude of 7.17 m. at M37.

Above the grey silty sand and gravel layer is a widespread well humified peat layer often dry and crumbly. The transition from the lower clastic sequence to the peat layer is variable in thickness and character. In boreholes M29B, M31, M35, M36 and M37 there is a gradual transition zone of brown organic silts and clays while in M29A, M30 and M32 the transition is abrupt over 1 cm. at M32. The regressive contact falls in altitude from 7.33 m. at M37 to 5.60 m. at M30 though it is not known if the lower clastic units in M41 and M42 relate to a marine event. The thickness of the peat layer also varies from 38 cm. at M29B to 240 cm. at M30.

In certain boreholes, M29B, M31 and M32 the peat layer is succeeded by a thin intercalated clastic layer - not exceeding 19 cm. at M29B. In M29B, a larger diameter borehole,this unit is itself comprised of three parts, a lower dark grey organic silt overlain by a grey sandy silt which is in turn overlain by a grey-brown organic silt. In M31 such detail was not observed, the unit comprising an 18 cm. thick grey organic silt. No such layer was recorded in M30 though bad sampling through the lower peat sequence may have resulted in the layer not being observed.

A similar layer has been recorded between 8.00 m. and 8.19 m. at M36 and also in M37 (fig. 5.15) though in these boreholes the altitudes are generally higher and there is no intercalated peat layer between it and the blue-grey silty clay of the upper clastic sequence.

If the correlations shown on figs. 5.13 to 5.16 are correct then there is evidence at Moniack for a thin grey silty sand layer, proved at M4B to be of marine origin, intercalated between peat in boreholes M4B, M5A, M29B, M31 and M32 and within the blue-grey silty clay sequence in boreholes M8/24, M9, M20, M21, M22, M23 and perhaps M26, M36 and M37.

Given in tabulated form the unit shows a vertical range of 152 cm. using only the upper surface values and has a mean thickness of 25 cm. Asterisks denote uncertain correlation.

TABLE 5.1

Borehole	base		top
M11	5.95	-	6.12
M4B	6.87	-	7.24
M5A	6.50	-	6.81
M29B	6.93	-	7.06
M31	6.93	-	7.11
M32	7.94	-	8.09
M8/24	7.38	-	7.61
M9	7.21	-	7.42
M20	6.95	-	7.05
M21	6.89	-	6.94
M22	6.66	-	6.73
M23	6.50	-	6.91
M26*	7.90	-	8.33
M36*	8.00	-	8.19
M37*	7.65	-	8.32

In boreholes M29B, M31 and M32 there is a peat layer above the thin grey silty sand unit, 142 cm. thick in M31. The transgressive contact of this peat falls from 9.59 m. at M32 to 7.29 m. at M29B where stratigraphy and diatoms prove the contact is erosive.

Overlying the interfingering peat sequences in M29B, M30, M31, M32 and M35 and above the grey silty sand unit in M36 and M37 is a blue-grey silty clay unit 205 thick in M29B. There is little internal variation in the unit within each borehole though it changes laterally, in M30 and M31 there is a higher organic content. Diatom analysis from M29B shows this unit to be predominantly of marine origin. In M41 however the lateral equivalent of this unit is a grey-brown silty sand. Diatom samples taken in the field at this level proved entirely fresh and fresh-brackish forms including <u>Tabellaria fenestrata</u>, Anomeoneis serians, Cymbella ventricosa, Pinnularia mesolepta, Diatoma c.f. hiemale, Navicula pusilla, Stauroneis smithii, Eunotia sp., Gomphonema sp. and other Pinnularia sp. confirming the lithologic evidence for a difference between the two layers. As such the clastic layer between 8.33 m. and 9.59 m. in M41 is attributable to an alluvial or other fresh-water habitat. Similarly all other clastic units above this in M41 are non-marine in origin.

Above the blue-grey silty clay unit in M35 and M36 there is an organic cover sequence of 462 cm. and 442 cm. respectively showing a lower woody detrital peat and an upper well humified monocotyledonous peat. In boreholes M29A to M33 the upper peat is intercalated by a series of clastic units, three in M29B which diatom analysis (figs.5.19 and 5.20) shows to be of fresh and fresh-brackish origin. In M41 diatom analysis from all clastic layers contain fresh and fresh-brackish forms indicating that all the clastic horizons above the blue-grey silty clay sequence which reaches a maximum of 9.57 m. in M37 (above the upper line in figs.5.15 and 5.16) are either alluvial fan deposits or slopewash. The coarser sandy silt stratum in M37 between 9.57 m. and 10.77 m. may well be such a colluvial deposit. The surface sequence in M29A, M30, M41 and M42 comprises 150 cm. orange brown sand and gravel in M42, a silty sand and gravel in M41 and grey sandy silt in M30 - it is the surface expression of the Moniack alluvial fan.

5.2.2 M29B

M29B (fig.5.12) was chosen for further analysis since the complex stratigraphy, 6 organic layers and 6 minerogenic layers needed further explanation. The borehole was also considered typical of those nearer to the Moniack alluvial fan and knowledge of the influence of this feature is an important factor if the detailed history of marine clastic, terrestrial clastic sedimentation is to be evaluated at the Moniack site. The sample was taken using a 48 mm. diameter modified Livingstone sampler and the stratigraphy described in the laboratory comprised

	cm.	m.O.D.	Description
	0 - 99	12.33 - 13.32	not sampled.
31.	99 - 108	12.24 - 12.33	Dark brown to black well humified monocot, peat with traces of silt and sand and with woody detritus. Sh2 Th^{2}1 Dl1 Ag+ As+ nig. 3+ strf. 2 elas.1.sicc. 3.
30.	108 - 163	11.69 - 12.24	Lighter brown fibrous monocot. peat and *Phragmites* rhizomes. Sh1 Th^{2}2 Th^{2}(Phra.) 1 nig. 3 strf. 1 elas.2 sicc. 2 l.s.0.
29.	163 - 176	11.56 - 11.69	Dark brown well humified monocot. peat with woody detritus. Traces of carbon also present. Sh2 Th^{2}2 Dl+ anth.+ nig. 3+ strf. 1 elas.2 sicc.2 l.s.0.
28.	176 - 188	11.44 - 11.56	Brown monocot. peat. Wood at 183 - 184 cm. Sh2 Th^{2}1 Dl1 nig.3 strf. 2 elas. 1 sicc. 2 l.s.0.
27.	188 - 211	11.21 - 11.44	Dark brown, crumbly, well-humified monocot. peat. Wood (*Pinus*?) at 203-204 cm. Sh3 Th^{2}1 Dl+ nig.3+ strf. 0 elas.1 sicc. 2+ l.s.0.
26.	211 - 216	11.12 - 11.21	Finely laminated brown and dark brown organic silt. Sh2 Ag2 As+ nig.3 strf. 3 elas.0 sicc.2 l.s.0.
25.	216 - 224	11.08 - 11.12	Light grey sand flecked with dark brown organic material. Ga4 Sh+ Ag+ nig. 2 strf.0 elas.0 sicc.2 l.s.3.
24.	224 - 242	10.90 - 11.08	Light grey silty sand with some herbaceous detritus and dark brown organic staining. Ga3 Ag1 As+ Dh+ Sh+ nig.2- strf.0 elas.0 sicc.3 l.s.1.
23.	242 - 254	10.78 - 10.90	Grey silty sand. Wood at 244 cm. Increasing organic content. Ga3 Ag1 As+ Dl+ Sh+ nig.2+ strf.0 elas.0 sicc.2 l.s.1.
22.	254 - 258	10.74 - 10.78	Yellow grey sand. Traces of carbonized material. Ga4 Ag+ anth.+ nig.1+ strf.0 elas.0 sicc.2- l.s.1.

	cm.	m.O.D.	Description
21.	258 - 270	10.62 - 10.74	Grey organic silt with traces of sand and carbonized wood. Ag3 ShI As+ Ga+ anth.+ nig.2+ strf.2 elas.0 sicc.2 1.s.1.
20.	270 - 285	10.47 - 10.62	Dark brown detrital peat with some silt. Betula sp. fruit and leaf fragments at 284 cm. Sh3 Dl1 Dh+ Ag+ nig.3 strf. 1 elas.2 sicc. 1.s.1.
19.	285 - 296	10.36 - 10.47	Light grey silty clay with black banding of totally humified organic material. Ag1 As3 Dh+ Sh+ anth.+ nig.2- strf. 2 elas.0 sicc.2 1.s.0.
18.	296 - 311	10.21 - 10.36	Dark brown monocot. peat with some herbaceous detritus and Phragmites rhizomes. Hippuris vulgaris seed at 296 cm. Sh2 $Th^2$1 Th^2(Phra .)1 Dh+ nig.3 strf.2 elas.2 sicc.2 1.s.1.
17.	311 - 333	9.99 - 10.21	Dark brown detrital peat. Potamogeton natans seed at 311 P.c.f. alpinus, Juncus sp. seeds at 330. Sh3 Dl1 Dh+ nig.3 strf.2 elas.1 sicc.2 1.s.0.
16.	333 - 393	9.39 - 9.99	Grey brown clayey silt with traces of mica. Some root channels and carbonized herbaceous material. Betula sp. fruit and Juncus effusus type seed at 333 cm. Carex rostrata seed at 334 cm. Ag3 As1 Ga+ Sh+ Dh+ Th^3+ anth.+ nig.2+ strf.0 elas.0 sicc.2 1.s.0.
15.	393 - 398	9.34 - 9.39	Grey brown clayey peat. Sh3 Dh+ Th^2I As+ Ag+ Dl+ nig.3- strf.2 elas.1 sicc.2 1.s.I.
14.	398 - 441	8.91 - 9.34	Grey silty clay with monocot. rootlets. As3 AgI Th^2+ nig.2 strf.2 elas.0 sicc. 1.s.0.
13.	441 - 472	8.60 - 8.91	Light grey clay silt with traces of mica. Fines upwards, some organic staining at top of layer. Ag3 As1 Dl+ Ga+ Sh+ Dh+ nig.2 strf.1 elas.0 sicc.2+ 1.s.0.
12.	472 - 511	8.21 - 8.60	Light grey silty clay with herbaceous and woody detritus. As3 Ag1 Ga+ Dh+ Dl+ nig.2- strf.1 elas.0 sicc.2 1.s.0.

	cm.	m.O.D.	Description
11.	511 - 540	7.92 - 8.21	Light grey silty clay. Woody detritus, possibly tree roots present. As3 Ag1 Dl+ nig.2 strf.1 elas.0 sicc.2 l.s.0.
10.	540 - 603	7.29 - 7.92	Light grey silty clay, with woody detritus. As3 Ag1 Dl+ nig.2 strf.2 elas.0 sicc.2 l.s.0.
9.	603 - 606	7.26 - 7.29	Dark brown, dry, very well humified monocot. peat. Sh4 Dh+ Dl+ nig.3+ strf.2 elas.1 sicc. 2+ l.s.2.
	606 - 617	7.15 - 7.26	not sampled.
8.	617 - 626	7.06 - 7.15	Dark brown, dry, crumbly monocot. peat. Sh4 Dh+ Dl+ nig.3+ strf.2 elas.1 sicc.2+ l.s.obscured.
7.	626 - 631	7.01 - 7.06	Grey brown organic silt with traces of mica. Transition zone. Sh1 Ag3 Ga+ As+ Dh+ nig. 2+ strf.0 elas.0. sicc. 2 l.s.0.
6.	631 - 639	6.93 - 7.01	Grey sandy silt. Ag3 Ga1 Sh+ As+ Dh+ nig. 2. strf. 0 elas.0 sicc.2 l.s.0.
5.	639 - 645	6.87 - 6.93	Dark grey organic silt with some sand and organic staining. Monocot. roots present. Ag3 Sh1 As+ Ga+ Th^{2}+ Dh+ nig.2+ strf.1 elas.0 sicc.2 l.s.0.
4.	645 - 650	6.82 - 6.87	Light brown organic clay with organic staining. Seeds of <u>Menyanthes trifoliata</u> and Carex sp. (2) at 649 cm. Sh1 As3 Dh+ nig.1+ strf.2 elas.0 sicc. 2 l.s.0.
3.	650 - 688	6.44 - 6.82	Dark brown well humified monocot. peat, silty inwash at 673-675 cm. <u>Juncus articulatus</u> type seed at 685 cm. Sh3 Th^{2}1 Dl+ nig.3 strf.2 elas.1 sicc.2 l.s.0.
2.	688 - 705	6.27 - 6.44	Light grey organic clay with laminations of darker organic material. Laminations diffuse. Bryophyte remains (<u>Fontinalis?</u>) at 690 but widespread throughout the layer. Tb^{3} As2 Sh1 Dl+ Dh+ nig.2+ strf.2 elas.0 sicc.2 l.s.0.
1.	705 - 718	6.14 - 6.27	Light grey sand and gravel with some herbaceous detritus in the upper part of the layer. Ga2 Ag+ Gg(min)1 Gg(maj)1 Dh+ nig.2- strf.0 elas.0 sicc,2 l.s.0.

Base not reached. Further samples down to c 825 cm. were not retained in the sampling chamber.

5.2.2.1 M29B Pollen

14 samples were counted for pollen between 270 cm. and 685 cm. The results are shown in figs. 5.17 and 5.18 and the diagrams zoned into four local pollen assemblage zones. The counts are tabulated in Appendix I. On figs. 5.17 and 5.18 *Corylus* should read Coryloid.

Zone M29B1 685 - 670 cm.

The zone comprises only one level, at the base of the lower peat. Pollen concentration is high at 160.6 grains x $10^3/cm^3$ but this is almost entirely composed of Cyperaceae at 87.2% TLP + Group and Gramineae with 8.4%. The upper limit is located at the significant fall in the pollen of Cyperaceae from 87.2% to 19.2% and rises in *Betula*, *Pinus* and Coryloid.

Zone M29B2 670 - 620 cm.

The zone consists of counts either side of the clastic sequence, strata 5 to 7 and is dominated by Coryloid which reaches 38.1% at 625 cm, Cyperaceae and Gramineae. *Equisetum* reaches 27.4% at 620 cm.

Zone M29B3 395 - 290.5 cm.

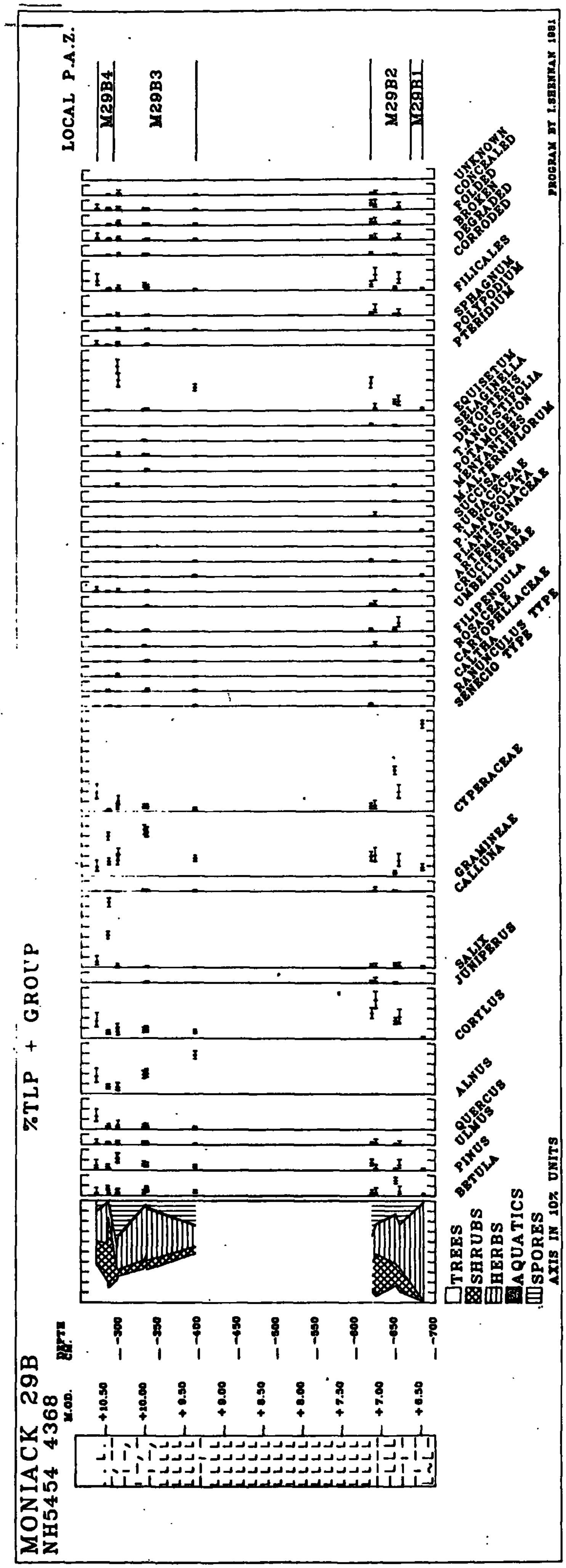
The zone comprises six levels, the lowermost, 395 cm. within the thin peat layer overlying the marine silty clays. The other five are at the base and top of an organic horizon, strata 17 and 18 which is underlain and overlain by non-marine clastic sequences, strata 16 and 19 respectively. *Alnus* and Gramineae dominate the zone, the former reaching 38.6% and 29.1 grains x $10^3/cm^3$ at 395 cm. though falling to 6.9% at 296 cm. Gramineae has consistent, high per cent values of c 45% in the three levels at the base of stratum 17 though it too falls to 21.1% and 15.9% at the top of stratum 18. *Pinus* rises consistently through the zone from 3.7% at 395 cm. to 11.6% at 296 cm. *Equisetum* too rises, reaching 43.9% at 296 cm. Total concentration is high,

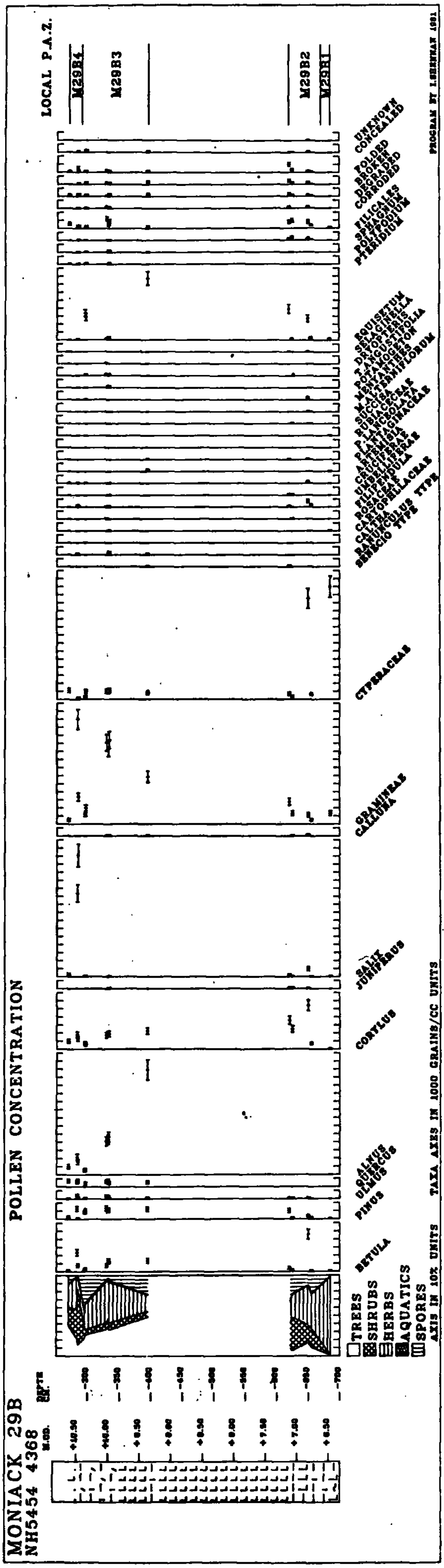
Fig. 5.17 Moniack 29B, %TLP + Group.

N.B. <u>Corylus</u> should read Coryloid

Fig. 5.18 Moniack 29B, Pollen concentration

Horizontal scale should read "Taxa Axes in 10 x 10^3grains/cm^3 units.


MONIACK 29B
NH5454 4368
M.O.D.
DEPTH CM.
+10.50
+10.00
+9.50
+9.00
+8.50
+8.00
+7.50
+7.00
+6.50
-300
-350
-400
-450
-500
-550
-600
-650
-700
%TLP + GROUP
LOCAL P.A.Z.
M29B4
M29B3
M29B2
M29B1
BETULA
PINUS
ULMUS
QUERCUS
ALNUS
CORYLUS
JUNIPERUS
SALIX
CALLUNA
GRAMINEAE
CYPERACEAE
SENECIO TYPE
RANUNCULUS TYPE
CALTHA
CARYOPHYLLACEAE
ROSACEAE
FILIPENDULA
UMBELLIFERAE
CRUCIFERAE
ARTEMISIA
PLANTAGINACEAE
P.LANCEOLATA
RUBIACEAE
SUCCISA
M.ALTERNIFLORUM
MENYANTHES
POTAMOGETON
T.ANGUSTIFOLIA
DRYOPTERIS
SELAGINELLA
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
CONCEALED
UNKNOWN
□ TREES
▩ SHRUBS
▤ HERBS
■ AQUATICS
▥ SPORES
AXIS IN 10% UNITS
PROGRAM BY I.SHENNAN 1981


MONIACK 29B
NH5454 4368
POLLEN CONCENTRATION
M.OD.
DEPTH CM.
+10.50
+10.00
+9.50
+9.00
+8.50
+8.00
+7.50
+7.00
+6.50
-300
-350
-400
-450
-500
-550
-600
-650
-700
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
TAXA AXES IN 1000 GRAINS/CC UNITS
BETULA
PINUS
ULMUS
QUERCUS
ALNUS
CORYLUS
SALIX
JUNIPERUS
GRAMINEAE
CALLUNA
CYPERACEAE
SENECIO TYPE
RANUNCULUS TYPE
CALTHA
CARYOPHYLLACEAE
ROSACEAE
FILIPENDULA
UMBELLIFERAE
CRUCIFERAE
ARTEMISIA
PLANTAGINACEAE
P.LANCEOLATA
RUBIACEAE
SUCCISA
M.ALTERNIFLORUM
MENYANTHES
POTAMOGETON
T.ANGUSTIFOLIA
DRYOPTERIS
SELAGINELLA
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
CONCEALED
UNKNOWN
LOCAL P.A.Z.
M29B4
M29B3
M29B2
M29B1
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334.7 grains x $10^3/cm^3$ at 395 cm. The upper boundary is placed at the significant rise in Salix from 1.1% at 296 cm. to 63.8% and 150.8 grains x $10^3/cm^3$ at 285 cm.

Zone M29B4 290.5 - 270 cm.

The zone comprised of three levels - two at the base and one at the top of stratum 20, a dark brown detrital peat over and underlain by non-marine clastic units - is dominated by Salix which reaches 63.8% at 285 cm. but falls to 5.4% at 270 cm. Quercus, Alnus and Coryloid rise at 270 cm. to 14.6%, 17.1% and 17.1% respectively.

5.2.2.2 M29B Diatoms

32 levels were analysed and counted for diatoms, at 690 cm, 700 cm. and 710 cm. in stratum 1, 630 cm, 635 cm, 645 cm, and 649 cm. through strata 4 to 7, 11 levels at 20 cm. intervals through strata 10 to 14, 7 levels through stratum 6 at 10 and 20 cm. intervals, 3 levels, 286 cm, 290 cm, and 294 cm. in stratum 19, one at 269 cm in stratum 21 and the remainder at 216 cm, 230 cm and 240 cm.

In all levels traversed below 600 cm. diatoms were absent or too few to count. At 649 cm. and 645 cm. only a few fragments attributable to Pinnularia sp. and Cymbella sp. remained. At 294 cm. diatoms were present though sparse and all were fresh and as all were fresh and fresh-brackish forms the count was discontinued. At 240 cm, 230 cm and 216 cm. again diatoms were rare, often only fragments encountered, the few species identifiable were fresh or fresh-brackish taxa.

The remaining 21 levels between 600 cm. and 269 cm. are shown in figs. 5.19 and 5.20 and are zoned into 3 local diatom assemblage zones. Counts are tabulated in Appendix II.

Zone M29BD1 600 - 450 cm.

Marine and marine-brackish forms dominate the zone most notably Paralia sulcata and Grammatophora oceanica var. macilenta. P.sulcata is consistent in showing high values from 84.5% at 600 cm. to 62.2% at 460 cm. G. oceanica var. macilenta, a marine-brackish epiphyte rises from 4.7% at 600 cm. to 18.9% at 500 cm. and falls subsequently to 12.0% at the end of the zone. Another consistent curve is that of Nitzschia punctata, a brackish-marine benthonic form which reaches 6.7% at 570 cm. Numbers of species recorded at each level is also consistent through the zone (fig.5.20) ranging from 13 at 600 cm. and 460 cm. to a maximum of 20 at 500 cm. The upper limit is placed where there is a significant fall in the curves of P.sulcata and G.oceanica var. macilenta, a termination of the curves of many marine and marine-brackish forms formerly showing sporadic occurrence and at the significant rise in the curve of Diploneis interrupta from 4.4% at 460 cm. to 89.8% at 440 cm.

Zone M29BD2 450 - 396.5 cm.

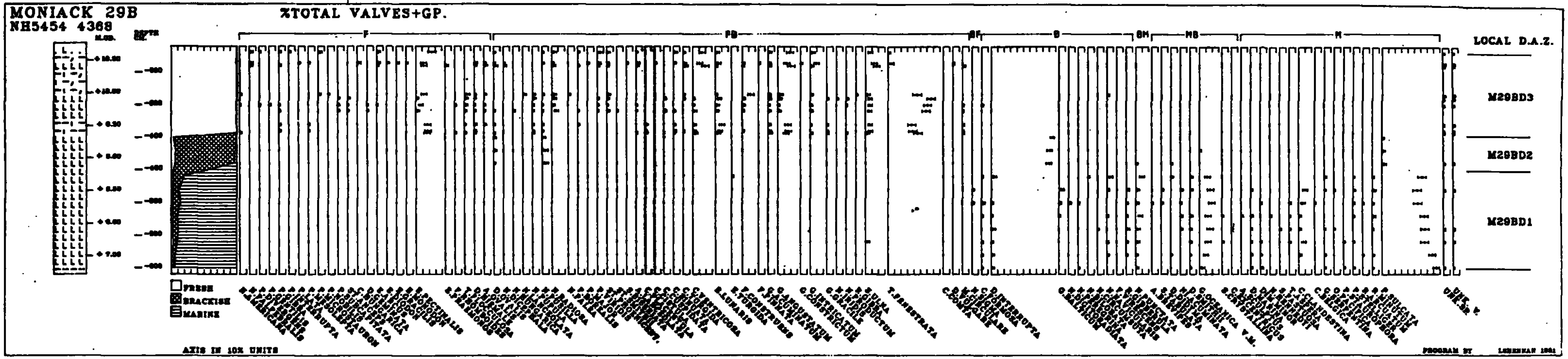
Diploneis interrupta, a brackish benthonic form reaches values of 89.8%, 91.5% and 95.5% for the three levels included in this zone. The only other notable contribution is from Paralia sulcata which is present in much reduced numbers at 3.4%, 2.0% and 1.0%. The number of species recorded also falls to only 4 at 400 cm. The upper boundary is placed at 396.5 cm. at a marked change from brackish to fresh forms. With the exception of sporadic counts of Caloneis formosa and Nitzschia punctata no brackish to marine forms occur above zone M29BD2. The zone boundary also coincides with the middle of a thin peat layer, stratum 15.

Zone M29BD3 396.5 - 269 cm.

The zone is dominated by fresh and fresh-brackish taxa even

Fig. 5.19 Moniack 29B, Diatoms, % Total Valves

Fig. 5.20 Moniack 29B Diatom summary diagram.
Shading as for fig. 5.7.


MONIACK 29B
NH5454 4368
M.OD.
DEPTH CM.
%TOTAL VALVES+GP.
F
FB
BF
B
BM
MB
M
LOCAL D.A.Z.
M29BD3
M29BD2
M29BD1
FRESH
BRACKISH
MARINE
AXIS IN 10% UNITS
E.VALVES-DORSALIS
P.DIVERGENS
P.GIBBA
P.INTERRUPTA
P.MICROSTAURON
P.NOBILIS
P.SUBCAPITATA
S.ANCEPS
D.HUNGARICA
E.ARCUS
E.GRACILIS
E.MONODON
E.PECTINALIS
S.PHOENICENTERON
N.RADIOSA
N.PUPULA
N.VIRIDIS
C.VENTRICOSA
S.LUNARIS
S.TURGIDA
F.CONSTRUENS
F.PINNATA
G.ACUMINATUM
G.ANGUSTATUM
G.INTRICATUM
G.CONSTRICTUM
G.GRACILE
N.IRIDIS
R.GIBBA
E.PRODUCTUM
S.ULNA
T.FENESTRATA
C.COMTA
D.INTERRUPTA
C.FORMOSA
N.DIGITORADIATA
O.BALTICUM
N.PUNCTATA
A.BREVIPES
D.DIDYMA
N.PEREGRINA
C.OCEANICA V.M.
D.SMITHII
S.CRYSTALLINA
C.BELGICA
C.CLANDESTINA
T.ASPERA
S.FASTUOSA
P.SULCATA
P.MINUTUM
P.ARCUATUM
UNK. V.
UNK.SP.
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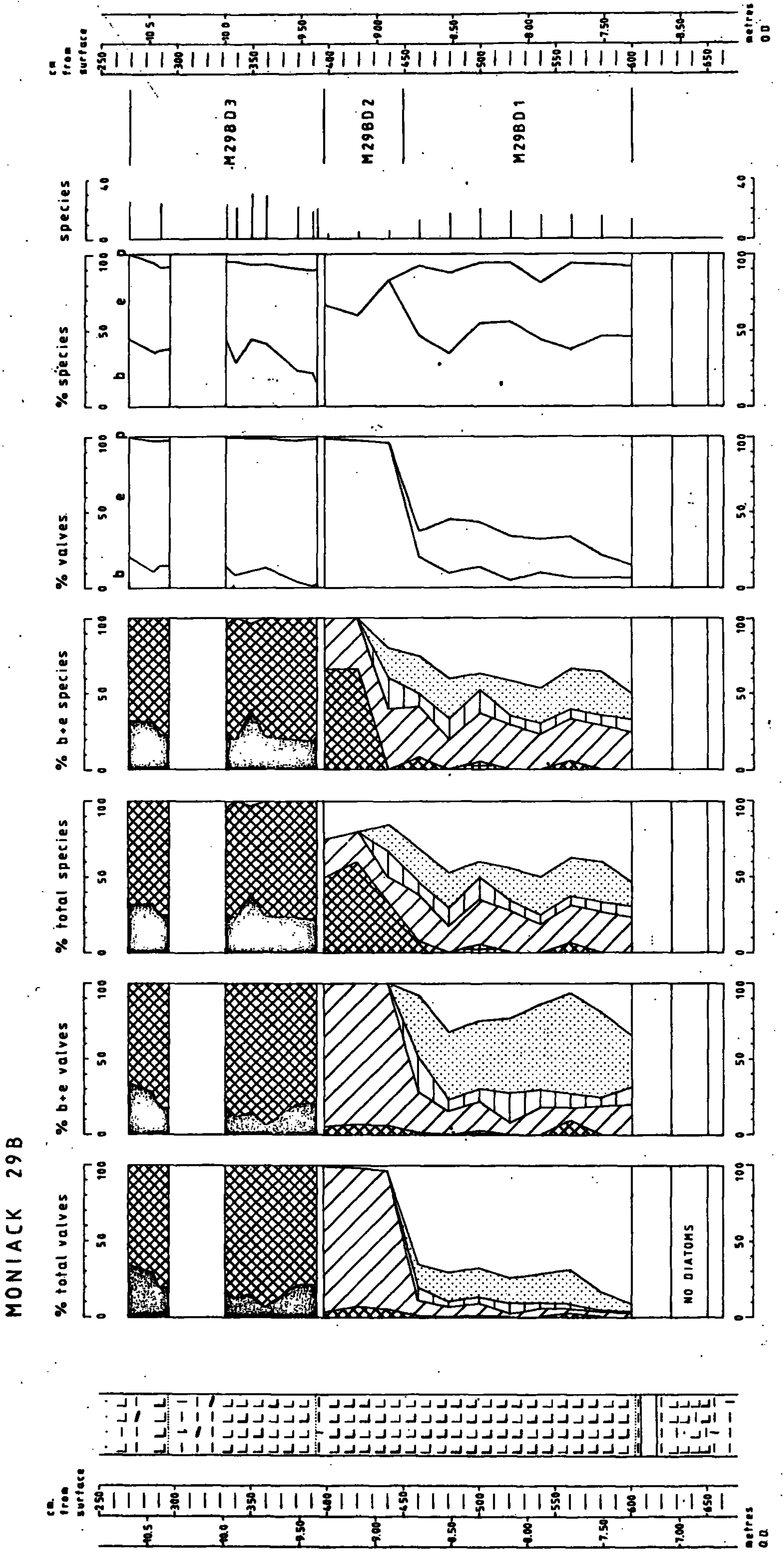

MONIACK 29B
% total valves
% b+e valves
% total species
% b+e species
% valves
% species
species
b
e
p
0
50
100
40
M29BD3
M29BD2
M29BD1
NO DIATOMS
cm from surface
250
300
350
400
450
500
550
600
650
metres O.D.
10.5
10.0
9.50
9.00
8.50
8.00
7.50
7.00

though the counts cover three separate clastic sequences interrupted by organic layers. The zone is characterized by large numbers of species occurring in low percentages. Tabellaria fenestrata reaching 66.2% at 340 cm, Synedra Ulna rising to 14.6% at 290 cm, Gomphonema angustatum, Cymbella ventricosa, Navicula radiosa and Eunotia pectinalis are the dominant forms. There is little internal variation save in the decline of T.fenestrata from 44.4% at 334 cm. to only sporadic occurrences above that level.

5.2.3 Moniack 4B

The M4B borehole was chosen for further micropalaeontological analysis because the grey, silty sand horizon, mentioned in section 5.2.1 here forms an intercalated sequence with the lower peat. In M4B it is 37 cm. thick. The stratigraphy of the core, taken with a Russian sampler and described in the laboratory comprised:-

	cm.	m. O.D.	Description
	0 - 280	8.79 - 11.59	Not sampled
10.	280 - 289	8.70 - 8.79	Dark brown detrital peat. Dh1 Th^{2}1 Sh2 Dl+ nig.3 strf.2 elas.1 sicc.2 l.s.0.
9.	289 - 305	8.54 - 8.70	Grey-brown organic clay. Diploneis interrupta and other brackish diatoms at c. 295 cm. Sh2 As2 lso+ Dh+ nig.2 strf. 1 elas.0 sicc.2 l.s.0.
8.	305 - 419	7.40 - 8.54	Grey-brown laminated organic clay Diploneis ovalis at 320 cm. Sh1 Dh+ As3 Lso+ Ag+ Th^2+ nig.2 strf.1 elas.0 sicc.2 l.s.0.
7.	419 - 431	7.28 - 7.40	Dark brown monocot.peat with Phragmites rhizomes. Sh2 Th^{2}2 Dh+ Th^2(Phra.)+ nig.3 strf.2 elas.1 sicc.2 l.s.0.
6.	431 - 435	7.24 - 7.28	Dark brown monocot. peat with some clay. Transition zone. Some Phragmites rhizomes. Th^2(Phra.)1 Th^{2}2 Sh1 As+ nig.3 strf.3 elas.1 sicc.2 l.s.0.

	cm.	m.O.D.	Description
5.	435 - 442	7.17 - 7.24	Grey silty clay with herbaceous detritus. Ag1 As2 Dh1 Th^2+ nig.2 strf.2 elas.0 sicc.2 l.s.0.
4.	442 - 467	6.97 - 7.17	Grey clay-silt with herbaceous detritus Ag2 As2 Dh+ Th^2+ nig.2 strf.1 elas.0 sicc.2 l.s.0.
3.	467 - 468.5	6.905- 6.92	Dark brown totally humified peat. (Peat ball) Sh4 As+ Ag+ nig.4- strf.0 elas.0 sicc.2 l.s.0.
2.	468.5 - 472	6.87 - 6.905	Dark grey micaceous silty fine sand. Marine diatoms <u>Paralia sulcata</u> and <u>Grammatophora oceanica</u> at 471 cm. Ga2 Ag2 Lso+ nig.2+ strf.0 elas.0 sicc. 2 l.s.0.
1.	472 - 490	6.69 - 6.87	Dark brown well humified monocot. peat with some <u>Phragmites</u> and silt in the upper layers of the stratum. Th^2(Phra.)+ Sh3 Th^{2}1 Dl+ Ag+ nig.3 strf.1 elas.1 sicc.2 l.s.3/4 erosion contact.

Stratum 3 directly overlying the silty fine sand of stratum 2 is only 1.5 cm. thick and probably represents an eroded peat ball incorporated in the marine clastic sequence. Above stratum 3 the clastic units fine upwards changing from a grey clay-silt to a silty clay. The peat layer represented by strata 6 and 7 is only 16 cm. thick and is succeeded upwards without break by a grey-brown organic clay that is the lateral equivalent of the blue-grey silty clay sequence of boreholes M5A to M12.

5.2.3.1 <u>M4B Diatoms</u>

12 samples were prepared for diatom analysis, ten between 471 and 442 cm. in strata 2 → 4 and two, 400 cm. and 410 cm. in stratum 8. All contained sufficient diatoms to count and are shown in figs. 5.21 and 5.22. Counts are tabulated in Appendix II. The diatoms are divided into 3 local diatom assemblage zones.

Zone M4BD1 471 - 447.5 cm.

The zone is characterized by the dominance of the marine diatom Paralia sulcata which rises to 48.5% at 445 cm. It is present in consistently high values throughout the zone. Cocconeis scutellum, a marine-brackish epiphyte rises from 7.2% at 471 cm. to 33.7% at 469 cm. but falls subsequently through the zone to 5.8% at 455 cm. Grammatophora oceanica var. macilenta is the third main constituent of the zone reaching 23.8% at 465 cm. Numbers of species recorded is high - 28 at 471 cm. There may be some justification for regarding the first three levels of the zone as a sub-zone since at 471 cm, 470cm. and 469 cm. there is evidence for transition. Certain forms such as Amphora ovalis, Achnanthes lanceolata, Tabellaria fenestrata and Navicula peregrina occur along with other fresh-brackish to brackish species. Together with smaller values for the three main marine and marine-brackish taxa mentioned above it does suggest a slight brackish-marine transition. The upper boundary is much clearer, placed at the significant rise in Navicula peregrina and a fall in Paralia sulcata.

Zone M4BD2 447.5 - 442 cm.

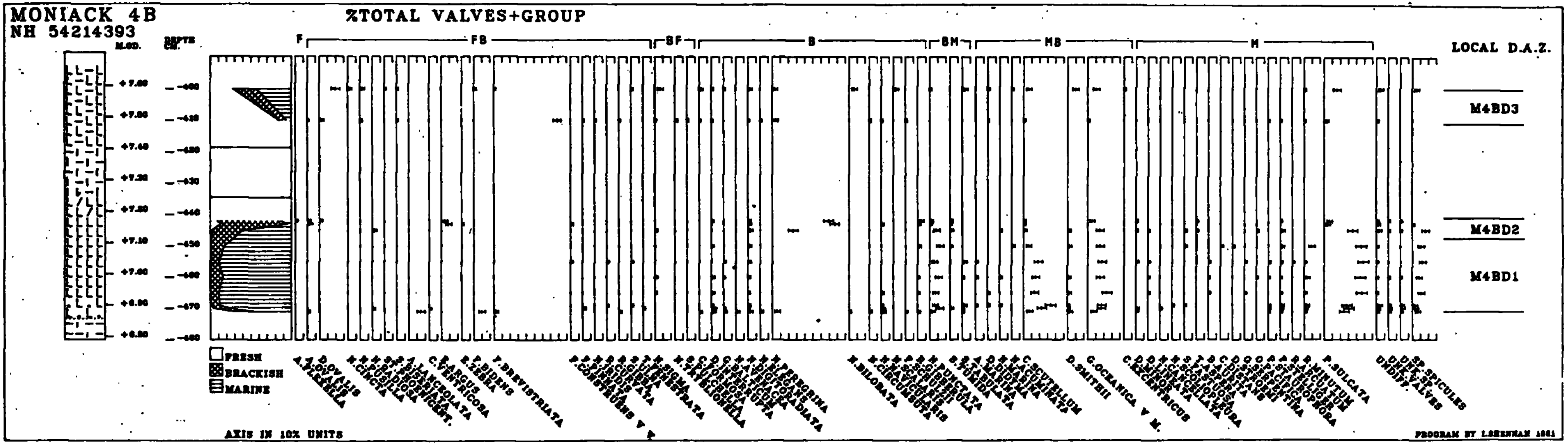
Navicula peregrina appears for the first time since 471 cm. at a value of 25.3% and has values of 77.2% and 69.6% for the remaining levels in the zone. Paralia sulcata falls from 46.1% at 450 cm. to 35.4% at 445 cm. over the zone boundary but the most significant fall is between the next two levels to 4.2% at 443 cm. Other fresh-brackish to brackish forms such as Amphora ovalis and Navicula radiosa return and new ones such as Epithemia argus appear.

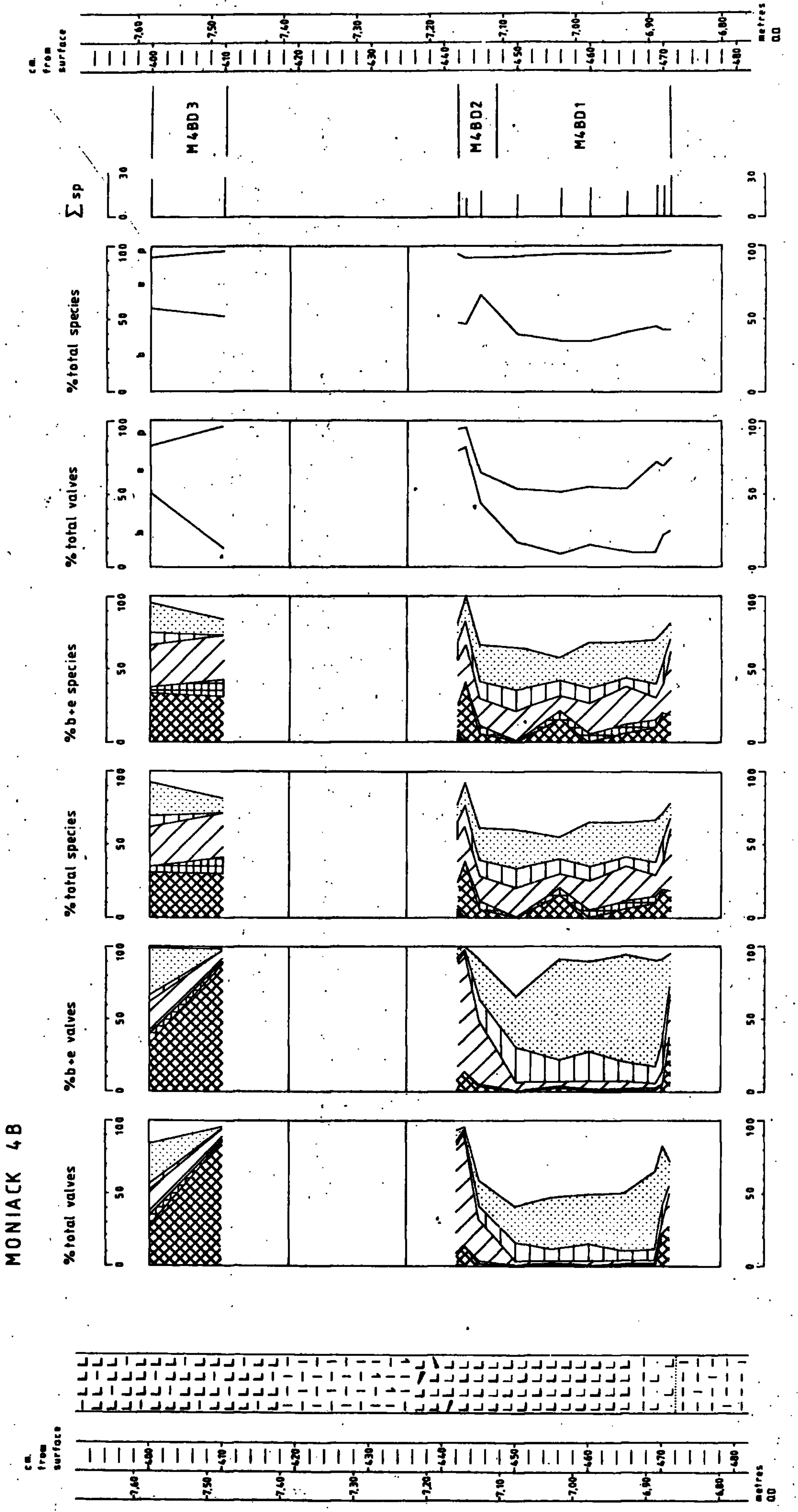
Zone M4BD3 410 - 400 cm.

The zone comprises only two levels and contains mainly fresh-brackish to brackish forms. Fragilaria brevistriata dominates the lower spectrum

Fig. 5.21 Moniack 4B, Diatoms, % Total Valves

Fig. 5.22 Moniack 4B, Diatom summary diagram.
Shading as for fig. 5.7


MONIACK 4B
NH 54214393
%TOTAL VALVES+GROUP
M.OD.
DEPTH CM.
+7.60
+7.50
+7.40
+7.30
+7.20
+7.10
+7.00
+6.90
+6.80
-400
-410
-420
-430
-440
-450
-460
-470
-480
F
FB
SF
B
BM
MB
M
LOCAL D.A.Z.
M4BD3
M4BD2
M4BD1
FRESH
BRACKISH
MARINE
A.FLEXELLA
A.OVALIS
D.OVALIS
N.CINCTA
N.PUSILLA
N.RADIOSA
ST.PHOENICENT.
S.BISERIATA
A.LANCEOLATA
C.VENTRICOSA
E.ARGUS
E.ZEBRA
P.BIDENS
P.BREVISTRIATA
F.CONSTRUENS V V
F.PINNATA
N.IRIDIS
R.CURVATA
R.GIBBA
S.ULNA
T.FENESTRATA
N.SIGMA
N.TRYBLIONELLA
S.PULCHELLA
C.FORMOSA
D.INTERRUPTA
G.BALTICUM
N.AVENACEA
N.DIGITORADIATA
N.ELEGANS
N.PEREGRINA
N.BILOBATA
N.CIRCUMSUTA
N.NAVICULARIS
N.SCALARIS
P.SCHULZII
R.GIBBERULA
N.PUNCTATA
S.TUMIDA
S.TABULATA
A.MARINA
D.DIDYMA
N.MARINA
N.ACUMINATA
C.SCUTELLUM
D.SMITHII
G.OCEANICA V M.
C.EXCENTRICUS
D.MINOR
D.LINEATA
N.CANCELLATA
N.SCOLIOPLEURA
S.FASTUOSA
T.ASPERA
B.AURITA
C.DISTANS
D.STROEMI
G.SERPENTINA
O.PACIFICA
P.STAUROPHORA
P.STELLIGER
R.ARCUATUM
R.MINUTUM
P.SULCATA
UNDIFF.
UNK.VALVES
UNK.SP
SP.SPICULES
AXIS IN 10% UNITS
PROGRAM BY I.SHENNAN 1981


MONIACK 4B
cm. from surface
400
410
420
430
440
450
460
470
480
metres OD
-7,60
-7,50
-7,40
-7,30
-7,20
-7,10
-7,00
-6,90
-6,80
M4BD3
M4BD2
M4BD1
Σ sp
0
30
% total species
% total valves
% b+e species
% b+e valves
0
50
100
p
m
b

with 79.0%, the only other notable contribution is from *Navicula peregrina* with 4.3%. The upper level contains *Diploneis ovalis*, 19.8%. *Nitzschia sigma*, 6.6%, *Nitzschia bilobata*, 6.1% *Diploneis smithii*, 9.4%, *Grammatophora oceanica var. macilenta*, 10.3% and *Paralia sulcata* at 16.0% and forms perhaps a slightly more saline spectrum.

5.2.3.2 M4B ^{14}C Dating

4 samples were submitted from M4B to the University of Birmingham, Department of Geological Sciences for radiocarbon assay. Results are expected in November or December 1981. The four samples, full details of which are given in Appendix IV on I.G.C.P. sea-level computer forms and the positions of which are illustrated by asterisks in fig. 5.14, comprised -

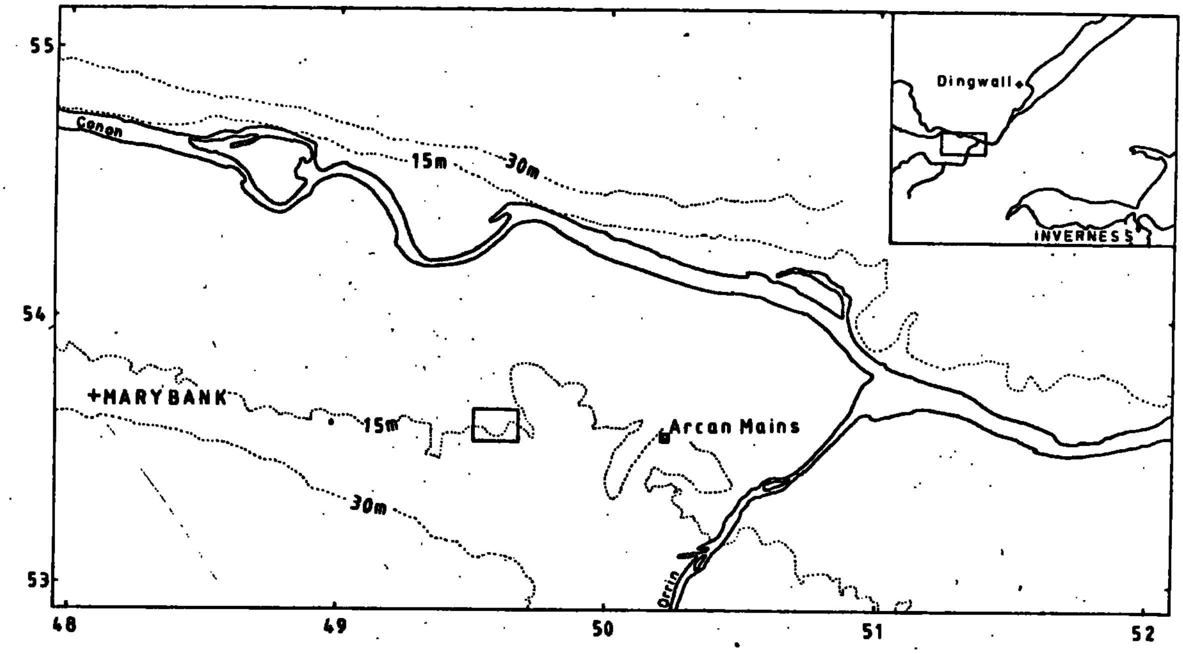
Depth (cm.)	283 - 288	419 - 424	426 - 431	472 - 477
Altitude (m.O.D.)	8.71 - 8.76	7.35 - 7.40	7.23 - 7.28	6.82 - 6.87
Thickness (m)	0.05	0.05	0.05	0.05
Components	Sh2 Th^{2}1 Dh1	Sh2 Th^{2}2	Th^{2}2 Sh1 Th^2(Phra.)1	Sh3 Th^2 1
Wet wt. (g)	79	76	63	52

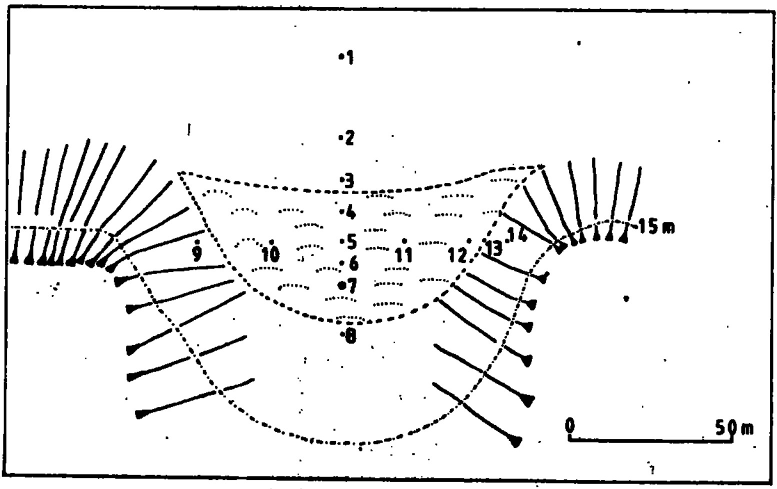
5.3 Arcan Mains

The Arcan Mains site is located in lower Strathconon, 3 km. east of Marybank and 1 km. west of Arcan Mains itself (fig.5.23).

The site is small, measuring only 90 m^2 and fourteen boreholes were put down in two transects across the small gully feature, 1 to 8 in a north-south direction and 9 - 14 oriented east-west (fig. 5.23). Despite the close sampling interval great variation is seen in the stratigraphy. Because of this the stratigraphic diagrams (figs. 5.24 and 5.25) will be discussed in groups of boreholes rather than systematically by sequence.

Fig. 5.23 Arcan Mains site map showing location of boreholes


55
54
53
48
49
50
51
52
Conon
15m
30m
+MARYBANK
15m
30m
Arcan Mains
Orrin
Dingwall
INVERNESS


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15m
0
50m

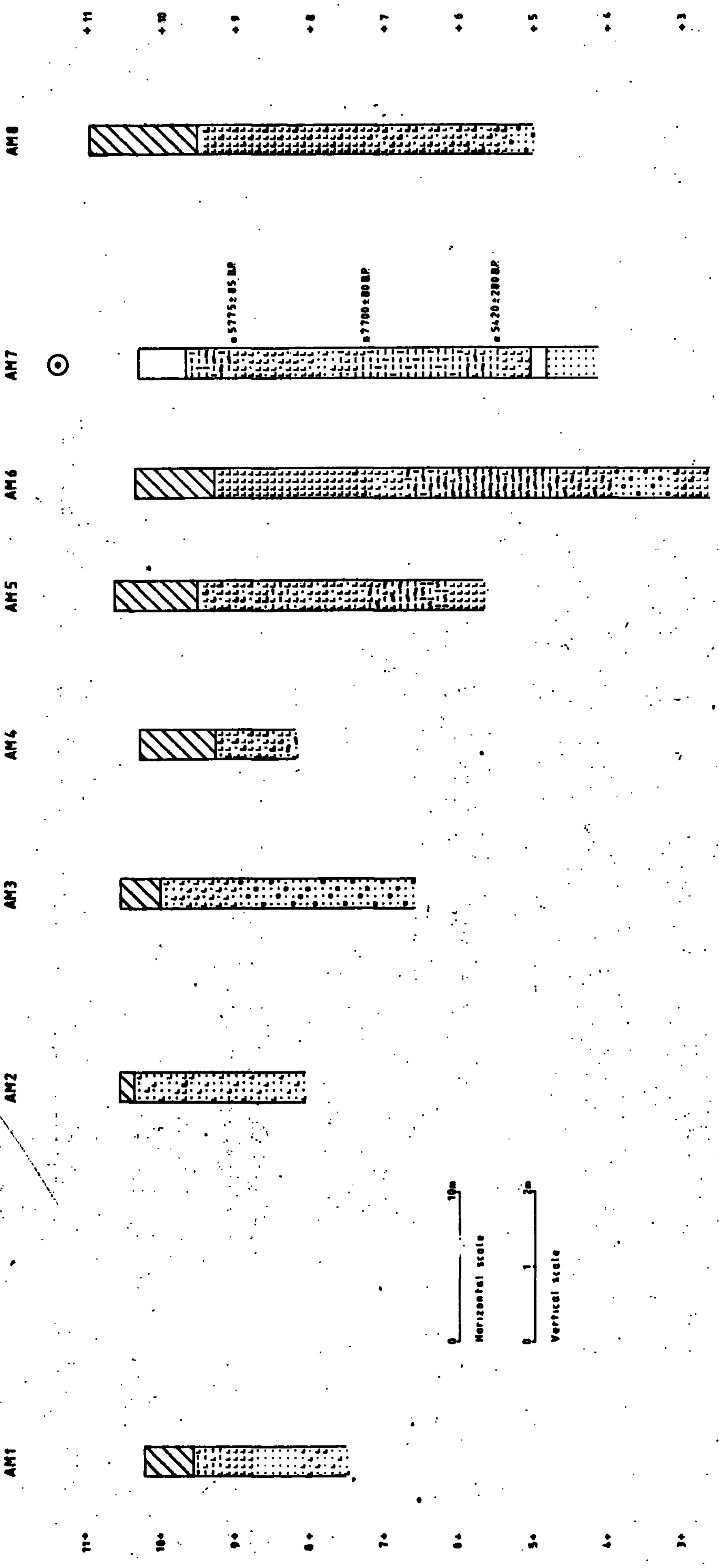
Boreholes AM1 to 4 are all of shallow depth. Apart from a thin surface peat in AM1 all are dominantly minerogenic; sampling usually was stopped by compact silty sand or sand and gravel. All four boreholes are outside the central area of the gully and probably represent riverine channel deposits. The vegetation, predominantly _Juncus effusus_, _Sphagnum_ sp, _Equisetum sylvatiia_, _Gramineae_ sp. and _Carex_ sp., different from the surrounding areas does suggest the possibility of former channels.

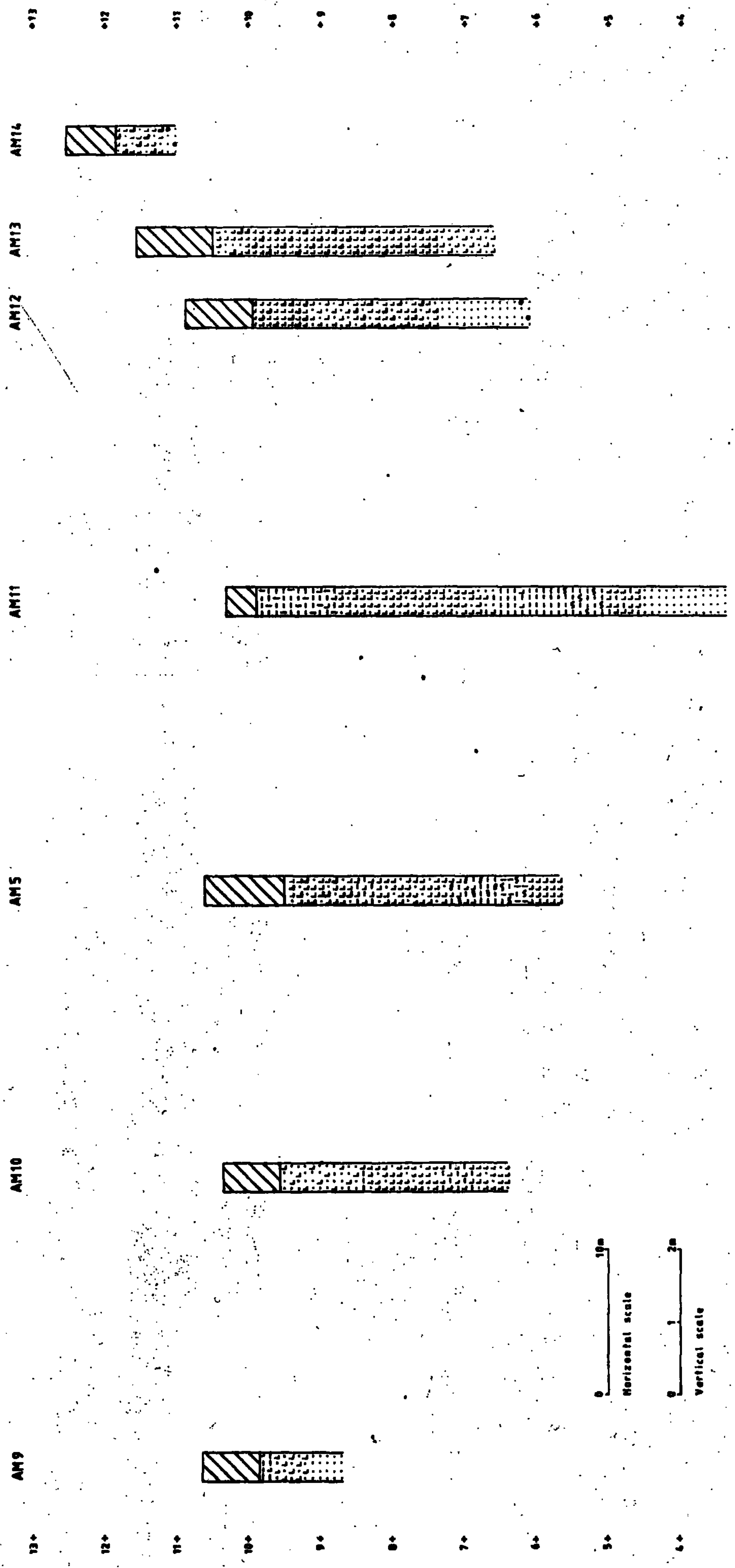
The central area of the gully now dominated by _Salix_ sp. including _Salix cinerea_ and _Salix caprea_ forms a _Salix_-carr with _Equisetum sylvatica_, _Filipendula ulmaria_, _Galium palustre_, _Stellaria palustris_, _Solanum dulcamara_ and _Juncus effusus_. This area shows the greatest consistency in stratigraphy. Boreholes AM5, 6, 7, 10 and 11 all show a basal minerogenic sequence which exhibits a coarse → finer succession. For example in AM7 grey sand between 4.52 m. and 4.84 m. is succeeded upwards by at least 35 cm. of sandy silt. In AM11 grey sand between 3.35 m. and 4.22 m. is overlain by 47 cm. of grey-brown organic silt. Above the basal clastic sequence in the central area is an intercalated peat layer which also shows great variation in altitude and composition between boreholes. In AM5 the peat layer is 71 cm. thick and is composed of a lower mixed monocot. - bryophyte peat and an upper monocot. peat with woody detritus. At AM11 it is 149 cm. thick, again comprising a lower bryophyte peat and an upper well humified monocot. peat. At AM6 the peat sequence appears to be divisible into three units, a lower well humified monocot. peat, a middle yellow-brown bryophyte peat and an upper brown monocot. peat with woody detritus and silt.

The lower contact of the peat varies in altitude from 6.88 m. at AM10 where it contains a significant silt component to 5.08 m. at AM11 and 4.71 m. at AM6. The upper contact similarly shows variation from 7.28 m. at AM5 to 6.70 m. at AM6, a difference of 58 cm. in 7.5 m.

Fig. 5.24 Arcan Mains stratigraphy, AM 1 - 8

Fig. 5.25 Arcan Mains stratigraphy, AM 9 - 14


+11
+10
+9
+8
+7
+6
+5
+4
+3
AM8
AM7
5775±85 B.P.
7700±80 B.P.
5420±280 B.P.
AM6
AM5
AM4
AM3
AM2
Horizontal scale
0
10m
Vertical scale
0
1
2m
AM1
11+
10+
9+
8+
7+
6+
5+
4+
3+


+13
+12
+11
+10
+9
+8
+7
+6
+5
+4
AM14
AM13
AM12
AM11
AM5
AM10
AM9
0
10m
Horizontal scale
0
1
2m
Vertical scale

Above the lower peat sequence is a sandy silt unit. In boreholes AM5, 7, 10 and 11 it is overlain by an upper peat but in AM6 the peat is absent and it forms the cover sequence. This clastic unit containing marine diatoms at 7.81 m. in AM7 varies in thickness with little consistency between boreholes, though there is a broad similarity in altitude of the regressive contact of the overlying peat in boreholes AM5, AM10 and AM11 at 8.30 m, 8.39 m and 8.77 m. respectively. At AM7, the sampled site, this contact is at 9.00 m.

The upper peat layer forms the upper organic unit in the qhA or splitting up sequence of the central gully area. It is composed of a woody detrital peat at AM11 and shows little regularity in thickness - at AM6 and AM10 there is a clastic cover sequence of grey sand, silt and clay. No diatoms were counted in this sequence and its origin must remain speculative but it could relate to a riverine flood deposit. Floods were common before c. 1853 when the embankment controlling the course of the Conon was built (Davis 1979). In these boreholes the upper peat is either completely eroded or contains a significant minerogenic component.

The margins of the gully, shown by boreholes AM8, 9, 12, 13 and 14 show no intercalations of peat and the clastic units in these boreholes must relate to marine colluvial and alluvial deposition. Further differentiation of these deposits is not possible without further analysis.

5.3.1 Arcan Mains 7

AM7 was considered the best location to sample for further laboratory analysis since it is representative of the central gully area. The core was taken with a 48 mm. diameter modified Livingstone corer and the stratigraphy, described in the laboratory comprised -

	cm.	m.O.D.	Description
	0 - 63	9.68 - 10.31	Not sampled
19.	63 - 65	9.66 - 9.68	Light brown crumbly organic silt with occasional iron concretions and monocot. rootlets. Ag2 As1 Sh1 Ga+ Lf+ Th^2+Dl+ nig.2+ strf.0 elas.1 sicc.2.
18.	65 - 71	9.60 - 9.66	Dark brown well humified peat with crumbly structure. Sh3 Th^{2}1 As+ nig.3 strf.1 elas.1 sicc.2 l.s.0.
17.	71 - 88	9.60 - 9.43	Dark brown well humified peat with crumbly structure and occasional woody detritus. Sh3 Dl+ Th^{2}1 As+ nig.3+ strf. 1 elas.1 sicc.2 l.s.0.
16.	88 - 128	9.03 - 9.43	Dark brown well humified peat. Sh2 Dl1 Th^{2}1 As+ nig.3 strf.1 elas.1 sicc.2 l.s.0.
15.	128 - 131	9.00 - 9.03	Dark brown well humified peat with some included silt and sand. Transition zone. Upper boundary diffuse. Sh2 Dl1 Th^{2}1 Ga+ Ag+ As+ nig.3 strf.1 elas.1 sicc.2 l.s.0.
14.	131 - 236	7.95 - 9.00	Light grey sandy silt with occasional herbaceous detritus and root channels. Wood at 194-206. Ga1 Ag3 As+ Dl+ Dh+ nig.2 strf.0 elas.0 sicc.2 l.s.0.
13.	236 - 252	7.79 - 7.95	Light grey silty clay with sand laminations at 238 and 246 cm. Root channels present. Ag1 Ga+ As3 Th^1+ nig.2- strf.3 elas.0 sicc.2 l.s.0.
12.	252 - 268.5	7.625 - 7.79	Grey silty sand. Ag1 Ga3 Dh+ nig.2 strf.0 elas.0 sicc.2 l.s.0
11.	268.5- 272	7.59 - 7.625	Grey-brown organic silt. Short transition zones above and below a thin organic band of totally humified material. Ag1 As+ Sh2 Th^{3}1 Dl+ nig.3- strf. 2 elas.2 sicc.2 l.s.1.
10.	272 - 276.5	7.545 - 7.59	Transition zone. Grey-brown organic silt. Occasional herbaceous rootlets and detritus. As2 Sh2 Ga+ Th^2+ Dh+ nig.2+ strf.1 elas.0 sicc.2- l.s.0.

	cm.	m.O.D.	Description
9.	276.5 - 284	7.47 - 7.545	Grey sandy silt. Rare fragments of monocot. detritus. Upper boundary gradual. Ga1 Ag3 As+ Dh+ Sh+ nig.2- strf.2 elas.0 sicc.2 l.s.0.
8.	284 - 288	7.43 - 7.47	Grey-brown organic silt with woody and herbaceous detritus. Dl+ Sh2 As2 Ag+ Ga+ Dh+ nig.2 strf.2 elas.1 sicc.2 l.s.0.
7.	288 - 296	7.35 - 7.43	Grey organic silt with monocot. rootlets and herbaceous detritus Ag3 Th^{2}1 Ga+ As+ Sh+ Dh+ nig.2- strf.2 elas.1 sicc.2 l.s.0.
6.	296 - 304	7.27 - 7.35	Transition zone. Grey-brown organic silt with <u>Phragmites</u> rhizomes at 297 cm. and black laminations of totally humified organic material (Sh) at 299 and 301 cm. More organic to base. Sh3 Ag1 Th^{2} (Phra.)+ Th^{2}+As+ Ga+ nig.3- strf.3 elas.2 sicc.2 l.s.0
5.	304 - 431	6.00 - 7.27	Dark brown well humified peat with occasional monocot. rootlets wood at 333 - 38 cm, 329 - 31 cm, 354 - 58 cm, 410 - 12 cm. Th^{3}1 Sh3 Ga+ Dh+ nig.3 strf.2 elas.2 sicc.2 l.s.0.
	400 - 408		Not sampled.
4.	431 - 465	5.66 - 6.00	Grey-brown silty peat. Transition zone. Upper boundary diffuse. Sh2 Ag1 Dl1 Dh+ Ga+ nig.2+ strf.2 elas.2 sicc.2 l.s.0.
3.	465 - 490	5.41 - 5.66	Grey organic silt with woody detritus. Wood at 483 - 85 cm. Dl+ Dh+ Sh2 Ag1 Ga1 As+ nig.2 strf.2 elas.1 sicc.2 l.s.0.
2.	490 - 525	5.06 - 5.41	Light grey sticky sandy silt with rare monocot. rootlets. No visible structures. Upper boundary a sharp erosion contact running diagonally through 1 cm. Ag3 As+ Ga1 Th^{2}+ nig.1 strf.0 elas.0 sicc.2 l.s.3/4.
	525 - 547	4.84 - 5.06	Possible contamination.
1.	547 - 579	4.52 - 4.84	Grey sand with occasional quartz grains Ga4 Ag+ As+ nig.2 strf.0 elas.0 sicc.2+ l.s.2.

5.3.1.1 AM7 Pollen

A standard pollen diagram for Arcan Mains already exists (Davis 1979) and it was decided only to analyse levels at the upper and lower contacts of the lower peat and the lower contact of the upper peat.

12 levels were analysed for pollen though at 500 cm. the pollen content was negligible. It was not possible to zone the diagrams in the normal manner and the three local pollen assemblage zones described merely reflect the three separated areas of core analysed. The pollen diagrams are shown in figs. 5.26 and 5.27 and the pollen counts are tabulated in Appendix I. On figs. 5.26 and 5.27 *Corylus* should read Coryloid.

Zone AM1 491 to 485 cm.

Betula is present in consistently high values ranging from 65.5% at 490 cm. to 76.1% at 485 cm. Other taxa present but in lower percentages are *Pinus*, Coryloid, *Juniperus*, *Salix*, Gramineae, *Filipendula* and *Myriophyllum alterniflorum*. Total concentration values increase from 75.4 grains x $10^3/cm^3$ at 490 cm. to 121.0 grains x $10^3/cm^3$ at 486 cm. the greater part of which is contributed by *Betula*.

Zone AM2 302 - 301 cm.

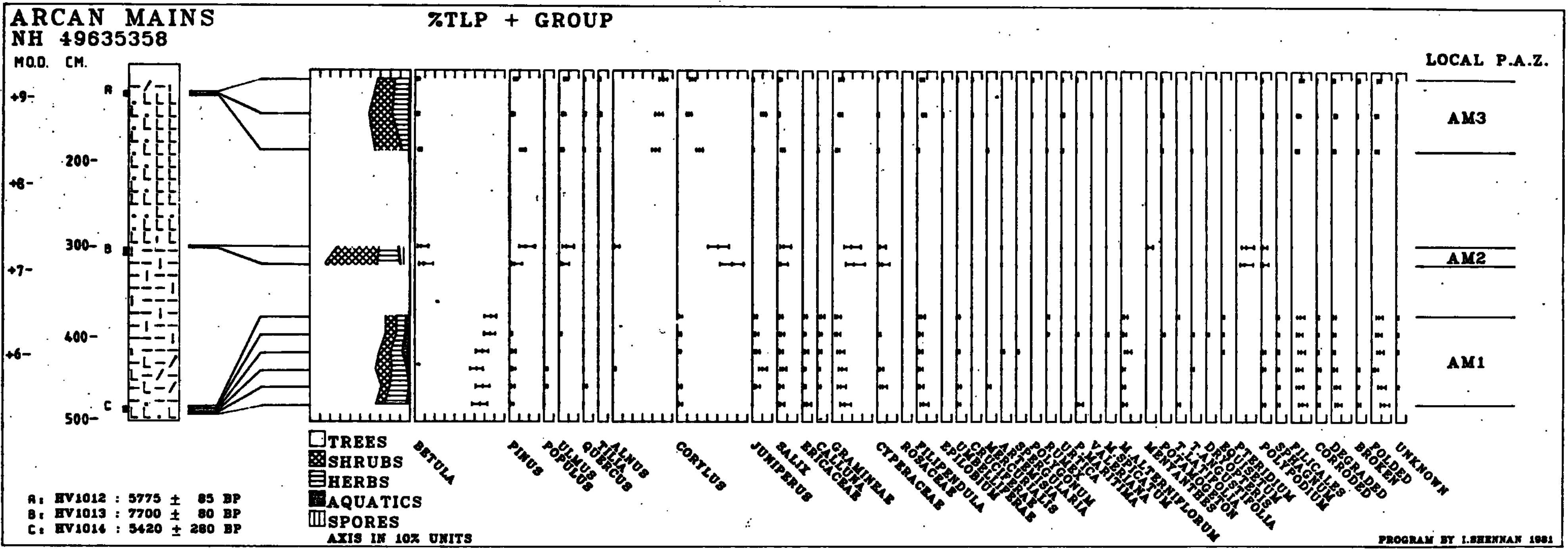
This zone consists of only two levels.Coryloid and Gramineae are the predominant taxa with 40-50% and 18-20% respectively. Concentration values are 71.6 and 87.9 grains x $10^3/cm^3$ and Coryloid is the major contributor.

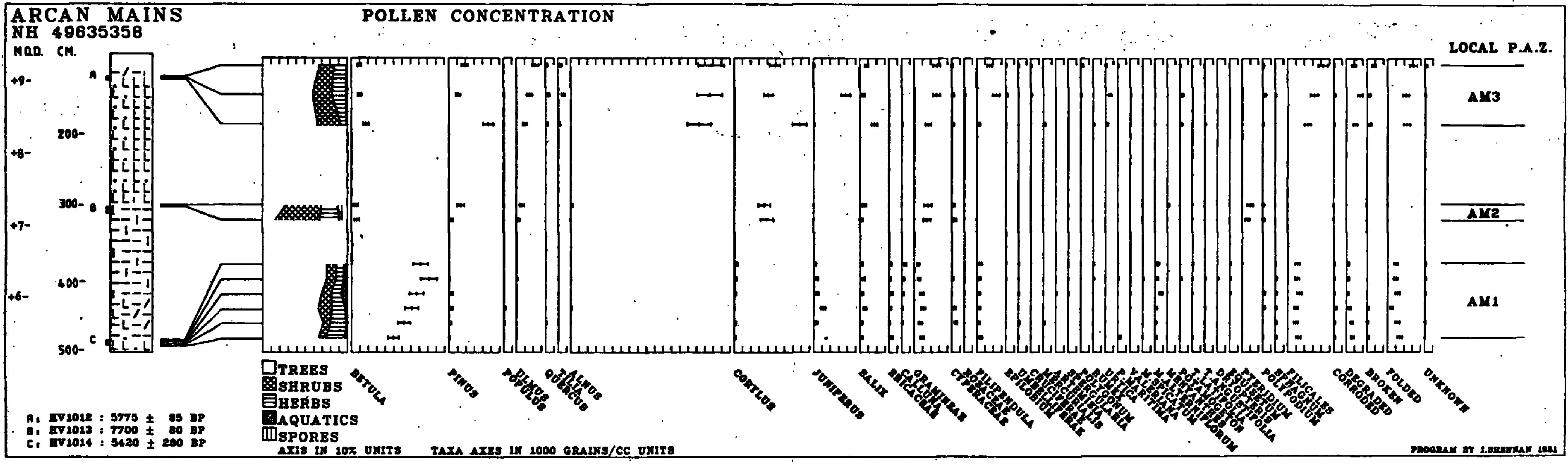
Zone AM3 132 - 128 cm.

The most noticeable feature of this zone is the high concentration and percentage values of *Alnus* at 153 grains x $10^3/cm^3$ and 43.2% at 132 cm. The Coryloid and *Pinus* curves fall from 132 cm. to 130 cm. perhaps reflecting the change from minerogenic to biogenic sedimentation recorded

Fig. 5.26 Arcan Mains, %TLP + Group.
N.B. *Corylus* should read Coryloid.

Fig. 5.27 Arcan Mains, Pollen concentration,
N.B. Horizontal scale should read
"Taxa Axes in 10 x 10^3 grains/cm^3 units"


ARCAN MAINS
NH 49635358
%TLP + GROUP
M.O.D.
CM.
+9-
+8-
+7-
+6-
200-
300-
400-
500-
A
B
C
LOCAL P.A.Z.
AM3
AM2
AM1
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
BETULA
PINUS
ULMUS
POPULUS
QUERCUS
TILIA
ALNUS
CORYLUS
JUNIPERUS
SALIX
ERICACEAE
CALLUNA
GRAMINEAE
CYPERACEAE
ROSACEAE
FILIPENDULA
EPILOBIUM
UMBELLIFERAE
CRUCIFERAE
MERCURIALIS
ARTEMISIA
SPERGULARIA
POLYGONUM
RUMEX
URTICA
P.MARITIMA
VALERIANA
M.SPICATUM
M.ALTERNIFLORUM
MENYANTHES
POTAMOGETON
T.LATIFOLIA
T.ANGUSTIFOLIA
DRYOPTERIS
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
UNKNOWN
A: HV1012 : 5775 ± 85 BP
B: HV1013 : 7700 ± 80 BP
C: HV1014 : 5420 ± 280 BP
PROGRAM BY I.SHENNAN 1981


ARCAN MAINS
NH 49635358
POLLEN CONCENTRATION
M.O.D. CM.
+9-
+8-
+7-
+6-
200-
300-
400-
500-
A
B
C
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
TAXA AXES IN 1000 GRAINS/CC UNITS
BETULA
PINUS
POPULUS
ULMUS
QUERCUS
TILIA
ALNUS
CORYLUS
JUNIPERUS
SALIX
ERICACEAE
CALLUNA
GRAMINEAE
CYPERACEAE
ROSACEAE
FILIPENDULA
EPILOBIUM
UMBELLIFERAE
CRUCIFERAE
MERCURIALIS
ARTEMISIA
SPERGULARIA
POLYGONUM
RUMEX
URTICA
P.MARITIMA
VALERIANA
M.SPICATUM
M.ALTERNIFLORUM
MENYANTHES
POTAMOGETON
T.LATIFOLIA
T.ANGUSTIFOLIA
DRYOPTERIS
EQUISETUM
PTERIDIUM
POLYPODIUM
SPHAGNUM
FILICALES
CORRODED
DEGRADED
BROKEN
FOLDED
UNKNOWN
LOCAL P.A.Z.
AM3
AM2
AM1
A: HV1012 : 5775 ± 85 BP
B: HV1013 : 7700 ± 80 BP
C: HV1014 : 5420 ± 280 BP
PROGRAM BY I.SHENNAN 1981

at the boundary between strata 14 and 15. Also of note is the consistent, if low, value for the Tilia curve. Though only reaching 1.7% at 130 cm. its concentration is 6.0 grains x $10^3/cm^3$, a high value for such a northerly site.

5.3.1.2 AM7 Diatoms

Representative samples were taken from the lower and upper clastic sequences at AM7 and prepared for diatom analysis. Strata 1 to 3 contained no diatoms or fragments of diatoms. Strata 7 to 14 however contained sufficient for counting and a qualitative scan revealed diatoms of fresh to fresh-brackish affinity. Only in stratum 13 at 250 cm., 7.81 m., were diatoms of marine and brackish diatoms found comprising, Paralia sulcata, Nitzschia punctata, Cocconeis scutellum, Diploneis smithii, Cocconeis clandestina, Grammatophora oceanica var. macilenta, Navicula lyra, Navicula clementis and Caloneis formosa.

5.3.1.3 AM7 Particle Size and Loss on Ignition

Eleven samples were bulked from contiguous intervals, usually 5 cm., between 575 and 505 cm. and particle size analysis carried out. A subsample of each was also taken for loss on ignition determination, however none contained more than 1% organic content. The results, tabulated in Appendix III do show a fining upwards sequence from 91% sand at 570 - 575 cm. through 56% sand 40.5% silt at 555 - 560 cm. to 4.5% sand, 75.9% silt, 19.6% clay at 500 - 505 cm.

5.3.1.4 AM7 ^{14}C Dating

3 samples were submitted from AM7 for radiocarbon assay. Full

details are given in Appendix IV on I.G.C.P. sea-level computer forms. The most relevant data comprised however:-

Lab.no.	Hv 10.012	Hv 10.013	Hv 10.014
Depth (cm.)	126 - 131	303 - 308	484 - 490
Altitude (m.O.D.)	9.00 - 9.05	7.23 - 7.28	5.41 - 5.47
Age (B.P.)	5775 ± 85	7700 ± 80	5420 ± 280
^{13}C (%)	-26.7	-26.2	-27.2
Thickness (m)	0.05	0.05	0.06
Components	Sh2 Dl1 Th^{2}1 Ga+ Ag+	Sh3 Th^{2}1 Ga+ Dl+	Sh3 Ga1 Ag+ Dl+ Dh+

CHAPTER 6

ENVIRONMENTAL EVIDENCE FOR SEA-LEVEL CHANGE

6.1 Introduction

The previous chapter provides new data from sites in the inner Moray Firth area for changes in deposition within the coastal zone. This zone is characterized by alternating biogenic and minerogenic sequences, the changes between which are often implicitly accepted as evidence for rises and falls in sea-level. The situation is far more complex however - as Streif (1979) correctly states:

> "Without a doubt, this zone is most sensitive to water-level fluctuations, but the vertical changes of sea level are only one component among a great variety of factors which influence the paleogeographic tendencies of a retreating or prograding coastline" (p.304)

The need to prove that the alternation of biogenic and minerogenic sequences mirror a change in the contemporary sea-level is just as great for the inner Moray Firth area as in areas showing less isostatic uplift. Isostatic recovery contributes only to the rate and direction of sea-level movement, not to the relationship of depositional environment and sea-level.

Many researchers engaged in outlining Flandrian sea-level changes accept that a transgressive overlap is generally good evidence for a positive movement of sea-level. However, especially in areas of little isostatic uplift, stability or subsidence difficulty often arises over the interpretation of the regressive overlap representing a fall in sea-level. It is essentially this debate that has divided studies into two informal schools, those who accept evidence for short term, low amplitude oscillations in sea-level (Fairbridge 1961, Tooley 1974, 1978b) and those who suggest that all the evidence can be explained by a smoothly rising sea-level (Jelgersma 1961).

Kidson and Heyworth (1973, 1979) suggest that the characteristic interfingering of biogenic and marine clastic layers is due to a continuously rising sea-level though the rate of change may vary. Local sedimentation conditions are considered of major importance. The overlap of a peat layer over marine facies is seen as the result of high biogenic sedimentation rates superimposed upon a lower rate of sea-level rise. Storm surges, local changes in the hydrological regime and other coastal processes such as the build-up and break-down of coastal barriers are considered adequate to explain the characteristic lithologic changes encountered. This view is similar to that of Jardine (1975) in his explanation of the regressive overlap of the upper peat in the Lochar Gulf area of the Solway Firth (see Chapter 3).

Tooley (1978a, 1979) cites evidence from north-west England of continuity in deposition and an inherent cyclicity in the removal and replacement of marine conditions as shown by pollen, diatoms and chemical analyses to suggest positive and negative movements of sea-level. At Downholland Moss 15, for instance, the successive pollen assemblages

> "indicate an autogenic plant succession followed by a retrogressive one, from saltmarsh plant communities to reedswamps and oak-dominated fen, back through reedswamps to saltmarsh communities" (Tooley 1979, 504)

When further micro and macrofossil analyses of the clastic layers reveal an increasing followed by a decreasing marine influence

> "the conclusion is difficult to avoid that the changes in water quality and water depth were a consequence of actual changes in the sea-level surface" (Tooley 1979, 504)

The debate has not attracted much attention in Scottish sea-level research primarily because isostatic recovery in conjunction with the eustatic sea-level has produced a series of raised and tilted beaches. Once the succession of shorelines, in effect marine limits, has been determined it can provide an excellent 'sea-level indicator'- defined here as any lithostratigraphic or biostratigraphic evidence used as an indicator to the direction of sea-level movement. The investigation of the Flandrian shoreline sequence of the Forth by Sissons (1966), Sissons et al. (1966), Kemp (1975) and Smith et al. (1978) provided detailed evidence for the direction and relative timing of sea-level movements. When coupled to a sea-level curve based on ^{14}C dated index points of known position in the shoreline sequence it gives incontrovertible evidence for rises and falls in sea-level (Sissons and Brooks 1971).

However where such a comprehensive stratigraphic succession has not yet been developed the interpretation of regressive and transgressive contacts in terms of sea-level movement must be argued from other sea-level indicators.

In the Solway Firth area for example - an area comparable in isostatic uplift to the Tay - the shoreline sequence has not been determined with the result that the sea-level curves produced (figs. 3.1, 2 and 3) have no limits set on the direction of sea-level movement save for the original or derived altitude of the index point and its age. No other sea-level indicators are used and consequently there is no consistent model for the interpretation of transgressive and regressive overlaps. Indeed as noted in Chapter 3 the same regressive contact at Newbie Cottages provides evidence for a rise in sea-level and also the culmination of the Flandrian rise in sea-level in the area.

In the inner Moray Firth area the supporting arguments of a shoreline sequence, more strictly a marine limit sequence, have not been determined. An alternative approach is therefore proposed using other lithostratiigraphic and biostratigraphic sea-level indicators to interpret the peat-clay transitions as vertical movements in sea-level.

In the remainder of the chapter the idea of indicative meaning will be outlined. Indicative meaning (van de Plassche 1979, Shennan 1980) is the concept that plant and animal assemblages and geomorphological features in the coastal zone have a measurable relationship to sea-level. It is an idea that is basic to all attempts at the reconstruction of former sea-levels (Johnson 1931). Some informal and formal models using lithostratigraphic and biostratigraphic sea-level indicators will be used to develop an argument for vertical movements in sea-level. Finally the data presented in Chapter 5 will be interpreted with the aid of these models.

6.2 Indicative range

Underpinning all reconstructions of former sea-level is the assumption that geomorphological features or biostratigraphic assemblages have a relationship to a contemporary tide level (indicative meaning). For instance Scott and Medioli (1978) claim to be able to identify accurately the position of former tide levels in a saltmarsh sequence to an accuracy of ±0.05 m. - in favourable circumstances - using foraminiferid assemblages.

In this study index points have been taken from Phragmites or other monocotyledonous peats and it is the understanding of the indicative meaning of former coastal plant communities that is essential for reconstruction of former sea-levels.

The evaluation of former indicative meanings is based on the study of contemporary indicative meanings. However there is a lack of contemporary sites showing a vegetation succession from low marsh through high marsh to reedswamp and fen woods remaining free from anthropogenic influence. Tooley (1978a) summarized the more relevant data but concludes that:

> "the altitudinal range of peat forming plant communities in the intertidal zone makes the interpretation of boundaries and boundary zones between biogenic and minerogenic strata difficult"(p.21)

However, as Shennan (1980) suggests the question to be asked is whether any reliable estimate can be given of the range over which certain vegetation communities occur with respect to a reference tide level (the indicative range). The size of the indicative range will almost certainly be affected by local factors such as aspect, wave energy, freshwater input and soil conditions but the error can be reduced by only using samples from levels showing a change in the sedimentary environment from saltmarsh to freshwater reedswamp or fen. This is because the transition between the zones does not have an indicative range equal to the sum of both. Homogeneous layers are therefore less useful in reconstructing former sea-levels.

Shennan (1980) using information from Kidson and Heyworth (1979), van de Plassche (1979) and Tooley (1978a) provides a table of indicative range of commonly dated material.

TABLE 6.1

	Indicative range (cm)	reference water level
Phragmites or monocot. peat		
directly overlying saltmarsh	20	M' - 20 cm.
directly below saltmarsh	20	MHWST - 20 cm.
above fen wood peat	20	MHWST - 10 cm.
below fen wood peat	20	M' - 10 cm.
middle of layer	70	infer from stratig.
Fen wood peat		
directly overlying _Phragmites_ or saltmarsh deposit	20 cm.	M'
directly below _Phragmites_ or saltmarsh deposit	20 cm.	MHWST

M' = HAT + MHWST/2

These proposed values for reference water level contain two factors, a constant and a tidal factor which means the importance of the indicative range is dependent on the tidal range. For example the indicative range of a _Phragmites_ peat below a saltmarsh deposit (i.e. at a transgressive overlap) is in effect at a former MHWST - 20 ± 10 cm. This will encompass a greater proportion of the tidal curve in areas of low tidal range as opposed to areas of high tidal range. This has important repercussions in comparing sea-level curves from areas of differing tidal range and much more research needs to be undertaken on relating indicative range to proportions of the tidal curve (Shennan 1980). The proposed values for indicative range (table 6.1) will be used as an aid to the construction of a sea-level curve in chapter 7.

No published Flandrian sea-level curve for Scotland includes an explicit statement on the indicative range of the index points, nor which reference tide level the curve is supposed to represent. Peacock et al. (1977) and Peacock et al. (1978) do add error boxes for the altitudinal error on the index points which do include implicit use of the indicative range of certain marine molluscs. These curves are for the Late Devensian (fig 3.1, 4, 5).

6.3 Lithostratigraphic and biostratigraphic indicators of sea-level change

Once the relationship to a tide level of the feature to be used in reconstruction has been assessed the next step is the interpretation of the change in sedimentary environments in terms of sea-level movements. In the inner Moray Firth the shoreline sequence (sensu Sissons 1976) has not been determined and the assessment of tendency of sea-level movement depends on other sea-level indicators.

Shennan (1980) provides a lithostratigraphic model based on the work of Streif (1979) that is applicable in part to the successions found in the inner Moray Firth. He considers that only through evaluating the tendencies of sea-level movement using a number of indicators can vertical movements, especially negative ones, be proved. Streif (1979) provides three situations which can individually reveal negative movements of the watertable. These are:-

- fen peat layers which can occur within an intercalated peat layer or in a perimarine peat
- horizons of decomposition within fen peat layers
- soil horizons which cannot form below the water table nor below mean high tide level and their occurrence on top of tidal flat and lagoonal sediments can indicate a fall in watertable.

The evaluation of sedimentation rates is extremely important in the assessment of sequence development, especially since it is acknowledged that peat formation can keep pace with, and exceed sea-level rise in certain contexts, as at Flanders Moss (Sissons and Smith 1965). An important concept here is the equilibrium position of accretion and sea-level movement. According to Kidson and Heyworth (1979) vertical accretion is limited to the top of the contemporary high marsh and this probably represents the equilibrium position. Undoubtedly a prime factor in sedimentation rates and the vertical and horizontal succession of vegetation zones is the rate of sea-level movement. A change in the rate of sea-level rise would shift the equilibrium position to the low marsh, the high marsh environment would become narrower and if looked at in cross-section, coarser sediments would be deposited nearer to the transgressive overlap of the organic layer beneath. With the reverse, an increase in the rate of sea-level fall, the equilibrium zone is within the high marsh and this causes the depositional zones to wedge out in a seaward direction (Shennan 1980).

One possible method of evaluating sedimentation rates in both minerogenic and biogenic layers is through pollen concentration techniques. If pollen influx can be regarded as constant then changes in pollen concentration should reflect changes in sedimentation rate. It is unlikely that pollen influ x could ever be regarded in this study as constant, however, due to changes in the regional forest composition caused by immigration of new species and changes in local pollen production and preservation consequent upon environmental change.

Pollen and diatom evidence for consistent change in environment, coupled with lithologic changes outlined above, constitute sea-level indicators which taken together give good evidence for sea-level change.

The Moray Firth area has undergone considerable post-glacial uplift. Shennan (1982) considers that in an uplifted area the registration of a positive tendency of sea-level movement is more than a local phenomenon. Since isostatic uplift operates in the opposite direction only when the rate of eustatic sea-level rise exceeds the rate of isostatic uplift will a rise in sea-level be recorded. Similarly a fall in sea-level will be amplified.

Therefore in an uplifted area where a transgressive and regressive overlap sequence can be shown to be transitional, if an age and altitude range can be demonstrated along both contacts then factors of regional significance can be identified.

The corollary is of great importance in correlation. In a subsiding area where a regressive overlap is suggested to represent a fall in sea-level then this is likely to be an event of regional significance.

6.4 Interpretation of data in terms of sea-level movement

The remainder of the chapter will deal with interpretation of the pollen diatom, stratigraphic and ^{14}C data presented in Chapter 5 in an attempt to produce evidence for sea-level change. An attempt will also be made to assess the scales at which these interpretations are valid. Only brief account will be taken of the chronology of events. This will be discussed fully in Chapter 7.

6.4.1 Barnyards 3B

The stratigraphy of the lower clastic sequence at BY3B comprises two units, lower laminated grey sands and silts and an upper homogeneous grey sandy silt. The presence of laminated units within the coastal sequences has often been taken to indicate an intertidal environment (Tooley 1978a).

Certainly diatom zones BY3BD1 and 2 show a mixture of fresh,brackish and marine forms such as Achnanthes delicatula - a brackish epiphyte, Opephora martyii - a fresh-brackish epiphyte and Paralia sulcata - a marine planktonic form, which would tend to support such a hypothesis.

Above 400 cm. the marine influence demonstrated by such diatoms as P. sulcata, Podosira stelliger, Grammatophora oceanica var. macilenta, Biddulphia aurita and Actinoptychus undulatus decreases and the diatom spectra becomes almost monodominant with the rise of the brackish benthonic form Diploneis interrupta. This brackish zone corresponds approximately to stratum 2 between 393 and 402 cm. Pollen concentration in this stratum is uniformly low and with a high percentage of Filicales spores it probably indicates poor pollen preservation caused either by increased mechanical destruction or a decreased tidal cover allowing oxidation. The good preservation of diatom frustules and gradual decrease in particle size support the latter. A third interpretation could be that the stratum 2 represents a small channel deposit or pipe fill, common on salt marshes in the area today (Kesel and Smith 1978).

Pollen content is little help in interpreting environments of deposition within the lower clastic sequence. The major component of the tree pollen is Betula which is a characteristic feature of early Flandrian pollen diagrams from northern Scotland.

The transition to the biogenic layer stratum 3 is sharp, over 1 cm, is in accord with the models of Shennan (1980) and Kidson and Heyworth (1979) for the regressive overlap near the seaward extreme of biogenic sedimentation under an increased rate of sea-level fall.

A single diatom count from the base of the peat at 392 cm. includes the fresh diatom *Pinnularia subcapitata* which is also an acidophile tolerant of habitats with a pH between 4.0 and 8.0. The occurrence of seeds attributable to *Juncus effusus* type and one to *J.geradii* suggest slightly acid waterlogged conditions. *J. geradii* is an important component of the upper saltmarsh and commonly found in estuarine-marine deposits of Flandrian age (Godwin 1975). However the diatom spectrum at 392 cm. still contains a large element of brackish and marine forms also.

The pollen data for BY3B2 supports the suggestion of an upper saltmarsh - reedswamp environment since the zone contains Gramineae in high percentages, probably attributable to *Phragmites*, the rhizomes of which are abundant in the stratigraphy. The marked rise in pollen concentration through the zone is a remarkable feature of the site (fig.5.8). It is probably due to an increase in pollen production by reedswamp vegetation but also perhaps to an increase in pollen preservation in the prevailing waterlogged conditions allowing the regional pollen rain to be preserved with the increased local pollen contribution.

The marked rise in Coryloid pollen at the beginning of zone BY3B3 is a further notable feature of the pollen diagram. It may represent a slight lowering of the watertable allowing *Corylus* to colonize drier areas in the vicinity, or alternatively it could be explained in climatic terms. The *Corylus* rise is a widespread feature in British pollen diagrams and has traditionally been used to delimit the Godwin zone IV/V boundary (Godwin 1940b)and the Flb/c chronozone boundary (Hibbert & Switsur 1976). *Corylus* is considered a high pollen producer in open conditions (Birks 1973) and the high pollen frequencies recorded may suggest small amounts of the shrub growing in the local area.

There is supporting evidence for a slight fall in watertable. Seeds attributable to Juncus effusus type are common to 389 cm. Filipendula, Chenopodiaceae and Umbelliferae pollen decline at this level also. In addition the appearance of desmids at 389 cm. points to a slight lowering of the watertable and a disappearance of brackish conditions. Kidson and Heyworth (1979) suggest that desmids are useful indicators in defining the upper limit of standing brackish water. The interpretation is only one of degree for the continued high values of Gramineae through zone BY3B4, together with the continued presence of Chenopodiaceae and the appearance of the aquatics Potamogeton and Typha latifolia, illustrate reedswamp conditions persisted throughout the formation of the peat layer.

The transgressive overlap is gradual above 376 cm. and diatoms show little variation throughout zones BY3BD5 and 6 with a mixture of fresh, brackish and marine forms suggesting little change in water depth or salinity. Three particle size determinations show a lack of the sand and coarser fractions suggesting a position high in the tidal range.

Strata 6 to 9 show a slight coarsening of the particle size distribution and a decrease in organic content reflecting an increase in water depth. The existence of an iron-stained layer to a depth of c. 220 cm. suggests a subsequent fall in watertable and by implication sea-level.

In conclusion the lithostratigraphy and biostratigraphy of the deposits recorded in BY3B suggests a gradual decrease in water depth from intertidal through saltmarsh to reedswamp formation. The entire peat layer is probably attributable to deposition in a reedswamp environment, perhaps with some slight evidence for a lowering of the watertable but not of sufficient duration or magnitude to allow fen woods to colonize the site. Above the peat layer the transition to intertidal conditions and full marine cover is gradual, without any discernible hiatus. A final fall in watertable is inferred from the presence of the iron stained layer to a depth of c. 220 cm.

6.4.2 Barnyards 14B

Although no diatoms were counted through the lower clastic sequence at BY14B, strata 4 to 6 are interpreted as marine or estuarine in origin. Particle size analysis (fig. 5.11) shows a predominance of the silt and clay fraction and a tendency to fine upwards towards the regressive overlap. Stratum 5 is considered to be a reworked deposit consisting of intermixed peat and silty clay. The presence of peat balls is not uncommon in Flandrian marine sediments. At Innernethy in lower Strathearn a similar peat band, 1 cm. thick, lies 18 cm. below the base of the main peat bed. Its presence is taken to prove that the buried shoreline of the estuarine deposits upon which the main peat bed rests is transgressive in character (Cullingford et al. 1980). Greensmith and Tucker (1973) consider that peat balls are a product of erosion on saltmarshes and require only the existence of a peat seam or plant rich clayey-silt layer within or at the surface of the marsh undergoing erosion, it does not require a specific direction of sea-level change. The pollen content of stratum 5 is essentially the same as the lowermost levels of the main peat layer suggesting little difference in age. It is considered here that the reworked nature of stratum 5 represents a phase of channel cutting during a period of sea-level fall.

The transition from the lower clastic sequence to the lower peat layer is again sharp, over 1 cm., which is contrary to the suggestion of Shennan (1980) that the transition zone of a peat layer should be thicker at landward sites under conditions of an increasing rate of sea-level change. This could be taken as an argument for an initial rapid rate of sea-level fall since in an uplifted area isostatic recovery would tend to increase the rate of sea-level fall. Alternatively it could suggest an hiatus in deposition.

Pollen in stratum 6 at 366, 364 and 363 cm. contains no indication of an hiatus. High values of Gramineae, Cyperaceae and the sporadic occurrence of Chenopodiaceae is interpreted as evidence for a reedswamp environment. The transition to biogenic sedimentation is marked by a significant increase in total pollen concentration to 45.0 grains x $10^3/cm^3$, by an increase in the broken and folded classes of determinable pollen (fig. 5.11) and the broken, folded and concealed classes of indeterminable pollen (fig.5.9). The environment during the transition was probably one of reedswamp with Salix carr and Corylus on the surrounding drier areas and slopes overlooking the site.

The Coryloid curve is considered to represent the presence of Corylus rather than Myrica. Myrica gale grows in acidic fen conditions of extreme oligotrophy or eutrophy and is common in the area today (Duncan 1980). Chesters (1931) reported the macrofossil remains of Myrica from the basal layers of an oligotrophic peat overlying the "50' beach" near Crinan. At Barnyards and Moniack however the pollen and stratigraphic evidence suggests that suitable acid conditions preferrred by Myrica were not present. Most peats encountered are considered eutrophic with no evidence of ombrogenous peat development.

Of note also in the transition zone and basal layers of the lower peat at BY14B is the Juniperus curve which shows a peak of 19.0% at 360 cm. Juniperus does not reach above 2% throughout the deposition of the thin peat layer at BY3B and this is taken to suggest a distance decay effect away from the source area of the Juniperus pollen which would probably be located on the driver slopes to the east of the sampling site.

It could also be taken as evidence for the time-transgressive nature of peat development at Barnyards. In pollen zones BY14B2 to 4 there is a record of the rise in Coryloid pollen - again probably attributable to Corylus - at the expense of Betula perhaps reflecting competition between these species.

There is evidence for watertable fluctuations throughout the formation of the lower peat. High Gramineae, Cyperaceae, Salix, Filipendula and Potamogeton values suggest an environment transitional between reedswamp and freshwater fen dominated by Salix with a high watertable during zones BY14B1 and 2. Between 286 and 346 cm. the stratigraphy comprises a monocotyledonous peat with woody detritus and this corresponds with the disappearance of the aquatics Potamogeton and Myriophyllum alterniflorum which suggests a slight lowering of the watertable allowing the Salix fen to be colonized by Corylus. Additional support is given by the low pollen count at 319 cm. At first, this was considered an error in the pollen preparation technique but an adjacent sample from 320 cm. also showed a scarcity of pollen. Total pollen concentration at this level is only 11.4 grains x $10^3/cm^3$.

During zone BY14B4 the Coryloid curve reaches a consistently high value of 33-63% but towards the top of the zone aquatics, such as Potamogeton and Typha angustifolia return with other indicators of waterlogged conditions such as Equisetum and Filipendula. This suggests a rise in watertable.

The transgressive overlap of the upper peat layer is clearly erosional with a large piece of coarse gravel 55 x 40 x 26 mm. resting directly on the peat. Pollen supports this conclusion : there are taxa indicative of a rise in watertable but there is no suggestion of a return to reedswamp or saltmarsh conditions.

The intercalated minerogenic layer which consists of a lower light grey micaceous sand and gravel and fines upwards contains the highest total pollen concentration recorded at the site, 259.9 grains x $10^3/cm^3$ at 170 cm. Most is contributed by Pinus which reaches 138.3 grains x $10^3/cm^3$. High values of pine pollen in marine or estuarine deposits are a common occurrence. Godwin (1975) notes that:

> "where estuarine clays occur between peat layers the clays invariably yield high values for the percentage of contained Pinus pollen, values greatly in excess of those in the adjacent peat layers" (p.106)

Reasons given for the high Pinus frequencies include long distance wind transport, surface drifting, differential destruction and the incorporation of secondary pollen by the erosion of pine peat layers. Pinus pollen is well known for its buoyancy in water and this factor combined with one or all of the above reasons probably contributes to the high values encountered. There is evidence that Pinus immigrated into the immediate area prior to the clastic sedimentation of stratum 10, indeed the lower boundary of zone BY14B is located at a significant rise in Pinus.

No diatoms were counted through the upper marine clastic layer of the interfingering sequence at BY14B and therefore statements of changing water depth and salinity are not possible at present. The sequence does show a marked fining upwards however.

The transition to the upper peat layer was not sampled but the lowermost pollen spectrum of this peat layer does show high values for Gramineae both in percentage and concentration, abundant Phragmites rhizomes recorded in the stratigraphy, Chenopodiaceae pollen and inclusions of silt. A Phragmites reedswamp environment is therefore inferred.

Zone BY14B7 contains a decline in Pinus and an increase in Alnus pollen representation. The decline in Pinus pollen can in part be regarded as due to the reversion to biogenic sedimentation eliminating the bias given to Pinus pollen in marine sediments by its buoyancy. The expansion of Alnus to form an Alder carr with Corylus may also have contributed to the decline by filtering out more Pinus pollen from the regional pollen rain.

It is interesting to note that Alnus fills the niche that Salix developed in the lower peat, values of Salix are only sporadic in the upper peat. Evidence also exists for a falling watertable. This is suggested by the presence of woody detritus in the matrix of the peat, a horizon with little pollen (total concentration = 8.7 grains x $10^3/cm^3$) at 130 cm. and an increase in the corroded class of determinable pollen (fig.5.11).

Above 130 cm. damper habitats and a rise in watertable are inferred from spores of Selaginella selaginoides, a clubmoss which occurs in damp slacks along the present coast (Duncan 1980) and Equisetum. This interpretation is supported by the pollen of the aquatics Potamogeton and Myriophyllum spicatum.

The minerogenic layer overlying the upper peat at BY14B is interpreted as a colluvial deposit consisting of yellow-brown silty sand and gravel with iron-staining and little organic content.

In conclusion environmental evidence suggests a decrease in water depth with a gradual transition to reedswamp at the base of the lower peat. Within the lower peat there is an indication of a fall in watertable with the development of Salix-fen. There is also some evidence for destruction of some pollen types perhaps by oxidation. Increased frequencies of pollen of damp-loving and aquatic taxa suggest a rise in watertable towards the transgressive contact though the erosive nature of that contact has removed evidence, if any, for a return to reedswamp and saltmarsh conditions.

The intercalated marine clastic layer shows evidence for a fining upwards sequence interpreted as a decrease in water depth.

The upper peat at BY14B contains evidence for an initial reedswamp community succeeded by an Alder carr with Corylus and the woodland epiphyte Polypodium which suggests a lowering of the watertable. Towards the top of the peat the return of aquatic pollen and other indicators of damp conditions suggests a return to wetter conditions.

6.4.3 Barnyards - site interpretation

The Barnyards site provides some very good indicators of the tendency of sea-level movement. The lower regressive contact is interpreted as representing a fall in sea-level. The altitude of the regressive overlap falls from 8.76 m. at BY14B to 1.94 m. at BY3B and an age difference of c.400 years is inferred from one radiocarbon date at BY3B (9200 ± 100 B.P. Hv 10.010) and pollen evidence at BY14B (see Chapter 7). This variation of age and altitude is considered a good indicator of sea-level movement. Consistent environmental change from an intertidal deposit to a reedswamp is recorded at BY3B while at BY14B to landward, a reedswamp community is succeeded by a Salix-fen with some evidence for a decomposition layer.

The transgressive overlap also shows a measurable age gradient even though the contact is erosive at BY14B. The altitude of the transgressive overlap also varies from 2.11 m. at BY3B to 7.88 m. at BY14B, a rise of 5.77 m, again supporting the evidence of a rise in sea-level. Further indications are given by a rise in watertable at BY14B below the erosion contact and at BY3B a reedswamp environment changes to a saltmarsh environment.

The upper regressive contact does not show a difference in altitude or age though a fall in sea-level is inferred since the stratigraphy and pollen at BY14B show a reedswamp to Alder fen succession and at more seaward sites the presence of iron-stained horizons in the upper layers of the upper clastic sequence strongly supports a fall in watertable.

Because the site is on a relatively open coast and because of the measurable age and altitude gradients on two of the contacts, the Barnyards site is considered to contain evidence for regional changes in sea-level. The detailed evidence outlined for the site will therefore be used as an informal model to supplement the data from other sites in the area.

6.4.4 Moniack 29B

M29B is a complex core since it comprises six biogenic layers and six minerogenic layers, the lower three of which are considered to represent marine events.

The lowermost pollen spectrum is at 685 cm. in stratum 3 at the transition between the lower clastic sequence and lower peat. The depositional environment of the lower clastic sequence at M29B is uncertain since no diatoms have been preserved. However shell fragments presumed to be of marine origin were found in a similar stratigraphic position in the adjacent M29A borehole. Stratum 2 at M29B contains bryophyte remains attributable to Fontinalis sp. at 690 cm. which suggests the presence of small pools or streams in the vicinity. The lowermost pollen spectrum reveals a high total pollen concentration of 160.6 grains x $10^3/cm^3$ though nearly all is contributed by Cyperaceae. Pollen of Gramineae, spores of Equisetum and a seed of Juncus articulatus type all suggest an open reedswamp area with pools of water and a vegetation cover of sedges, grasses and rushes. No evidence for saltmarsh vegetation is present, though the stratigraphy does not indicate a depositional hiatus.

Strata 4 to 6 have been correlated with the grey silty sand layer in M4B (6.87 - 7.24m.) which contains marine diatoms. Two pollen counts below this layer in M29B contain Cyperaceae, Gramineae, Filipendula and spores of Equisetum and Selaginella which suggest a high watertable prior to clastic deposition. The stratigraphy of stratum 3 shows little internal variation and gives no evidence for succession to fenwood environments, indicating reedswamp conditions persisted throughout.

At 649 cm. in stratum 4 seeds of Carex sp. and Menyanthes trifoliata are indicative of freshwater littoral habitats which could suggest only strata 5 and 6 relate to a marine event.

The two pollen spectra above the inferred marine layers show a return to an almost identical environment of open reedswamp with standing fresh water, though the increase of Coryloid pollen to 38.1% may reflect some colonization of Corylus onto the bog surface.

The clastic strata 10 to 14 contain abundant diatoms (figs.5.19 and 5.20). The transgressive overlap with stratum 9 is erosional. The diatom assemblage in zone M29BD1 shows no evidence of transition with the marine planktonic form Paralia sulcata reaching 84.5% of total valves at 600 cm. If the data are considered as a sum of total species then the swamping effect of P.sulcata can be gauged. Even so there is a complete lack of diatom species with an affinity to fresh and fresh-brackish water conditions and an interpretation of fully marine conditions during zone M29BD1 is hard to escape.

The abrupt change to a brackish diatom assemblage zone M29BD2 dominated by Diploneis interrupta is correlated with a change in stratigraphy from a light grey clayey silt, stratum 13, to a grey silty clay with monocot. rootlets at 441 cm, 8.91 m. O.D. As in zone BY3BD3 at Barnyards Diploneis interrupta becomes almost monodominant. Other species include Diploneis ovalis and Navicula pusilla, both indicative of an upper saltmarsh environment (Round 1960). D. ovalis is also able to withstands periods without water cover. The continued presence of Paralia sulcata (c 1-3% total valves) suggests periodic marine inundation.

The isolation contact is a concept used by Fennoscandian researchers to denote the change from brackish to fresh conditions in lake basins consequent upon isostatic uplift raising the threshold of the lake basin above the level of marine activity (e.g. Alhonen, 1971, Eronen 1974, Kjemperud 1981). However at M29B because of the dominance of Diploneis interrupta when calculated as a percentage of total valves the fresh and fresh-brackish zone is restricted. If a sum using % species is used the fresh and fresh-brackish curve rises dramatically to c. 60% (fig.5.20). Therefore whether or not an isolation contact is defined depends entirely on the sum used.

A thin peat band, stratum 15, between 393 and 398 cm. (9.34-9.39 m.) marks the return to biogenic sedimentation and provides evidence consistent with a reduction in water depth and the removal of marine conditions. One pollen spectrum from 395 cm. shows a high concentration of Alnus, Gramineae and Equisetum. The proximity of the high ground of the eastern crag and tail feature could have provided a suitable habitat for Alnus with reed-swamp vegetation at the sampling site.

Above the thin peat layer is a series of three minerogenic and three biogenic layers. The minerogenic layers are totally dominated by fresh and fresh-brackish forms and are interpreted as alluvial or lake deposits. The Moniack alluvial fan provided a possible dam to the north east and any water held behind it would also be enclosed by the high ground of the eastern crag and tail feature and the high ground of Cabrich to the south and east. Ephemeral shallow lake deposits could have accumulated behind the alluvial fan until the outlet lowered the threshold. An alternative explanation could be that the three minerogenic and three biogenic layers represent a gradual filling-up process with renewed clastic deposition caused by renewed activity of the Moniack alluvial fan.

The first non-marine clastic layer comprising stratum 16, 333-393 cm. is a grey-brown clayey silt and includes certain diatoms indicative of oligotrophic conditions such as Pinnularia gibba, P.mesolepta, *Eunotia pectinalis*, *Tabellaria flocculosa* and *Frustulia rhomboides* which can indicate dystrophic conditions. A seed of *Carex rostrata* at the transition to the overlying peat suggests a shallow aquatic environment with standing or slowly flowing water.

The overlying peat layer strata 17 and 18 contains rhizomes of *Phragmites* and high Gramineae pollen frequencies, *Potamogeton* pollen and seeds attributable to *P.natans* and *P.c.f. alpinus*, an *Hippuris vulgaris* seed and pollen of *Typha angustifolia* all suggesting an open reedswamp area with shallow pools.

Two further clastic and biogenic layers overlie strata 17 and 18 but the processes of formation and environments of deposition are similar to the first example. One feature worthy of note is the development of *Salix* fen during zone M29B4 largely at the expense of *Alnus*.

In conclusion the paucity of biostratigraphic evidence for the basal peat at M29B allows no firm conclusions to be made concerning the transition to the lower peat. The peat itself was probably formed entirely by reedswamp communities and there is little evidence for watertable fluctuations. Strata 5 to 6 at least are considered to be marine in origin by analogy with M4B, however bad diatom preservation precludes any positive conclusions on changes in water quality and depth. The peat layer above shows a return to reedswamp conditions with little differentation in habitat discernible. The transgressive overlap to the marine clastic sequence of strata 10 to 14 is erosional with the superposition of marine sediments directly on peat.

Diatoms through this layer show marine conditions obtained to c.440 cm. above which the increase in brackish taxa and a change in the stratigraphy is interpreted as a decrease in water depth and salinity. The peat layer marking the return to terrestrial sedimentation is only thin yet suggests the environment of deposition was that of a reedswamp.

Above the marine clastic layers lie three biogenic and three clastic layers, the latter are interpreted as shallow lake deposits formed behind the dam afforded by the Moniack fan. Subsequent changes in watertable movement and sedimentation regime are not considered to have a marine cause.

6.4.5 Moniack 4B

No pollen was counted for M4B so information is only available from diatom counts through the minerogenic layers and from the stratigraphy. Stratum 1 contains evidence for a reedswamp environment with abundant Phragmites rhizomes recorded. The contact with the overlying clastic layer is however clearly erosional with stratum 2, a dark grey micaceous silty fine sand containing the marine diatom Paralia sulcata in frequencies of 25-30%. There is a suggestion of transition however with fresh-brackish and brackish forms including Amphora ovalis, Navicula radiosa, N.peregrina, N. digitoradiata, N. elegans, Caloneis formosa and Diploneis interrupta in the lower levels of zone M4BD1. Although redeposited at M4B certain of these forms, including Navicula peregrina, N. radiosa, N. elegans and Achnanthes lanceolata were found living by Round (1960) exclusively on the higher parts of the vegetated saltmarsh.

The decrease of fresh-brackish and brackish forms coincides with increases in marine and marine-brackish diatoms including Paralia sulcata, Grammatophora oceanica var. macilenta, Cocconeis scutellum and Rhabdonema minutum, the latter three species of which were considered by Edsbagge (1965) to favour the west coast living as attached forms down to 15-20 m. water depth. An increase in water depth through zone M4BD1 is inferred.

M4BD2 is dominated by the brackish water species Navicula peregrina which reaches 77.2% total valves. With the reappearance of the fresh-brackish species Amphora ovalis and Navicula radiosa together with the persistence of the marine planktonic form Paralia sulcata, an upper saltmarsh environment with both freshwater and marine influences is inferred. The supposition of decreasing water depth and a transition from saltmarsh to reedswamp is supported by a decrease in particle size and an increase in organic content between strata 4 and 5, stratum 6 contains abundant Phragmites rhizomes.

There is little evidence of vegetation succession within the thin (16 cm) Phragmites peat of strata 6 and 7. The transition to minerogenic sedimentation is gradual and the two diatom counts at 400 and 410 cm. that comprise zone M4BD3 do show a gradual increase in marine and marine-brackish species.

6.4.6 Moniack - Site Interpretation

The overriding difficulty with Moniack as a site for the interpretation of sea-level changes is that it lies landward of the marked constriction provided by the Moniack alluvial fan. Changes in sedimentation regime from biogenic to minerogenic could therefore be caused by the periodic build up and breakdown of barriers to seaward. Due to difficulties in sampling only a small number of borings were put down through the surface of the fan and these were all towards its edge. Consequently the exact nature of its extent through time is not known. However certain suggestions can be made:-

(1) In all the deeper boreholes the lower peat layer of the splitting up sequence appears to be intact save for M26 where it has been eroded by subsequent marine action.

(2) In all boreholes save for those nearer to the alluvial fan, M12, 26, 41 and 42 the blue grey silty clay unit above the lower peat is also undisturbed. In M12 and M26 only the upper part of this unit has been eroded by alluvial or colluvial action. In M41 and M42 however

diatoms sampled in the field suggest all the clastic layers are non-marine in origin.

(3) In certain boreholes clastic material of non-marine origin is present only at altitudes above the regressive overlap of the blue-grey silty clay unit e.g. M6, 7, 8/24, 10, 11, 29A, 29B, 30, 31 and 32.

The evidence points therefore to a renewal of activity on the Moniack alluvial fan contemporary with or slightly after the culmination of marine conditions. It is suggested therefore that prior to this time the Moniack fan had not completely blocked the entrance to the Moniack site, however what effect the variation in width of constriction had on palaeotidal range is unknown. Boreholes M43, 44 and 45 to the east of the fan show little consistency in stratigraphy and do not help resolve the problem.

The regressive overlap above the lower clastic sequence does show evidence for a measurable fall in altitude over and above differences contributed by post-depositional processes. It falls from 7.48 m. at M1 to 4.33 m. at M9 though nearer the Moniack alluvial fan it rises again suggesting local control over sedimentation. The contact is transitional and therefore in an uplifted area must have an age gradient. This suggests a fall in sea-level, though the gradient of the contact is half that of the lower regressive contact at Barnyards. This suggests local factors contributed to the formation of the overlap.

The transgressive overlap of the lower peat rises from 5.53 m. at M7 to 9.95 m. at M1, a difference of 4.42 m. Even though some contacts are clearly erosional, as diatoms show at M29B, the gradient is taken to represent a time-transgressive sea-level rise over the land surface of regional significance.

Within the blue-grey silty clay sequence at Moniack there is evidence for a grey silty sand layer, the top of which ranges from 6.12 m. at M11 to 8.09 m. at M32. In places it is intercalated with peat layers as at M4B and M5A. At M4B diatoms show an initial erosive phase followed by gradual decrease in water salinity and depth and a transition to a thin Phragmites peat layer. It is considered to have been formed rapidly and probably represents a temporary increase in the rate of sea-level rise. The fact that the peat layer overlying it at M4B is composed entirely of Phragmites with no evidence for a fall in water-table confirms that the deposition of the grey silty sand layer took place within a period of more gently rising sea-level.

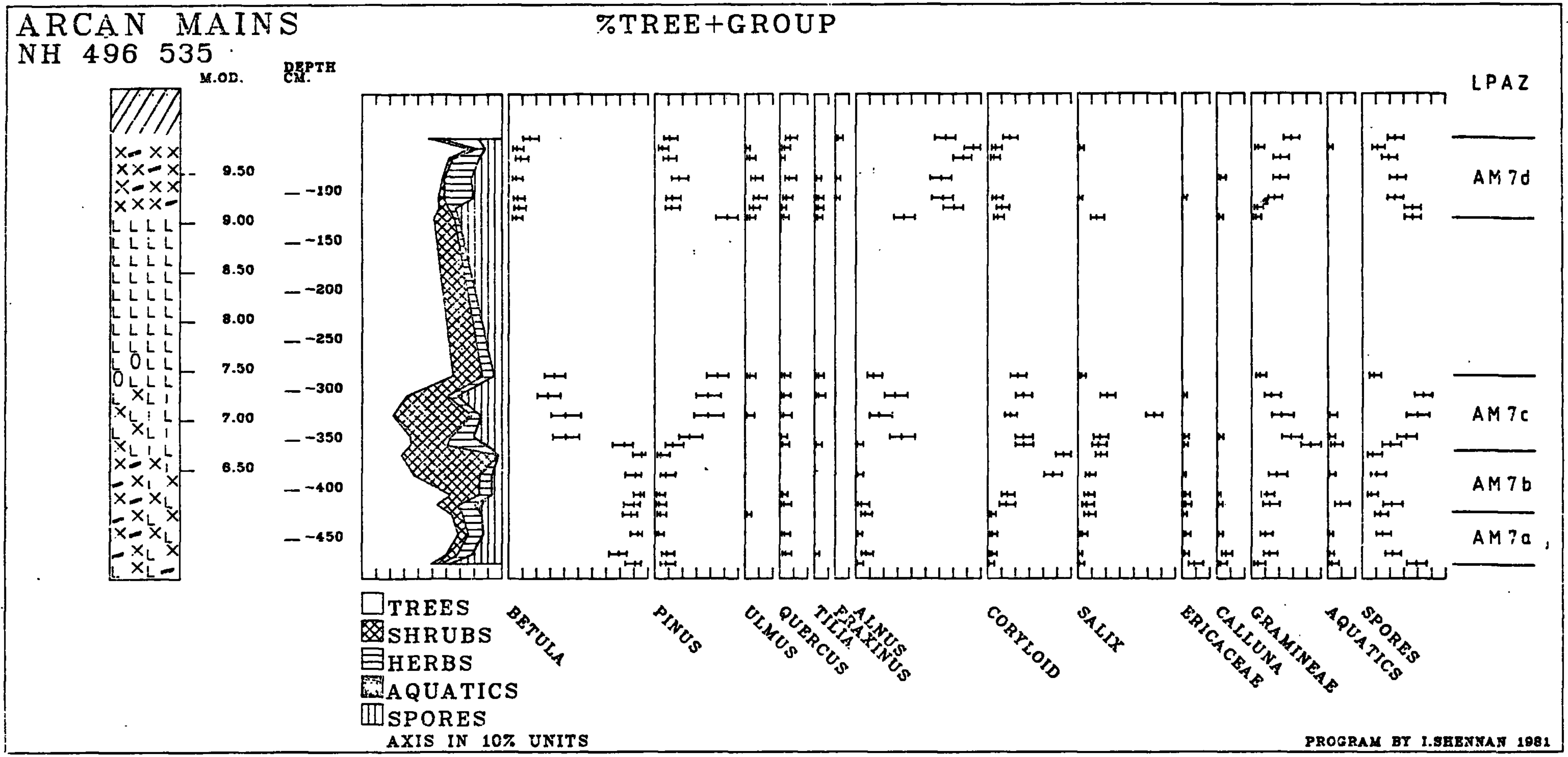
The regressive overlap above the marine blue-grey silty clay sequence is transitional as diatoms and pollen indicate at M29B. The overlap falls in altitude from M1 to M4A but seawards of M4B the overlap rises and continues with little altitudinal change. This is taken to suggest that local conditions of sedimentation contributed to the formation of the overlap. As an index point this overlap would therefore only be of local significance.

6.4.7 Arcan Mains 7

One full pollen diagram exists from Arcan Mains (Davis 1979) and selected curves are shown in fig. 6.1 using pollen counts by Davis.

No micro or macrofossil evidence is available from the lower clastic sequence at AM7 and its depositional environment is therefore unknown. Pollen from stratum 3, zone AM1 shows little variation in composition. High Betula values with Juniperus, Ericaceae and Calluna suggest a birch-juniper heath type of vegetation on the slopes surrounding the site with waterlogged conditions present at the site itself. This is demonstrated by pollen of Filipendula, Myriophyllum spicatum, M.alterniflorum, Potamogeton, Typha latifolia, Equisetum and Sphagnum.

Fig. 6.1 Arcan Mains Pollen Diagram after Davis (1979).
Only selected curves shown.


ARCAN MAINS
NH 496 535
%TREE+GROUP
M.OD.
DEPTH CM.
9.50
9.00
8.50
8.00
7.50
7.00
6.50
-100
-150
-200
-250
-300
-350
-400
-450
BETULA
PINUS
ULMUS
QUERCUS
TILIA
FRAXINUS
ALNUS
CORYLOID
SALIX
ERICACEAE
CALLUNA
GRAMINEAE
AQUATICS
SPORES
LPAZ
AM 7d
AM 7c
AM 7b
AM 7a
TREES
SHRUBS
HERBS
AQUATICS
SPORES
AXIS IN 10% UNITS
PROGRAM BY I.SHENNAN 1981

The transgressive contact of the lower peat is transitional and Phragmites rhizomes suggest a reedswamp environment. Diatoms through the overlying clastic layer reveal marine conditions obtained only during the deposition of strata 12 and 13 with a long transition of fresh and fresh-brackish species above and below 250 cm.

The transition to the upper peat layer is also transitional and contains abundant Alnus pollen with Filipendula, Gramineae and Salix suggesting an Alder carr with Betula, Ulmus, Quercus and Tilia growing on the surrounding slopes.

6.4.8 Arcan Mains - site interpretation

The site is a poor one for the evaluation of tendency of sea-level movement. The stratigraphy shows little consistency between boreholes. Only within the central area of the gully are there deposits less affected by subsequent erosion.

The lower regressive contact at AM7 may not relate to a marine event since no indication is given by pollen, diatoms or stratigraphy of a marine depositional environment.

The transgressive contact of the lower peat is transitional and can be correlated between boreholes AM5, 6, 7, 10 and 11 suggesting a consistency within the central gully area.

The marine horizon is extremely thin, only c. 10 cm. at AM7. This is in accord with the suggestion of Shennan (1980) that transition zones should increase in thickness landward under conditions of a rising and falling sea-level.

The upper regressive contact is also transitional and can be correlated between boreholes AM5, 7, 10 and 11.

With regard to the Barnyards model the transgressive contact at

Arcan Mains could represent a regionally significant event. The significance of the upper regressive contact is unknown however and more stratigraphic and micropalaeontological work needs to be undertaken before local influences on sedimentation can be assessed.

6.5 Conclusion

The data presented in this chapter contains consistent evidence for changes in watertable and sedimentary regime consequent upon rises and falls in sea-level. The three sites investigated are variable in quality in the registration of regional events.

Barnyards, with its more open location and consistency in lithostratigraphy and biostratigraphy seems to offer the best possibility for evaluating regional from local effects.

The stratigraphy of all three sites is basically similar in that it records two peat layers separated by marine clastic layers. Below the lower peat at Barnyards and Moniack there is a further series of marine strata whilst at Arcan Mains the depositional environment of the lower clastic sequence has not been determined with certainty.

At Moniack a third peat intercalated with marine strata has been described. The regional significance of the grey silty sand layer that underlies it is not certain, yet a similar sand layer occurs within the marine clastic cover sequence at Barnyards (BY 2-10) at similar altitudes. At Moniack, this layer seems to represent a minor transgressive event within a period of general sea-level rise.

The general consistency of stratigraphy suggests events of regional significance have an influence at all sites with local conditions modifying the sequences in detail.

CHAPTER 7

FLANDRIAN SEA-LEVEL CHANGES IN THE INNER MORAY FIRTH AREA

In the previous chapter the environmental evidence for sea-level change at each site was given in detail. This chapter provides chronological and altitudinal information in the form of a provisional time depth (or rather time-altitude) graph.

7.1 Barnyards

The rational rise in Corylus pollen is traditionally considered as the zone IV/V boundary (Godwin 1940b). Newey (1966) and Brooks (1971) use the Corylus rise as an aid to the dating of the Main Buried Beach and Shoreline of the Forth. The Corylus rise occurs near the base of the peat layer overlying the Main Buried Beach at West Flanders Moss, Bield and the Homesteads sites and is one criterion used to suggest an approximate age for the shoreline of c. 9600 B.P., a second criterion being a ^{14}C date of 9640 ± 140 B.P. for a comparable feature in the Tay estuary. However, the Corylus rise is demonstrably diachronous in northern-Scotland. Birks and Mathewes (1978) suggest a date of c. 8730 B.P. at Abernethy Forest while at Loch of Winless in Caithness the rational Corylus rise occurs in the lower half of zone LW3 which is dated 10300 - 9340 B.P., though the ^{14}C dates may be slightly old due to hard water error (Peglar 1979). Smith and Pilcher (1973) give nine dates on the rational Corylus limit which range from c. 7735 to c. 9550 B.P. for 9 sites in the British Isles. However, most of the nine sites used to delimit the age of the rational rise in Corylus are located in Northern Ireland and north-west England with only one site Bigholm Burn in Galloway, from Scotland. Recent work (Birks unpublished) does suggest a time transgressive immigration of Corylus north and eastwards throughout the British Isles supporting the earlier hypothesis of Deacon (1975) that refugia of _Corylus_ existed to the south and west of the British Isles during the last glacial period. The inferred time-transgressive immigration of _Corylus_ suggests that use of the rational _Corylus_ limit as an aid to dating sites without a radiocarbon chronology could introduce an age error band wider than previously suggested for the Main Buried Shoreline (Newey 1966, Brooks 1971).

At Barnyards the rational _Corylus_ limit marks the lower limit of zone BY3B3 at 391.5 cm, only 2 cm. above the regressive overlap with the lower clastic sequence. The radiocarbon date of 9200 ± 100 B.P. (Hv 10010) is therefore verified by the pollen evidence and records a falling sea-level at this time.

Correlation of pollen assemblage zones from BY3B and BY14B, given in table 7.1 below, does suggest an age gradient for the lower regressive overlap at BY14B estimated in chapter 6 at c.400 years.

TABLE 7.1.

<table>
<tr><th>BY14B</th><th></th><th>BY3B</th></tr>
<tr><td>9</td><td rowspan="13">9200 ± 100</td><td rowspan="5"></td></tr>
<tr><td>8</td></tr>
<tr><td>7</td></tr>
<tr><td>6</td></tr>
<tr><td>5</td></tr>
<tr><td rowspan="3">4</td><td>5</td></tr>
<tr><td>4</td></tr>
<tr><td rowspan="2">3</td></tr>
<tr><td rowspan="3">3</td></tr>
<tr><td>2</td></tr>
<tr><td rowspan="3">1</td></tr>
<tr><td>2</td></tr>
<tr><td>1</td></tr>
</table>

At BY14B the frequency of Juniperus pollen in the basal layers of the lower peat reaches 19.0% in BY14B2 and together with the rise of Coryloid concentration during BY14B3 and 4 it does suggest an earlier age for peat initiation on the lower clastic sequence at the more landward site.

This has recently been confirmed by a provisional ^{14}C date for the base of the lower peat at BY14B of 9610 ± 130 B.P. (BIRM 1123, R.E.G. Williams, pers. comm.). This indicates although the two dates at BY14B and BY3B are not significantly different at the 95% level, there was a period of falling sea-level of more than 400 years' duration.

The date of the beginning of the following rise in sea-level is not known though pollen evidence at BY3B suggests the peat layer was formed in less than c. 1000 yrs. since there is no indication of significant change in the regional pollen rain throughout the whole of peat formation. A rise in sea-level is therefore inferred by c. 8200 B.P. at BY3B.

At BY14B, the more landward sampled site, there is evidence for the immigration of Pinus into the local area prior to the marine clastic sedimentation of stratum 10. Birks (1970) and Birks and Mathewes (1978) note a rise in Pinus pollen at Abernethy Forest dated at c. 7225 B.P. while O'Sullivan favours a gradual immigration of Pinus into the Grampians between c.8000 B.P. and 6600 B.P. At Coire Bog, Ross and Cromarty, Birks (1975) has dated a pine stump within the peat profile at a level corresponding to the Alnus rise and Pinus decline. The date, 6980 ± 100 B.P. (Q887) is quite comparable to that suggested by Birks and Mathewes (1978) and O'Sullivan (1975). In coastal areas of Caithness, however, Pinus appears not to have reached high percentages (Birks 1977). Other Flandrian pollen diagrams from the Moray Firth do show high frequencies of pine before the alder rise supporting immigration into the area at this time (Kingsteps Quarry, Knox 1954, Whitehills near Alness, Durno, pers. comm.). Dating is therefore imprecise but suggests marine clastic deposition under a rising sea-level at BY14B between 8000 B.P. and 6600 B.P. - with a date of 7200 B.P. considered a good estimate. A provisional ^{14}C data for the base of the upper regressive overlap at BY14B yielded an age of 5510 ± 80 B.P. (Birm 1122, R.E.G. Williams pers. comm.).

The rise in <u>Alnus</u> pollen to 42.6% in BY14B7 is a feature common to many Flandrian pollen diagrams. In the eastern Grampians O'Sullivan (1975) has dated the <u>Alnus</u> rise to between 5600 and 5900 B.P. however in other less suitable areas <u>Alnus</u> never constituted a major part of the vegetation (Birks 1970). The age for the regressive overlap at BY14B is verified by pollen evidence but may be slightly young since the exact location of the overlap was not sampled, there being a 12 cm. gap between successive cores.

In conclusion, pollen, stratigraphy and three ^{14}C determinations on regressive overlaps show a fall in sea-level initiated at 9610 ± 130 B.P. and lasting until some time after 9200 ± 100 B.P. and ending before c. 8200 B.P. the subsequent rise in sea-level has not been dated but pollen analysis from the erosive transgressive overlap at BY14B suggests an age of c. 7200 B.P. The initiation of the subsequent fall is considered to be somewhat before 5510 ± 80 B.P.

There is additional stratigraphic evidence for sea-level change within the lower clastic sequence at Barnyards but it is unsupported by pollen, diatom, or ^{14}C analysis. At BY13B (fig.5.2) the lower marine clastic sequence lies between the upper layers of a glacial till and the regressive overlap dated between c.9600 and 9200 B.P. The whole of the lower clastic sequence is therefore considered chiefly of Late Devensian age. It shows a tripartite finer → coarser → finer succession with 67 cm. light grey silty clay overlain by 72 cm. grey silty sand and succeeded by 361 cm. of grey silts and clays. It is not knownif the coarser stratum is transitional with the layer beneath or above. The change in lithology could be suggested as representing a change in sedimentary environment within the Late Devensian perhaps reflecting a rise in sea-level followed by a fall.

Above the peat layer in boreholes BY2 → 10 is a thin layer of silty sand entirely within the upper marine clastic sequence. Again, no pollen or diatom evidence is available from this layer but it indicates an interval of coarser marine clastic sequence. An age bracket of c.8200 B.P. to c.5500 B.P. is suggested based on pollen evidence at BY3B and the provisional ^{14}C date at BY14B for the upper regressive overlap.

7.2 Moniack

At Moniack the regressive overlap of the peat layer overlying the marine lower clastic sequence has not been dated but pollen from the base of this peat at M29B shows the rational rise of Coryloid curve within zone M29BD2 and a lack of Juniperus pollen. A similar age to peat initiation at BY3B is assumed - c.9200 B.P.

At M4B four provisional ^{14}C dates provide a time control (R.E.G. Williams pers.comm.). The transgressive overlap of the lower peat directly beneath the dark grey micaceous silty sand of stratum 2 is dated at 7430 ± 170 B.P. (Birm 1127) This age is considered slightly old for the dating of the silty sand layer since the contact is erosional. A provisional data on the regressive overlap of the thin Phragmites peat of strata 6 and 7 gave an age of 7270 ± 90 B.P. (Birm 1126). As argued in chapter 6 this contact cannot be interpreted at present as a fall in sea-level since there is no independent evidence from other sea-level indicators such as a measurable age-altitude gradient or environmental succession within the overlying peat layer which could suggest a fall in sea-level. It is considered that the regressive overlap could equally represent a period of reduced sea-level rise after the deposition of the sand layer allowing peat growth to keep pace. The two dates are not significantly different at the 67% level though the means do show an increased age with depth. This does suggest the marine silty sand was deposited between 7430 and 7270 B.P. The weighted mean of the two dates is 7310 ± 80 B.P. but an age nearer to 7270 B.P. is preferred since the transgressive overlap is erosional.

A sample from the transgressive overlap of the thin Phragmites peat layer of strata 6 and 7 gave a provisional ^{14}C age of 7100 ± 120 B.P. (Birm 1126, R.E.G. Williams, pers. comm.) which again is not significantly different from Birm 1126 at the 67% level or Birm 1127 at the 95% level yet the means of the determinations are consistent with stratigraphy. At M29B the corresponding transgressive overlap is erosional since diatom zone M29BD1 directly overlying the peat is fully marine in character.

The upper regressive overlap at the base of the organic cover sequence at M4B gave a provisional ^{14}C age of 4760 ± 90 B.P. As noted in Chapter 6 the overlap shows a rise in altitude from M6 to M10 (fig.5.13) and local sedimentation factors were suggested responsible caused by the renewed activity of the Moniack alluvial fan contemporaneous with or slightly after the deposition of the marine blue-grey silty clay sequence. The radiocarbon date tends to confirm this hypothesis, being c.1000 years later than at the other two sites in the area - Barnyards and Arcan.

In conclusion, pollen from M29B and four ^{14}C dates from M4B give time control to the changes in sea-level suggested in Chapter 6.

A fall in sea-level is indicated at c.9200 B.P. by pollen evidence from M29B. The age of the initiation of the following rise in sea-level is unknown but three dates at M4B on the transgressive overlap below the silty sand layer and both contacts of the overlying thin peat layer - not significantly different at the 95% level - indicate a rise in sea-level between c.7400 and 7100 B.P. at M4B. The stratigraphic evidence may also provide evidence for different components of the rise, an initial rapid rise followed by a reduction in the rate of rise, or perhaps a fall, allowing peat growth to extend seawards. The final fall in sea-level from the site is considered to have taken place some time before 4760 ± 90 B.P.

7.3 Arcan Mains

Of three ^{14}C dates for Arcan Mains, two give evidence for change in sea-level. The base of the lower peat of AM7 is dated at 5420 ± 280 B.P. (Hv.10014) It is not known if the lower clastic sequence relates to a marine episode since there are no equivocal indicators of an intertidal or saltmarsh deposit. The age determination is, nevertheless, clearly erroneous. Regional pollen spectra at this level in zone AM1 (figs. 5.26 and 5.27) shows high *Betula* frequencies with some *Juniperus* suggesting an early Flandrian date. The reason for the erroneous date is unknown, it is considered unlikely that significant contamination occurred during sampling or in the removal of detrital material in the laboratory.

The transgressive overlap of the lower peat is dated at 7700 ± 80 B.P. consistent with pollen evidence for high Coryloid pollen frequencies and low *Pinus* and *Betula* values. The overlap is transitional with fresh and fresh-brackish diatoms in the clastic interfingering sequence. Marine or marine-brackish conditions are apparent only at c.250 cm. and are represented by a thin layer corresponding approximately to stratum 13. The long transition to marine conditions suggests that clastic deposition was initially fresh and caused by a rise in the watertable produced by a rise in sea-level. The date is therefore indirect evidence for sea-level rise at this time and gives a maximal age for the arrival of marine conditions at the site.

The upper regressive overlap is dated at 5775 ± 85 B.P., an age supported by pollen evidence from figs. 5.26 and 5.27 and from the diagram by Davis (1979) which shows the predominance of *Alnus*, a fall in *Pinus* and with *Ulmus*, *Quercus* and *Tilia* in consistent percentages. Despite the lack of consistent stratigraphic control at the site the date is considered to be good evidence for a fall in sea-level at this time.

7.4 Summary Chronology of Flandrian Sea-Level change in the inner Moray Firth

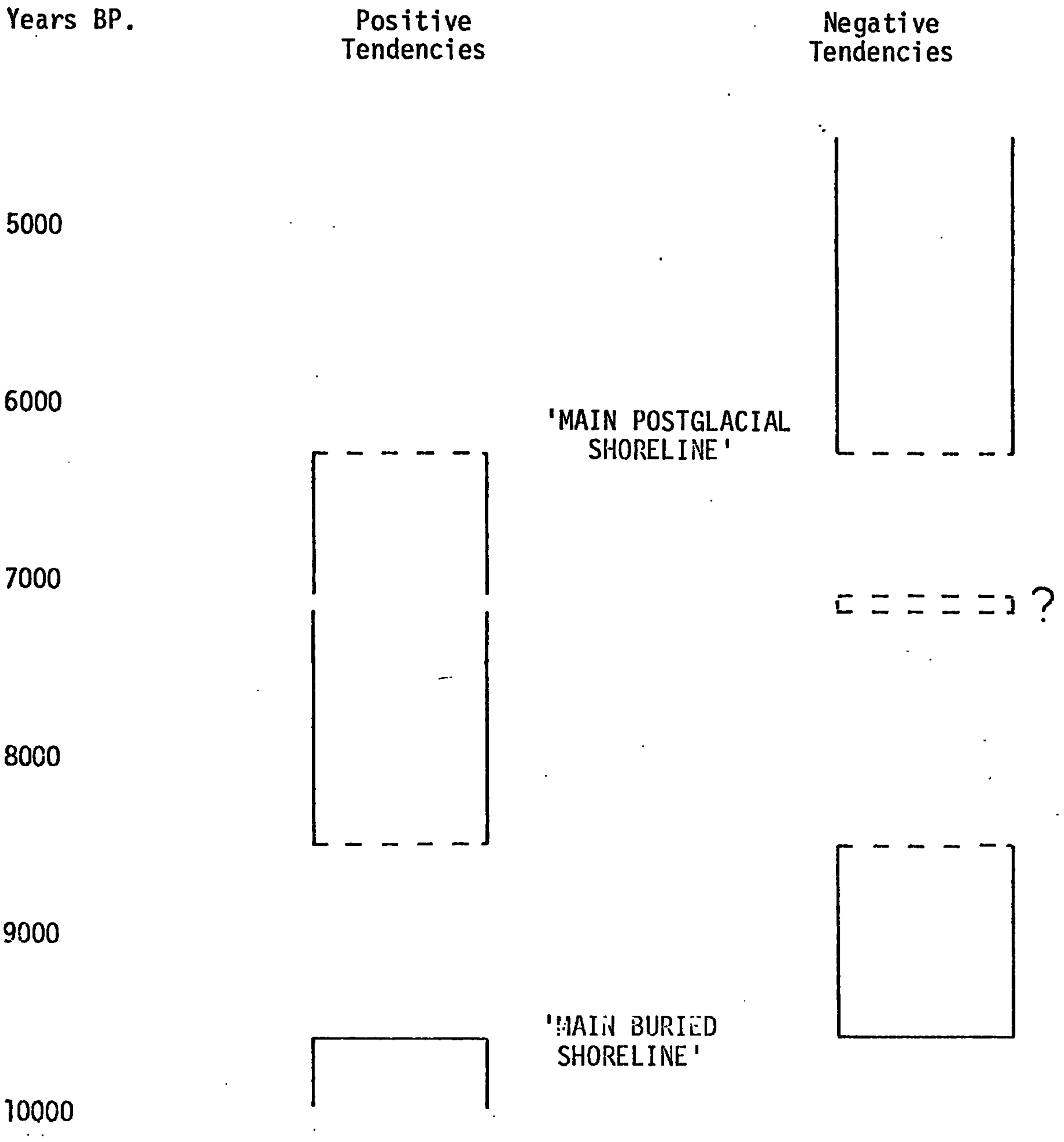
There is insufficient evidence to construct a detailed regional chronologial scheme of sea-level tendencies (Shennan 1982, Tooley 1982). However, certain broad conclusions can be drawn.

Between 9600 and 9200 B.P. the area was dominated by a falling relative sea-level. This fall in sea-level continued after 9200 B.P. but a more exact statement of the minimum sea-level reached cannot be made. A date from derived plant material of 8748 ± 100 B.P. (SRR 1068, Peacock *et al*. 1978) from 13.5 - 13.96 m. depth in Cromarty bore C2 supports the hypothesis of a low sea-level after 9200 B.P.

A rising sea-level is inferred by c. 8200 B.P. which is an estimate of the age of the transgressive overlap at BY3B. Provisional ^{14}C dates of 7430 ± 170, 7270 ± 90 and 7100 ± 120 B.P. from Moniack are considered

TABLE 7.2

Summary Chronology of Positive and Negative Tendencies



to represent the regional rise in sea-level, while the date of 7700 ± 80 B.P. from Arcan is thought to give evidence for a rise in the water table consequent upon a rise in sea-level to seaward.

The culmination of the rise in sea-level can only be dated between 7100 ± 120 B.P. and 5775 ± 85 B.P. with respect to dates at Moniack and Arcan Mains, though an estimate of the age is given as 6100 - 6400 B.P. After this date relative sea-level in the region fell towards the present. It is not known if any minor stillstands or rises in sea-level interrupted the general fall. Table 7.2 summarizes the chronology of positive and negative tendencies for the Moray Firth area.

7.5 A Time-Altitude Graph of Flandrian sea-level changes in the inner Moray Firth

The inclusion of altitudinal information incorporates a further error into the reconstruction of former sea-levels since the accuracy of the altitude determination is dependent upon the accuracy in determining present altitude, original altitude and the relationship of an index point to its contemporary sea-level.

In assessing the accuracy of present altitude, errors can occur in the measurement of depth, levelling to a benchmark and the accuracy of the benchmark related to O.D.Newlyn.

(a) Measurement of depth is dependent upon the ability to locate boundaries between strata accurately, the type of equipment used in boring and the angle of the borehole from the vertical.

(b) Levelling between borehole and benchmark in this study is generally considered to be accurate to ±0.05 m.

(c) The accuracy of a benchmark is dependent upon its distance from Newlyn and on the order of the benchmark (see Chapter 4). For inter-site comparison benchmarks are considered accurate relative to each other to

±0.01 m. whereas for inter-regional comparison the error can be up to ±0.20 m. for Scotland relative to O.D. Newlyn (Eady 1976).

One of the greatest errors inherent in evaluating the altitude of an index point is the degree of post-depositional consolidation that has occurred. According to Tooley (1978a) all

> "sediments undergo consolidation, the rate of which is a function of time, drainage and load" (p.16)

Jelgersma (1961) considers that the great variety of unconsolidated deposits in the coastal zone can mean consolidation may vary from 0 to 90%. If such large factors are correct then compaction can be a serious error in assessing the altitude of formation of the peat which constitutes an index point. Indeed van de Plassche and Preuss (1978) state :

> "Compaction is a very troublesome factor in sea-level height reconstruction and should be reckoned with as soon as the soft rock material underlying the sea-level indicator does not (consist of 100% sand). Samples that have been lowered as a result of compaction can only be used if the amount of lowering and the error interval can be reliably estimated or calculated. Relative sea-level curves based upon index points that have been subject to compaction for which no reliable correction can be applied are of very little use for the Sea-Level Project" (pp.2-3)

There have traditionally been two ways of overcoming the problem. One is only to use basal peat dates (c.f. Jelgersma 1961) - however Shennan (1980) has argued that this route produces the possibility of biased sampling. An alternative is to compute correction factors for consolidation of peat.

Cullingford et al. (1980) have applied correction factors for peats at transgressive overlaps by comparing the mean dry bulk density of uncompacted monocotyledonous peat to the fossil peat and assuming that the fossil peats before burial had a comparable bulk density to the unconsolidated peat and that the amount of subsequent compaction is directly proportional to the increase in bulk density. Using this method their estimated range of compaction varied from 40 to 68%.

Apart from the great variability in peat structure, the fact that consolidation is time-dependent militates against the use of a single correction factor. In this study no such factors are allowed for and it is recognized that this may be an important source of error. However six of the nine radiocarbon dates used in the time-altitude graph are on regressive overlaps where consolidation, although a problem will be of a smaller magnitude since the underlying predominantly minerogenic layers will compact less on application of load from above than a peat layer of comparable thickness.

For an index point to be used on a sea-level curve or time-altitude graph an explicit statement of the relationship of the sample to its contemporary reference tide level is needed. A table showing the indicative range of commonly dated materials and their reference tide levels was given in Chapter 6 (table 6.1). In this section the secondary component of indicative range, the accuracy of the reference tide level will be discussed.

Table 7.3 summarizes tide data for the twenty secondary parts around the Moray Firth, the locations of which are shown in fig. 7.1,A. For inter-site comparison only the correction factors derived from the inner Moray Firth sites are needed to reduce the reference tide levels to MHWS or MTL. If correlation between areas is the aim then comparable correction factors have to be calculated for these areas also. If relationship to O.D. is needed then the mean and standard deviation of the tide-level has to be used. An indication of the variability of tidal range around Scotland is given in fig. 7.1,B.

Changes in palaeo-tidal range are a potentially great source of

TABLE 7.3

Moray Firth Area Tide Levels (M.O.D)

	HAT[1]	M1[2]	MHWS	MHWN	MTL	MLWN	MLWS	LAT[1]
Aberdeen	2.55	2.3	2.05	1.15	0.225	-0.65	-1.65	-2.25
Peterhead	1.99	1.8	1.6	0.9	0.025	-0.7	-1.7	-2.32
Fraserburgh	2.11	1.91	1.7	0.9	0.075	-0.7	-1.6	-2.18
Banff	1.62	1.46	1.3	0.6	-0.25	-1.1	-1.8	-2.45
Whitehills	2.36	2.13	1.9	1.1	0.35	-0.3	-1.3	-1.77
Buckie	2.49	2.25	2.0	1.1	0.30	-0.5	-1.4	-1.91
Lossiemouth	2.49	2.25	2.0	1.1	0.30	-0.5	-1.5	-2.05
Burghead	2.49	2.25	2.0	1.1	0.30	-0.5	-1.5	-2.05
Nairn	2.74	2.47	2.2	1.2	0.375	-0.5	-1.5	-2.05
McDermott	2.61	2.36	2.1	1.2	0.425	-0.4	-1.2	-1.64
Fortrose	2.55	2.30	2.05	1.15	+	+	+	+
Inverness*	3.17	2.86	2.55	1.45	0.50	-0.45	-1.55	-2.11
Cromarty*	2.74	2.47	2.2	1.3	0.45	-0.4	-1.3	-1.77
Invergordon*	2.86	2.58	2.3	1.4	0.475	-0.4	-1.4	-1.91
Dingwall	2.86	2.58	2.3	1.5	+	+	+	+
Portmahomack	2.49	2.25	2.0	1.2	0.35	-0.4	-1.4	-1.91
Meikle Ferry	2.86	2.58	2.3	1.3	0.375	-0.6	-1.5	-2.05
Golspie	2.43	2.19	1.95	1.05	0.25	-0.55	-1.45	-1.98
Wick	2.10	1.9	1.69	0.99	0.29	-0.31	-1.21	-1.65
Duncansby Head	1.73	1.56	1.39	0.69	+	+	+	+

	All data n = 17	Inner Firths * n = 3
HAT	2.48 ± 0.37	2.92 ± 0.22
M[1]	2.23 ± 0.33	2.63 ± 0.20
MHWS	1.99 ± 0.29	2.35 ± 0.18
MHWN	1.12 ± 0.20	1.38 ± 0.07
MTL	0.28 ± 0.18	0.475 ± 0.025
MLWN	-0.52 ± 0.19	-0.42 ± 0.02
MLWS	-1.46 ± 0.16	-1.42 ± 0.13

Correction factors - Inner Firths * n = 3

HAT - MHWS	0.57 ± 0.04
M[1] - MHWS	0.29 ± 0.02
MHWS - MTL	1.88 ± 0.16
M[1] - MTL	2.16 ± 0.18
HAT - MTL	2.45 ± 0.20
MHWN - MTL	0.91 ± 0.05

\+ data not available. These secondary ports are ignored in further treatment

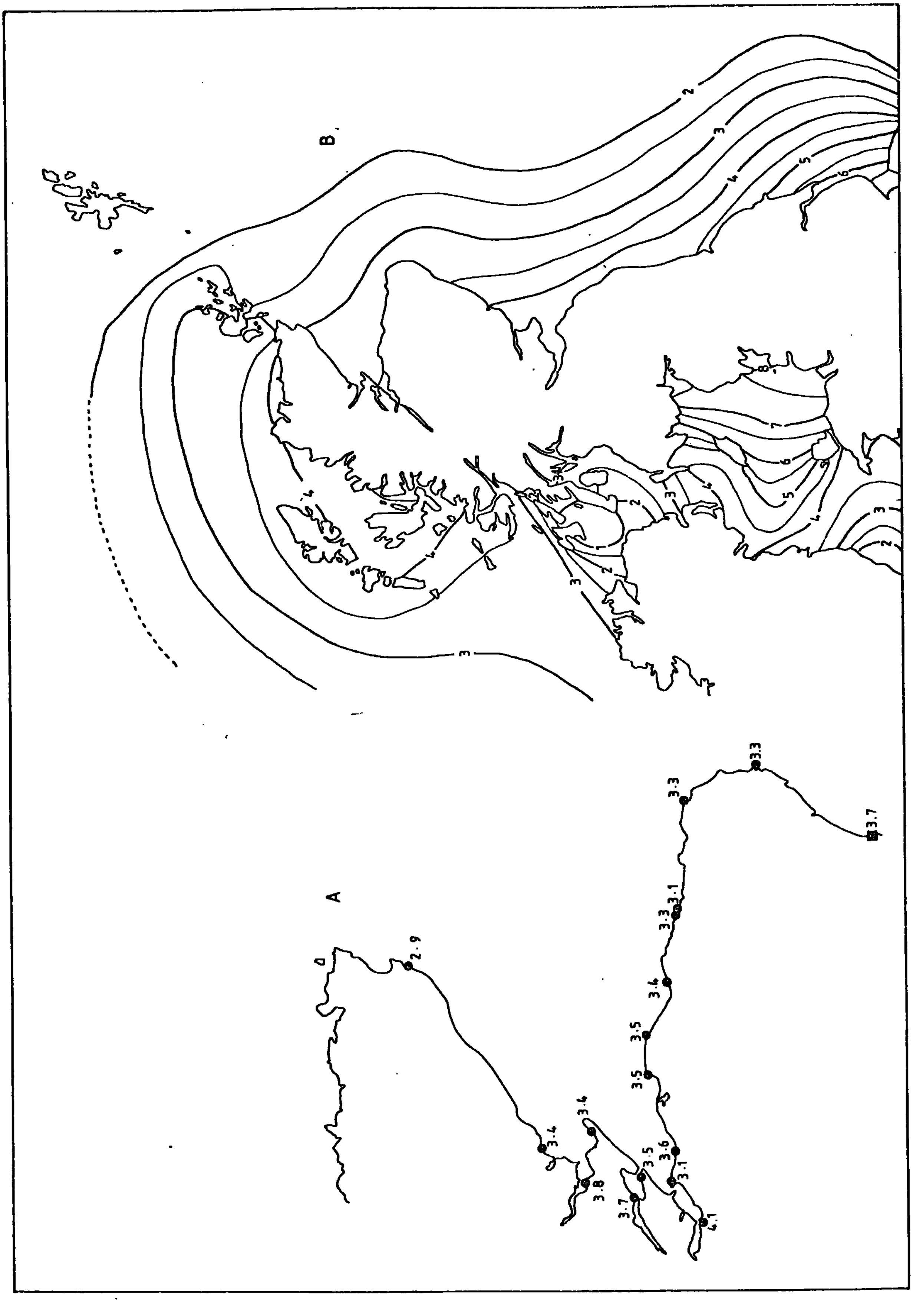
[1] HAT + LAT are extrapolated values

[2] $M1 = \frac{HAT + MHWS}{2}$

Fig. 7.1 Tidal Range around Scotland.

7.1A Secondary ports used in table 7.3.
Spring tidal range shown in metres.

7.1B Spring tidal range around Scotland


B
2
3
4
5
6
7
8
A
2.9
3.4
3.4
3.8
3.7
3.5
3.6
3.1
4.1
3.5
3.5
3.6
3.3
3.1
3.3
3.3
3.7

error in the construction of sea-level curves and their correlation between area. In this study a constancy of palae ntidal range is assumed.

7.5.1 Graph construction

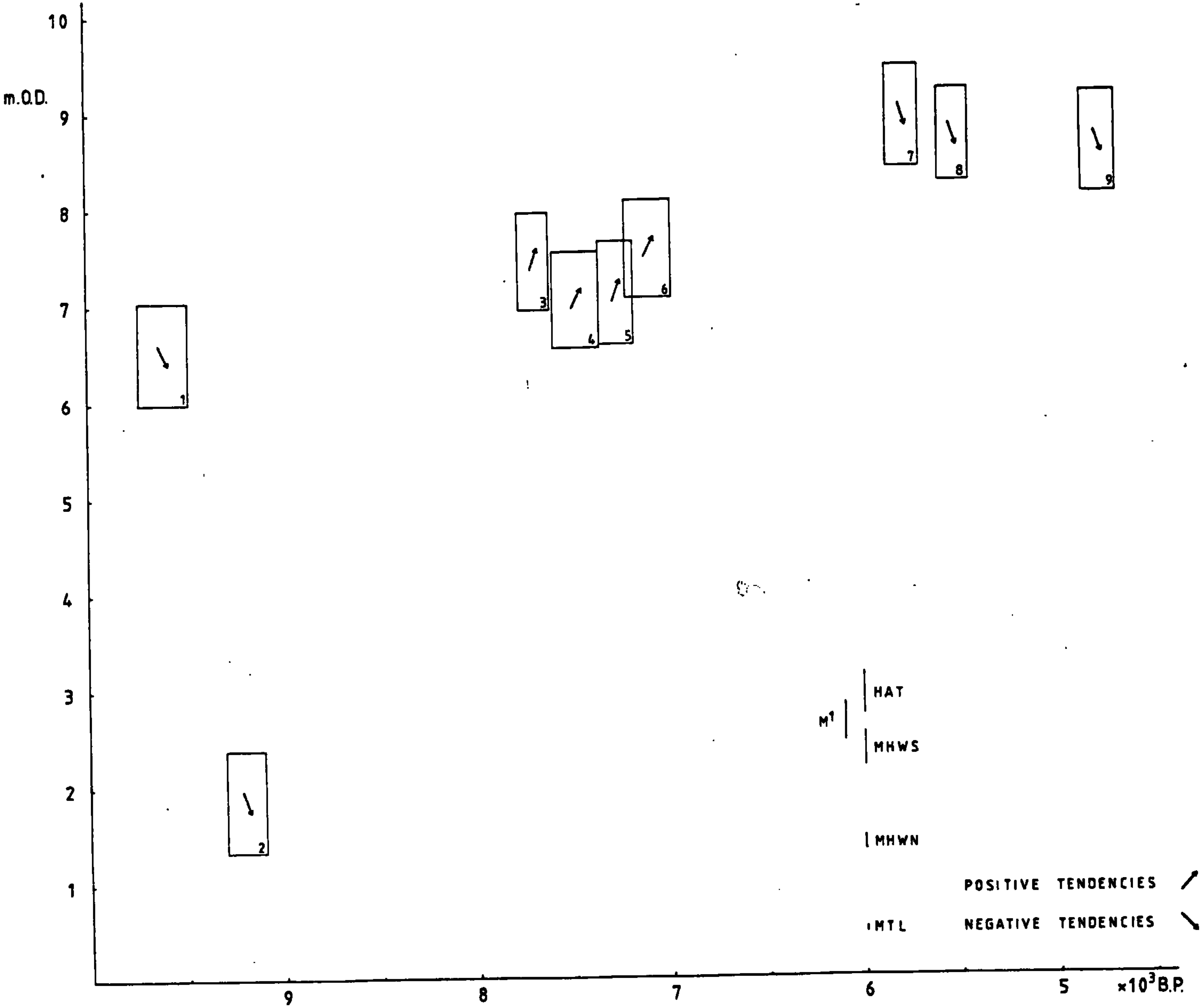
A provisional time-altitude graph for the inner Moray Firth area contains nine radiocarbon dated index points, the erroneous Arcan Mains date, Hv10014, 5420 ± 280 B.P. is not included in further analysis.

Each index point is plotted with respect to MHWS for the inner Moray Firth using the relationships of indicative range and tide-levels shown in tables 6.1 and 7.3. Included in the altitudinal error is a consideration of the following sampling errors, identification of boundary, measurement of depth, angle of borehole and sampling density (cf. Shennan 1980). Since the angle of borehole produces an unidirectional error the total sampling error equals +0.40 m. - 0.36 m. The width of each box is representative of a range of 1σ around the mean ^{14}C date. Also included on the diagram (fig.7.2) is an assessment of the tendency of sea-level movement represented by each index point.

For example index point 2 is from Barnyards 3B, Hv 10010 dated at 9200 ± 100 B.P. It has a present altitude of 1.94 - 1.99 m.O.D. Total sampling error of +0.40 - 0.36 m. gives an altitudinal range of 1.54 - 2.35 m. In addition the indicative range of Phragmites peat at a regressive overlap gives a final range of 1.33 - 2.38 m. A table of details of age and altitude of index points used is given in Table 7.4

No sea-level curve is drawn joining the error boxes because of the poor spread of data points. Little information is available on the age or altitude of the initiation of the main Flandrian rise in sea-level nor its culmination. However, the highest altitudinal limit of Flandrian marine deposition is c. 9m. for Barnyards and 10.05 m. Moniack.

Fig. 7.2 Sea-Level index points for the inner Moray Firth area showing tendency of sea-level movement.


m.O.D.
10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
×10³B.P.
1
2
3
4
5
6
7
8
9
HAT
M¹
MHWS
MHWN
MTL
POSITIVE TENDENCIES
NEGATIVE TENDENCIES

In addition consolidation is not taken into account and this could mean that the time course of MHWS lies some way above that shown in fig. 7.2. The evaluation of new data to enable a curve to be drawn is an aim for future research.

TABLE 7.4

Index point	Altitude (m)	Age B.P.	Site
1	5.98 - 7.03	9610 ± 130	Barnyards *
2	1.33 - 2.38	9200 ± 100	Barnyards
3	6.93 - 7.94	7700 ± 80	Arcan
4	6.52 - 7.53	7430 ± 170	Moniack *
5	6.57 - 7.62	7270 ± 90	Moniack *
6	7.05 - 8.06	7100 ± 120	Moniack *
7	8.15 - 9.20	5510 ± 80	Barnyards *
8	8.39 - 9.44	5575 ± 85	Arcan
9	8.10 - 9.15	4760 ± 90	Moniack *

* denotes provisional ^{14}C data (R.E.G. Williams, pers.comm.)

7.6 Flandrian sea-level change in the inner Moray Firth area

The course of MHWS is suggested to have fallen from between 5.98 - 7.03 m. at 9610 ± 130 B.P. to 1.33 - 7.38 m. at 9200 ± 100 B.P. both dates coming from the regressive overlap of the lower peat at Barnyards. Although the dates are not significantly different at the 95% level it is assumed an age difference of c. 400 years exists between these two points. This gives a maximum rate of fall of 3.17m./100 yrs and a minimum rate of 0.56m./100 yrs.

The minimum altitude of the early Flandrian fall in sea-level is not known but Peacock et al. 1980 suggest a figure of -6m. O.D. based on marine faunal studies of the Cromarty C2 borehole. Their ^{14}C date from derived plant debris at 8748 ± 100 B.P. could give a broad estimate of the age for this minimum. Morphological evidence for an early Flandrian low sea-level includes the impressive incised gullies between Jemimaville and Cromarty noted by J.S.Smith (1963).

Because of a lack of data points no reliable conclusions can be made concerning the initiation of the Flandrian rise in sea-level nor of the rates of rise involved. However, if the interpretation of the transgressive overlap at BY3B is correct then an age of c.8200 B.P. and an altitude of c. 2 m. O.D. may provide an estimate.

Index point 3 from Arcan Mains is considered to represent a rise in watertable prior to the arrival of marine conditions at the site and its age of 7700 ± 80 B.P. may be slightly early for the initiation of marine conditions. Index points 4 and 5 from Moniack lie either side of the grey micaceous silty sand layer. Both are shown as indicating positive tendencies since there is insufficient evidence as yet to interpret the regressive overlap of the thin peat layer above the sand as a fall in sea-level.

The culmination of the Flandrian rise is suggested to have taken place at c. 9 m., the altitudinal limit of the Flandrian marine sediments at Barnyards, at c. 6100 - 6400 B.P. The altitude may in fact be a little higher since colluvial deposition precluded the confident identification of the limit at Barnyards. The altitude at Moniack, some 1 m. higher is taken to represent local enhancement of the altitude of MHWS through the constricted nature of the site.

The final fall in sea-level is registered at Arcan Mains (index point 7) and Barnyards (index point 8) at 5775 ± 85 B.P. and 8.15 8.39 - 9.44 m. and 5510 ± 80 B.P., 8.15 - 9.20 m.O.D. The Moniack index point (9) is thought to reflect local conditions caused by the renewed activity of the Moniack alluvial fan and may reflect a delay in peat growth. Further research is needed to clarify this problem.

CHAPTER 8

INTER-REGIONAL CORRELATIONS

8.1 Introduction

In correlating between areas of differing tectonic history the wide variety of processes acting on a local and regional scale and over differing time periods makes meaningful altitudinal comparison difficult on all but the very broadest scale. The most hopeful avenue for present research correlating between areas of different tectonic history is that of the chronostratigraphic correlation of periods of positive or negative tendencies of sea-level.

In comparing the chronology of sea-level change between areas of different tectonic history the registration of events will differ in their duration and intensity with short period, high amplitude events offering the best possibility of recognition in all areas. However, meaningful correlation can only be attempted if similar features are compared. For example, the adoption and use of terms such as transgression and regression by different workers in slightly different senses has important repercussions for the correlation of schemes produced for each area (Shennan 1982, Tooley 1982).

In previous research in Scotland it has been implicitly accepted that the country as a whole has acted uniformly with respect to the eustatic factor and that if former tidal range can be regarded as constant then differences in index point altitude can be explained with reference to differential glacio-isostatic recovery. Previous attempts to correlate within Scotland have tended to use schemes of measured and named shorelines such as the sequence outlined for south-east Scotland (Sissons 1976) and their chronostratigraphic connotations rather than time periods of inferred rise and fall in sea-level. The use of shoreline studies is of great value in the following ways:-

(1) providing information on the post-formational tilting of such features across Scotland (e.g. Sissons 1966).

(2) providing a method of relative dating.

(3) that it allows approximate absolute time limits to be placed on undated shorelines from areas devoid of datable material - with reference to well defined sequences from other areas (e.g. Gray 1974).

(4) that such a scheme provides good altitudinal limits for the construction of sea-level curves.

However, it is suggested that this method is of less use in correlation between areas of differing tectonic history where such shorelines are absent or have not been traced. The construction of regional chronologies of positive and negative tendencies from all available evidence, including data from shorelines, will allow more flexibility for inter-regional comparison including the use of statistical techniques. It will also produce a less parochial view of sea-level study.

This is essentially the same kind of argument proposed in pollen analysis for the adoption and use of local and regional pollen assemblage zones once the limitations of the Godwin zonation scheme were realized. Like the Godwin scheme, shoreline sequences are an excellent tool for explanation within the area in which they occur.

However because no chronological scheme of periods of transgressive and regressive overlap has been outlined for Scotland and since insufficient data have been collected for the inner Moray Firth area for anything other than a preliminary outline, a further interesting technique of chronostratigraphic correlation, histogram analysis, will be discussed in section 8.2. This has direct relevance to the problem of synchroneity or diachroneity of shorelines.

Following this section, altitudinal comparisons will be made for Scotland in section 8.3 - assuming a constancy of palaeotidal range at the present stage of research. This leads on to the construction of a preliminary isostatic curve for the inner Moray Firth area and its comparison with two other published isostatic curves for Scotland (section 8.4). The final section contains a brief review of the timing of sea-level change in areas of different tectonic history, and comments on the use of shoreline studies in correlation.

8.2 Statistical evaluation of ^{14}C data

The statistical evaluation of ^{14}C data by means of histogram analysis offers an interesting tool for the consideration of regionally significant events such as rises and falls in sea-level. It has been applied to Flandrian sea-level studies in the southern North Sea (Geyh 1971, Geyh and Streif 1970) in the English Fenland (Shennan 1980, 1982) and North-West England (Tooley 1982). It can be applied to any phenomenon that causes the regional presence of dated material and has also been used to verify Weichselian chronostratigraphy on a 10^4 yr time scale (Geyh and Rohde 1972). In Scotland it can be applied to a preliminary assessment of the regional synchroneity or diachroneity of shorelines.

Radiocarbon ages with their standard deviations represent Gaussian frequency distributions and the area under the curve may be approximated by a polygon constructed, for example, by a number of rectangles. If the area under the curve is kept constant the standard deviation determines the height of the polygon - the larger the standard deviation the lower the height (Geyh 1980).

The program MHIST.GEN used in this study written by Dr. I.Shennan and developed by Mr. M.J. Davis uses class intervals of 50 years to group the data. It represents the area under the Gaussian frequency distribution curve for each data by eight rectangles. This means, for example, if one standard deviation of a ^{14}C date is 100 years then one rectangle is contained within each class interval. Histograms are in effect superpositions or summations of the Gaussian frequency distributions (represented by the rectangles) for each date considered.

The application of this method to coastal studies lies in the fact that periods of marine ingression should inhibit peat growth and be represented by minima in the histogram and periods of regression should produce optimum conditions for coastal peat growth and be represented by maxima in the histogram. It is therefore in the analysis of peaks and troughs in the resulting histogram that opportunity occurs for the identification of regionally significant events. The clarity of their expression in an uplifted area could be taken as evidence for the degree of synchroneity or diachroneity of regionally significant events.

There are many problems in the application of histogram analysis - both in its statistical testing and interpretation. Bias can enter the initial sample population through the relative accessibility of samples of different ages or preferred collection of samples related to a particular aspect or through contaminated or erroneous data.

Statistical problems include the probability of random fluctuations (Shennan 1979), the significance of the height of maxima and minima and the number of radiocarbon dates needed.

Geyh (1980) showed that the presence of significant maxima and minima i.e. those that relate to real events as opposed to random events is dependent on the number of dates used and the size of the class interval. He identified :

- reliable histograms, which are constructed from at least 25 dates per class interval of two standard deviations of the average ^{14}C date. Real minima with a width of at least 1 class interval can then be reliably identified.

- common histograms, with between 4 and 25 dates per class interval and

- unreliable histograms that have a population of less than 4 dates per class interval, real minima can then only be detected with reference to the geological record.

Interpretational difficulties arise because the exact nature of the relationship of peat growth to sea-level movement is poorly understood and it is not known how periods of synchronous peat growth and non-peat growth relate to the transgression - regression schemes derived by other methods (Shennan 1980).

An alternative but associated method is to screen the data before histogram construction assessing the tendency of sea-level movement for each index point (Morrison 1976, Shennan 1982). With the addition of this extra factor further difficulties are encountered. The initial histogram analysis charted peat growth and no peat growth. With tendencies added there is potentially more bias in between area comparison from the inclusion of data points from regions differing in isostatic uplift or subsidence and which will greatly affect the registration of positive and negative tendencies. In this study all dates are from isostatically uplifted areas and even though uplift may be differential (since areas with similar isostatic histories have not been defined) it is felt that less bias will accrue than if data points were included from areas with different tectonic histories of uplift and subsidence (Morrison 1976).

Theoretically areas showing greater uplift will register proportionately less positive tendencies. However much depends on the scale of resolution of the technique. With such a poor data base and with refinement of the ^{14}C method of the order of c. 100 yrs it is suggested that the technique should only be seen in this study as an exploratory attempt to identify regional tendencies with a timescale of c. 100 - 200 yrs, no different from that available from the geological record.

All published Scottish radiocarbon dates from a Flandrian coastal context were abstracted from the journal Radiocarbon and placed on computer file. Only Flandrian peat dates (Younger than 10,000 B.P) were retained for further analysis. 99 dates remained, including 3 dates from Barnyards and Arcan Mains (but not the 6 recent provisional ^{14}C dates) and they are shown in table 8.1. No tendencies of sea-level movement were assumed and no screening for erroneous dates such as those comprised of allochthonous material was undertaken.

A histogram was drawn using the program MHIST, GEN and it is reproduced in fig. 8.1. The ordinate scale or height is proportional to the standard deviation of the dates used. The 99 dates are spread over a period of c. 8000 yrs or 160 class intervals which means that it can be regarded, according to Streif (1980), as an unreliable histogram. However, certain tentative conclusions can be drawn with reference to the geological record. The broad minimum at 8700 - 9150 B.P. appears to be in agreement with the age of the Low Buried Shoreline of the Forth and Tay (Sissons and Brooks 1971, Cullingford et al. 1980). The peak between 8000 and 8700 B.P. suggests a period conducive to peat growth during a fall in sea-level. However, the minimum at c 7900 B.P. and the maximum at 7500 B.P. are harder to explain. There is little support in

TABLE 8-1 SCOTTISH C14 DATA - UNSCREENED

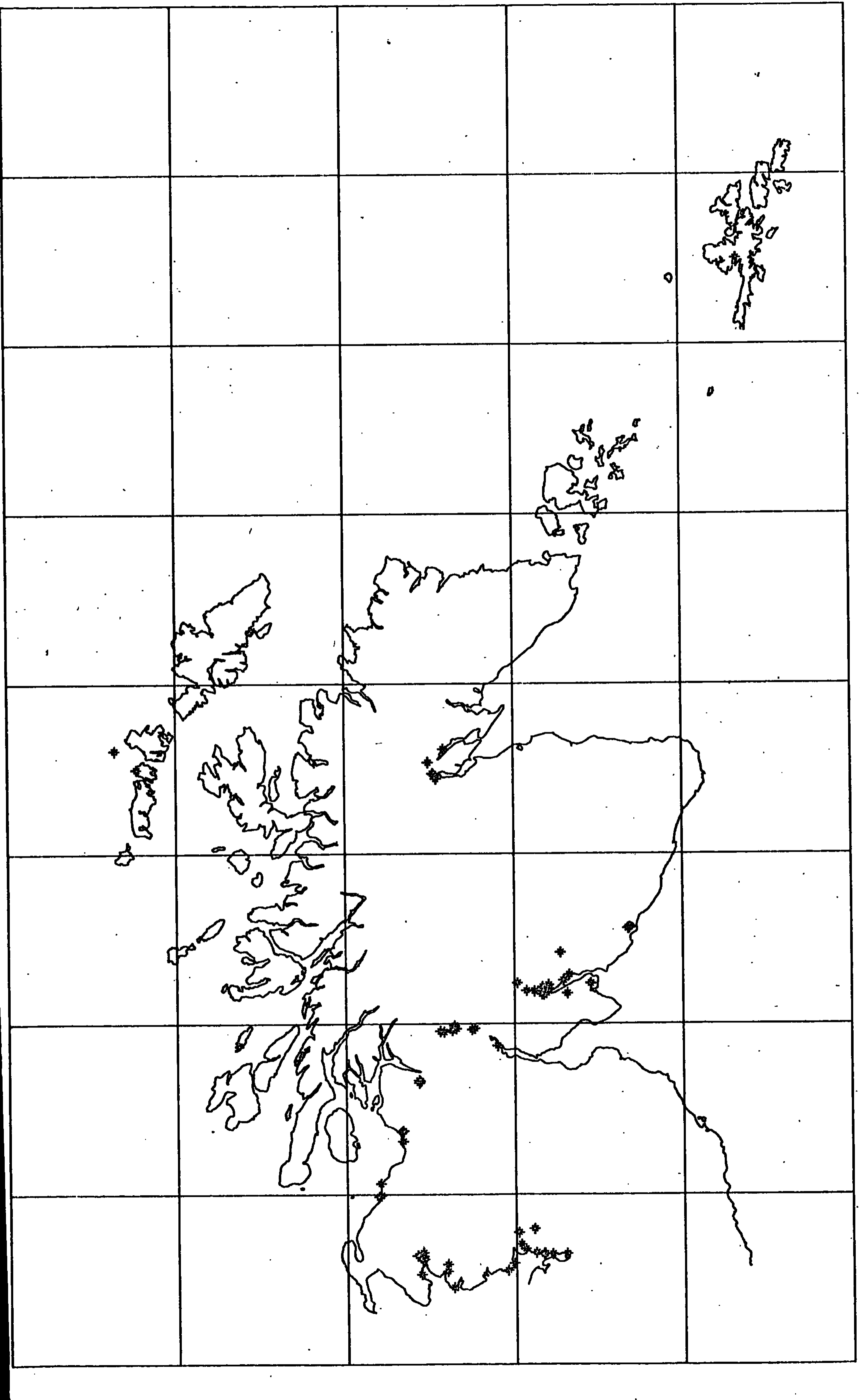
	LAB. CODE	SITE	AGE	STD. DEV.	N.G.R.	
901	SRR66	POWGAVIE,TAYSIDE	8150	50	32912	72532
902	SRR67	POWGAVIE,TAYSIDE	8320	57	32912	72532
903	SRR68	POWGAVIE,TAYSIDE	8331	74	32912	72532
904	SRR69	BURNSIDE,TAYSIDE	8170	67	33259	72861
905	SRR70	BURNSIDE,TAYSIDE	8616	52	33259	72861
906	SRR71	CAREY,STRATHEARN	7778	55	31747	71703
907	SRR72	CAREY,STRATHEARN	9524	67	31747	71703
908	NPL127	CAREY,STRATHEARN	7605	180	31717	71710
909	I2796	CAREY,STRATHEARN	9640	140	31717	71710
910	SRR1399	INNERNETHY	8555	60	31899	71783
911	SRR1398	INNERNETHY	8505	50	31899	71783
912	SRR1397	INNERNETHY	7530	50	31899	71783
913	SRR1147	CORDON,STRATHEARN	8370	45	31845	71813
914	SRR1394	CORDON,STRATHEARN	7525	50	31845	71813
915	SRR1396	CULFARGIE,STRATHEARN	7780	50	31625	71717
916	SRR1395	CULFARGIE,STRATHEARN	7555	50	31625	71717
917	SRR1401	KINTILLO,STRATHEARN	7465	55	33148	71766
918	SRR1400	KINTILLO,STRATHEARN	7180	55	33148	71766
919	SRR1150	GLENCARSE,STRATHEARN	6679	40	32022	72256
920	SRR1151	GLENCARSE,STRATHEARN	6083	40	32022	72256
921	SRR1510	HOLE OF CLIEN	6170	90	32050	72030
922	SRR1511	HOLE OF CLIEN	7500	90	32050	72030
923	IGS1	ST.MICHAELS,FIFE	5830	110	34541	72348
924	IGS2	ST.MICHAELS,FIFE	7605	130	34541	72348
925	IGS3	ST.MICHAELS,FIFE	9945	160	34541	72348
926	SRR1331	ST.MICHAELS,FIFE	5890	95	34540	72350
927	SRR1332	ST.MICHAELS,FIFE	7310	100	34540	72350
928	SRR1333	ST.MICHAELS,FIFE	7050	100	34540	72350
929	SRR1334	ST.MICHAELS,FIFE	7555	110	34540	72350
930	Q421	EASTF.OF DUNBARNEY	8421	157	0	0
931	Q422	BROOMBARNS,TAYSIDE	8354	143	0	0
932	SRR1148	FULLERTON,KINCARDINE	6704	55	36748	75605
933	SRR1149	FULLERTON,KINCARDINE	7086	50	36748	75605
934	BIRM867	FULLERTON,KINCARDINE	6880	110	36748	75605
935	BIRM823	FULLERTON,KINCARDINE	7140	120	36748	75605
936	SRR869	MARYTON,KINCARDINE	7340	75	36837	75650
937	SRR386	ARDLER,TAYSIDE	9730	60	32743	74173
938	SRR26	MUIRFAD FLOW	4746	50	24530	56200
939	Q640	GIRVAN,AYRSHIRE	9020	150	21910	59870
940	Q641	GIRVAN,ENOCH,AYR.	9362	150	22040	59930
941	Q639	NEWTON STEWART	6159	120	24160	56400
942	Q638	LOCHAR MOSS,DUMFRIES	6645	120	30560	56800
943	Q637	REDKIRK POINT	8135	150	33020	56510
944	I5070	NEWBIE COTTAGES	4290	100	31650	56510
945	I5069	WEST PRESTON	1850	95	29520	55530
946	I5068	WIGTOWN BAY	2290	95	24400	55300
947	I5514	CARSEMINNOCH	6325	120	24438	56263
948	I5513	MOSS OF CREE	4000	120	24456	56147
949	Q642	DUNDONALD BURN	9620	150	23370	63730
950	Q818	GATEHOUSE OF FLEET	6244	140	0	0
951	BIRM5	ROBERTHILL,DUMFRIES	3847	60	31100	57970
952	BIRM187	GIRVAN,RLY.BR.AYR	8400	200	21900	59850
953	BIRM190	TURNBERRY BR.AYR	8420	150	22020	60630
954	BIRM188	BARGALY	7960	350	25960	55890

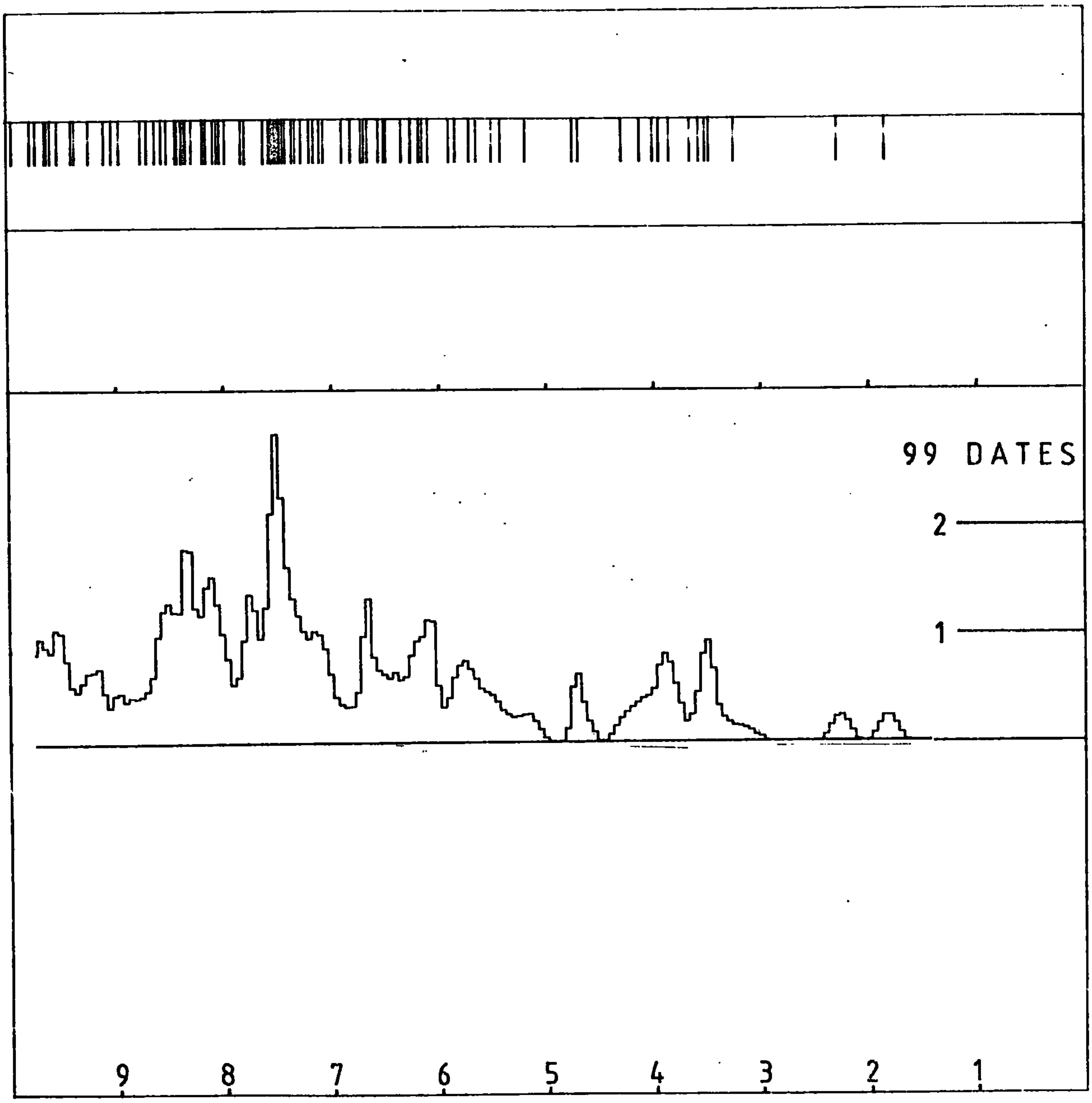
TABLE 8-1 (CONTINUED)

955	BIRM189	PALNURE	6240	240	24500	56367
956	Q398	BRIGHOUSE BAY	9640	180	0	0
957	BIRM219	PALNURE BURN	7450	200	24500	56576
958	BIRM221	WOODSIDE,IRVINE,AYR	3944	190	23300	63670
959	BIRM218	NEWBIE COTTAGES	3480	110	31680	56480
960	BIRM220	NEWBIE COTTAGES	5630	116	31670	56490
961	BIRM222	NEWBIE COTTAGES	7540	150	31660	56500
962	GU373	DUNDONALD BURN	8950	90	23370	63720
964	GU375	NEWBIE MAINS	7812	131	31710	56510
965	BIRM256	BATTLEHILL,ANNAN	6800	250	32157	56494
966	BIRM258	HORSEHOLM,DUMFRIES	5410	160	30313	57062
967	BIRM323	SOUTH CARSE	9390	130	29883	55944
968	BIRM324	MIDTOWN,DUMFRIES	6470	280	31189	56577
969	BIRM325	NEWBIE COTTAGES,AYR	7400	150	31644	56515
970	BIRM415	PALNURE	6540	120	24500	56367
971	IGS149	TROON,AYR	8015	120	23361	63111
972	IGS150	TROON,AYR	9090	320	23361	63111
973	Q1172	LOCH SNIOGRAVAT	4688	90	6380	6090
974	SRR381	DUNDONALD BURN,AYR	8070	70	23372	63717
975	SRR382	DUNDONALD BURN,AYR	9780	90	23372	63717
976	GU64	NEWBIE COTTAGES,	7254	101	31670	56490
977	GU65	SANDYKNOWE BRIDGE	7426	136	30170	57760
980	Q533	FLANDERS MOSS	5492	130	0	0
981	I1839	KIPPEN,FORTH VALLEY	8690	140	26300	69600
982	I1838	KIPPEN,FORTH VALLEY	8270	160	26300	69600
983		SOUTH FLANDERS	8010	130	26310	69610
984		EASTER OFFERANCE	7480	125	25820	69520
985		WEST FLANDERS MOSS	6490	125	25600	69550
986		WEST FLANDERS MOSS	6135	105	25600	69550
987		DRIPEND	4120	105	27490	69650
988	Q667	LITTLEWOOD,KIPPEN	3249	160	26549	69692
989	Q280	AIRTH COLLIERY	8421	157	29000	68700
991	BIRM652	KINFAUNS,PERTH	5180	100	21660	82140
992	SRR353	GREENHILL,CRIEFF	9590	70	20182	82376
993	I1543	BENBECULA	5700	120	769	88498
994	Q666	HEATHERSHOT,PERTH	3656	150	0	0
995	SRR371	SALT NESS,SHETLAND	3940	50	3443	5035
996	BIRM2	LINWOOD MOSS,RENFREW	3572	64	4330	6540
997	BIRM3	CLIPPENS FARM	9231	96	24330	66540
998	BIRM4	WESTER FULWOOD	8039	128	24320	66690
999	BIRM13	LINWOOD MOSS	3513	56	24390	66640
1002	SRR1068	CROMARTY FIRTH	8748	80	25870	86150
1003	HV1010	BARNYARDS	9200	100		
1004	HV1012	ARCAN	5775	85		
1005	HV1013	ARCAN	7700	80		
1006	BIRM1122	BARNYARDS 14B	5510	80		
1007	BIRM1123	BARNYARDS 14B	9610	130		
1008	BIRM1124	MONIACK 4B	4760	90		
1009	BIRM1125	MONIACK 4B	7100	120		
1010	BIRM1126	MONIACK 4B	7270	90		
1011	BIRM1127	MONIACK 4B	7430	170		

N.B. DATES 1006 TO 1011 ARE NOT INCLUDED IN THE HISTOGRAM ANALYSIS

Fig. 8.1 A	Location of index points used in initial histogram analysis including also the six provisional ^{14}C dates from the inner Moray Firth area.
Fig. 8.1 B	Frequency distribution histogram using 99 unscreened ^{14}C dates from a Flandrian coastal context.




99 DATES
2
1
9
8
7
6
5
4
3
2
1

the geological record as known to suggest a period of ingression and no peat growth followed by a period of sea-level fall and a greater extent of peat growth at these times. Alternative explanations could include a random factor, distortions of the ^{14}C time scale or sampling bias. A notable feature of the histogram is a consistent fall from 7500 to 6850 B.P. which could be correlated with the rapid rise of sea-level to the Flandrian maximum. In the Forth and Tay and on the outer east coast of Scotland Sissons (1976) and Morrison et al. (1981) consider the Main Postglacial Shoreline to be slightly diachronous having an age of c. 6400 B.P. in the western Forth Valley, c. 6100 B.P. in the mid Tay valley and 5800 B.P. on the east coast north of Aberdeen and in North East Fife. The histogram does show two minima at 6400 - 6450 B.P. and 5950 - 6000 B.P. with a slight rise in between. The significance of this rise is not known however. Minima from c. 5000 B.P. to the present probably record a lack of dated samples at these times.

The dates comprising the initial histogram were not screened and included clearly allochthonous dates such as SRR 1068 from the Cromarty Firth (Peacock et al. 1980). In order to remove dates of dubious quality and to assess the tendencies of sea-level movement the original 99 dates were screened individually to assess their relevance as sea-level indicators. 64 dates remained 35 were termed indicative of a positive tendency and 31 as negative. The discrepancy occurs since dates, such as Q641 9362 ± 150 B.P. from Girvan were considered to represent equal evidence for both positive and negative tendencies. The resulting double-edged histogram is shown in fig. 8.2 and the data given in table 8.2. It is comprised of an average of 0.5 dates per class interval for positive tendencies and 0.2 dates per class interval for negative tendencies again both showing unreliable types, maxima and minima can be expected to be influenced greatly by random factors.

TABLE 8-2 SCOTTISH C14 DATA WITH TENDENCIES

+ = POSITIVE TENDENCY
− = NEGATIVE TENDENCY

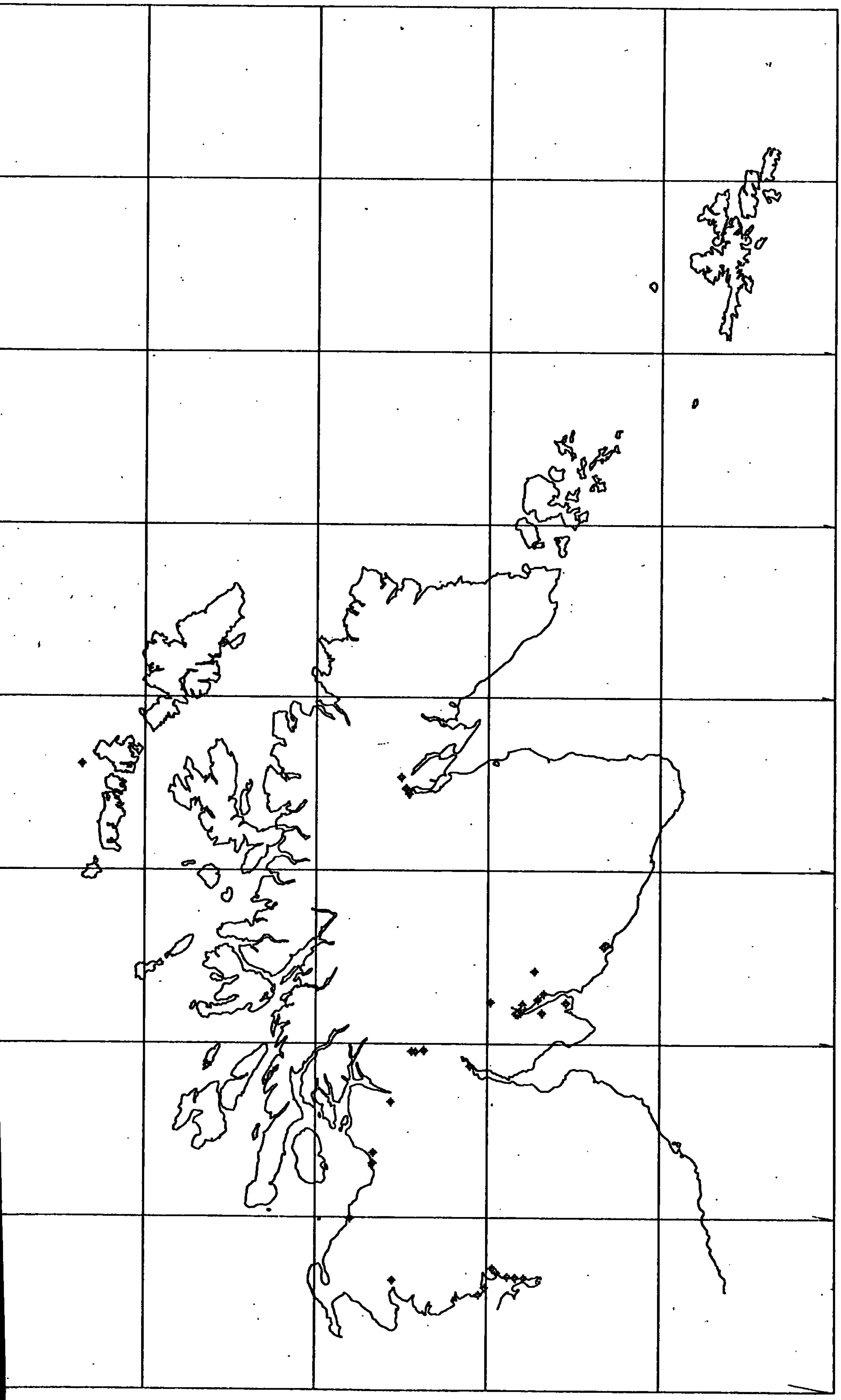
	LAB. CODE	SITE	AGE	STD. DEV.	N.G.R.		TENDENCY
901	SRR66	POWGAVIE,TAYSIDE	8150	50	32912	72532	+
902	SRR67	POWGAVIE,TAYSIDE	8320	57	32912	72532	−
903	SRR68	POWGAVIE,TAYSIDE	8331	74	32912	72532	+
903	SRR68	POWGAVIE,TAYSIDE	8331	74	32912	72532	−
904	SRR69	BURNSIDE,TAYSIDE	8170	67	33259	72861	+
905	SRR70	BURNSIDE,TAYSIDE	8616	52	33259	72861	−
906	SRR71	CAREY,STRATHEARN	7778	55	31747	71703	+
907	SRR72	CAREY,STRATHEARN	9524	67	31747	71703	−
908	NPL127	CAREY,STRATHEARN	7605	180	31717	71710	+
909	I2796	CAREY,STRATHEARN	9640	140	31717	71710	−
910	SRR1399	INNERNETHY	8555	60	31899	71783	+
910	SRR139	INNERNETHY	8555	60	31899	71783	−
911	SRR1398	INNERNETHY	8505	50	31899	71783	−
912	SRR1397	INNERNETHY	7530	50	31899	71783	+
913	SRR1147	CORDON,STRATHEARN	8370	45	31845	71813	−
914	SRR1394	CORDON,STRATHEARN	7525	50	31845	71813	+
915	SRR1396	CULFARGIE,STRATHEARN	7760	50	31625	71717	+
916	SRR1395	CULFARGIE,STRATHEARN	7555	50	31625	71717	+
917	SRR1401	KINTILLO,STRATHEARN	7465	55	33148	71766	+
918	SRR1400	KINTILLO,STRATHEARN	7180	55	33148	71766	+
919	SRR1150	GLENCARSE,STRATHEARN	6679	40	32022	72256	+
920	SRR1151	GLENCARSE,STRATHEARN	6083	40	32022	72256	−
921	SRR1510	HOLE OF CLIEN	6170	90	32050	72030	−
922	SRR1511	HOLE OF CLIEN	7500	90	32050	72030	+
923	IGS1	ST.MICHAELS,FIFE	5030	110	34541	72348	−
924	IGS2	ST.MICHAELS,FIFE	7605	130	34541	72348	+
925	IGS3	ST.MICHAELS,FIFE	9945	160	34541	72348	−
926	SRR1331	ST.MICHAELS,FIFE	5890	95	34540	72350	−
927	SRR1332	ST.MICHAELS,FIFE	7310	100	34540	72350	+
928	SRR1333	ST.MICHAELS,FIFE	7050	100	34540	72350	+
929	SRR1334	ST.MICHAELS,FIFE	7555	110	34540	72350	+
932	SRR114	FULLERTON,KINCARDINE	6704	55	36748	75605	−
933	SRR1149	FULLERTON,KINCARDINE	7086	50	36748	75605	+
934	BIRM867	FULLERTON,KINCARDINE	6880	110	36748	75605	+
935	BIRM823	FULLERTON,KINCARDINE	7140	120	36748	75605	+
936	SRR869	MARYTON,KINCARDINE	7340	75	36837	75650	−

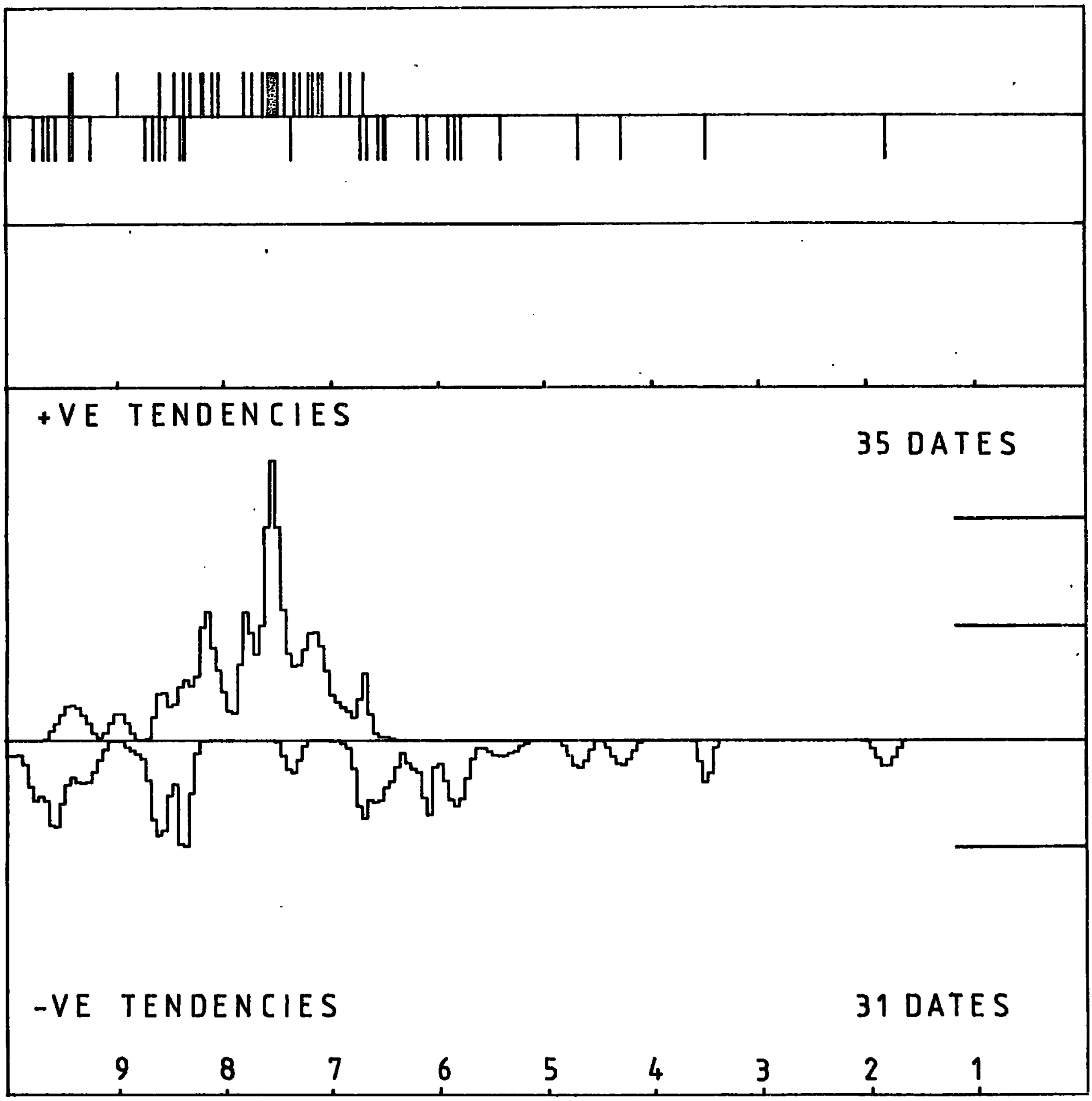
TABLE 8-2 (CONTINUED)

937	SRR386	ARDLER,TAYSIDE	9730	60	32743	74173	-
940	Q641	GIRVAN,ENOCH,AYR	9362	150	22040	59930	-
940	Q641	GIRVAN,ENOCH,AYR	9362	150	22040	59930	+
942	Q638	LOCHAR MOSS,DUMFRIES	6645	120	30560	56800	-
944	I5070	NEWBIE COTTAGES	4290	100	31650	56510	-
945	I5069	W.PRESTON	1850	95	29520	55530	-
961	BIRM222	NEWBIE COTTAGES	7540	150	31660	56500	+
962	GU373	DUNDONALD BURN	8950	90	23370	63720	+
965	BIRM256	BATTLEHILL,ANNAN	6800	250	32157	56494	+
966	BIRM258	HORSEHOLM,DUMFRIES	5410	160	30313	57062	-
967	BIRM323	SOUTH CARSE	9390	130	29383	55944	+
967	BIRM323	SOUTH CARSE	9390	130	29883	55944	-
968	BIRM324	MIDTOWN,DUMFRIES	6470	280	31189	56577	-
969	BIRM325	NEWBIE COTTAGES,AYR	7400	150	31644	56515	+
970	BIRM415	PALNURE	6540	120	24500	56367	-
971	IGS149	TROON,AYR	8015	120	23361	63111	+
973	Q1172	LOCH SNIOGRAVAT	4688	90	63800	60900	-
974	SRR381	DUNDONALD BURN,AYR	8070	70	23372	63717	+
976	GU64	NEWBIE COTTAGES	7254	101	31670	56490	+
981	I1839	KIPPEN,FORTH VALLEY	8690	140	26300	69600	-
982	I1838	KIPPEN,FORTH VALLEY	8270	160	26300	69600	+
983		SOUTH FLANDERS	8010	130	26310	69610	+
984		EASTER OFFERANCE	7480	125	25820	69520	+
985		WEST FLANDERS MOSS	6490	125	25600	69550	-
989	Q280	AIRTH COLLIERY	8421	157	29000	68700	+
992	SRR353	GREENHILL,CRIEFF	9590	70	20182	82376	-
999	BIRM13	LINWOOD MOSS	3513	56	24390	66640	-
1003	HV1010	BARNYARDS 3B	9200	100			-
1004	HV1012	ARCAN	5775	85			-
1005	HV1013	ARCAN	7700	80			+

Fig. 8.2 A Location of screened index points used in histogram analysis

Fig. 8.2 B Frequency distribution histograms using screened data. The number of dates for negative tendency should read 31




+VE TENDENCIES
35 DATES
-VE TENDENCIES
31 DATES
9
8
7
6
5
4
3
2
1

It should be expected that real minima - that represent an actual lack of peat dates caused by marine ingression - should be coincident in both histograms or perhaps slightly offset with the minimum being recorded in the transgressive tendency histogram slightly before the equivalent minimum in the regressive tendency histogram.

There are two such occurrences in the diagram. The upper histogram shows a minimum almost reaching the base line at 9150 B.P. with a corresponding though slightly later minimum in the lower histogram at 8900 - 9050 B.P. A second minimum occurs in the upper histogram between 6300 and 6450 and 6300 B.P. The two minima could be interpreted as correlating with the Low Buried Shoreline and Main Postglacial Shoreline of the Forth, Tay and east coast of Scotland.

A further notable feature is the lack of dates showing negative tendencies between 8000 and 6700 B.P. suggesting a significant regional rise of sea-level. After 6000 B.P. there are no dates that record a positive tendency indicating that relative sea-level fall obtained throughout Scotland contrary to Jardine (1975).

Histogram analysis is therefore likely to become an increasingly used technique as the data base expands. For Scotland the technique is based on poor data. It does show well the general rise in relative sea-level between 8000 and 7000 B.P. with a fall from c. 6000 B.P. It also perhaps indicates a degree of diachroneity for the formation of the Low Buried Shoreline and Main Postglacial Shoreline yet with a degree of precision no greater than that given by an initial inspection of the geological record.

8.3 Comparison of sea-level changes in the inner Moray Firth with other areas of Scotland

J.B. Sissons (1981b) has recently identified a thin but widespread gravel layer of marine origin between Late Devensian and marine deposits underlying the Beauly Carse. The shoreline of the gravel layer of which he correlates with the Main Lateglacial Shoreline (Sissons 1974) and he suggests it resulted from an erosional phase during the low sea-level of Loch Lomond Stadial times.

At Barnyards beneath the lower peat the presence of a coarser layer of silty sand overlying finer silty clays, all of Late Devensian age - suggests a higher energy environment. The altitude of the silty sand layer - at 1.25-1.95 m. is quite comparable in altitude to the feature described by Sissons. He considers the gravel layer to have two components, a gentle seaward sloping surface with a shoreline at the break of slope is suggested to vary between 1.1 and 2.6 m. O.D. The method used to detect the layer consisted of pushing rods down without sampling until a resistant stratum, presumed to be the gravel layer, was encountered. This method must produce a degree of subjectivity. However, the broad conclusions are accepted and the Barnyards site is suggested to contain evidence of an erosive phase during the Late Devensian which may correlate with the feature described by Sissons. Its composition is not of gravel, however, which probably reflects the different methods of sampling and recording.

The sequence of shorelines (*sensu* Sissons 1966) has not been outlined for the Moray Firth area yet sea-level movements for the period 9600 - 5800 B.P. have been described in Chapter 7. The lower peat at Barnyards has similar age, stratigraphic relationships and pollen characteristics to the thin peat layer overlying the Main

Buried Beach (Newey 1966, Sissons 1966, Brooks 1971). The age of the landward limit of marine clastic deposition preceding peat formation is given by the provisional ^{14}C data of 9610 ± 130 B.P. at BY14B - very comparable in age to the Main Buried Shoreline of the Forth and Tay dated at 9600 B.P.

Rates of sea-level change determined by the two dates on the regressive overlap at Barnyards calculated between BY14B and BY3B gives a maximum of 3.17 m/100 yrs and a minimum of 0.56 m/100 yrs (Chapter 7). In order to assess rates of change in sea-level in the Forth and Tay at this time data were extrapolated from the sea-level curves of Sissons and Brooks (1971) and Cullingford et al. (1980).

In the western Forth Valley if 9600 B.P. and 9.9 m. is accepted for the age and altitude of the Main Buried Shoreline and 8900 B.P. and 6.8 m. for the succeeding trough or regression minimum in the curve between the formation of the Main and Low Buried Beaches, it suggests a rate of fall of 0.44 m/100 yrs.

Similar calculations for lower Strathearn using 3.2 m. and 9600 B.P. for the age of the Main Buried Shoreline and 2.6 m. and 8800 B.P. for the succeeding minimum results in a rate of fall of 0.075 m/100 yrs. The comparison of rates therefore shows the minimum estimate from the Moray Firth is larger than the western Forth, an area accepted as having a greater magnitude of total uplift. Reasons for this could include

- a different isostatic history for the Moray Firth area in the early Flandrian caused for instance by the migration of the forebulge or a redistribution of the isobases.

- a phenomenon of the data collection. The accepted practice in the Forth and Tay has been to date shorelines, not the most seaward expression of biogenic sedimentation, therefore the minima on the curves of Sissons and Brooks 1971 and Cullingford et al. (1980) are extrapolations and may be in error. If isostatic history is to be explained then data are needed from other locations than at the landward limit of marine activity.

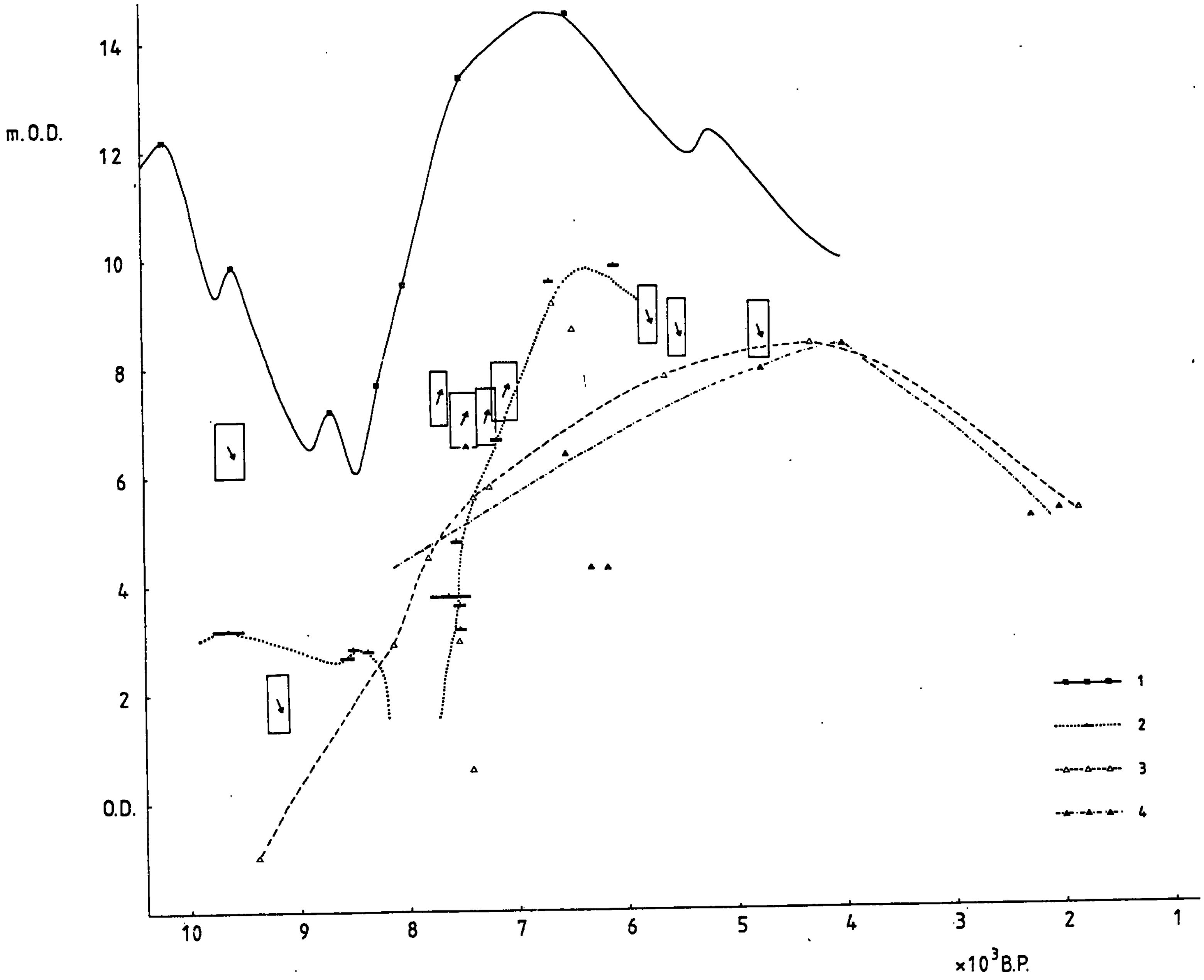
The difference in gradient of the respective curves can be seen in fig. 8.3 where selected sea-level curves are plotted on the same axis. The curves used are those from Sissons and Brooks (1971) Cullingford et al. (1980) and two from Jardine (1975) in addition to the index points from the Moray Firth area. The two curves from eastern Kirkcudbright - Dumfries and Wigtown Bay differ from the originals published by Jardine (1975) however. Jardine calculated tidal correction factors to reduce the 'primary' index points to 'secondary' ones which recorded the course of Mean Tide Level. Because none of the other curves have been drawn to MTL for ease of comparison in fig. 8.3, Jardine's two curves, 3 and 4 are drawn using the original primary points and will therefore differ from the published curve. The inner Moray Firth index points are the only ones to use indicative range of index point to a reference tide level and to include error boxes for age and altitude, the latter based on sampling error, error in tide level and indicative range.

It is not known if the equivalent of the Low Buried Beach of the Forth exists in the Beauly area. There is the suggestion of a break in slope between BY7 and BY8 (figs. 5.2 and 5.3) but it has been interpreted as a channel deposit. The pollen and ^{14}C data at BY3B suggest an age older than the Low Buried Beach of the Forth dated at 8800 B.P in the Forth (Sissons 1966) and perhaps 8500 - 8600 B.P. in lower Strathearn.

One of the more striking features about fig. 8.3 is the dissimilarity of the two curves for the north shore of the Solway Firth

Fig. 8.3 Selected sea-level curves from Scotland compared to the inner Moray Firth index points.

1. Western Forth Valley (Sissons and Brooks 1971)
2. Lower Strathearn (Cullingford _et al._ 1980)
3. Eastern Kirkcudbright and Dumfriesshire.
   N.B. Curve drawn through original data points (after Jardine 1975)
4. Wigtown Bay. N.B. Curve drawn through original data points (after Jardine 1975)


m.O.D.
14
12
10
8
6
4
2
O.D.
10
9
8
7
6
5
4
3
2
1
x10³B.P.
1
2
3
4

to the rest. This has been suggested, in Chapter 3, to be due to differences in data interpretation rather than to actual differences in the altitude and timing of transgressive and regressive overlaps. If the suggestions made in Chapter 3 are implemented and concerning the change in interpretation of certain index points (e.g. South Carse, 9390 ± 130 B.P.) and the rejection of others (e.g. Redkirk Point 8135 ± 150 B.P. and Newbie Mains 7812 ± 131 B.P.) it is remarkable how the 'redrawn' curve parallels that of lower Strathearn.

The period of low sea-level shown in the western Forth curve between 8690 ± 140 B.P. and 8270 ± 160 B.P. has a later age of between 8370 ± 45 B.P. and 7525 ± 50 B.P. for lower Strathearn perhaps indicating differential isostatic uplift causing slight diachroneity. The comparable low point in the inner Moray Firth area lies between 9200 ± 100 B.P. and c. 1000 yrs later estimated from pollen evidence at BY3B and supported by the radiocarbon date from the Cromarty bore C2 mentioned above. (Peacock <u>et al</u>. 1980). This difference in postulated age for the inner Moray Firth with respect to the Firth and Tay may again reflect the different approaches used and the fact that no oscillation equivalent to the rise and fall in sea-level that led to the formation of the Low Buried Beach has been determined in the inner Moray Firth.

The thin grey silty sand layer found at Moniack to certain marine diatoms and at Barnyards where it lies solely within the upper clastic sequence is provisionally dated between 7430 ± 100 B.P. and 7270 ± 90 B.P. It is correlated with the grey micaceous silty fine sand layer of Smith <u>et al</u>. (1980) and Morrison <u>et al</u>. (1981) which is dated between 7555 - 7180 B.P. in East Fife and 7140 - 7050 B.P. at Fullerton near Montrose. There is therefore evidence for a discrete event prior to the culmination of the main Flandrian rise in sea-level in eastern Scotland, though it is not recorded at all sites. The range of recorded altitude of the layer is approximately 4-6.5 m.O.D. in the Montrose area and c. 4.5-9 m. in the East Fife area. At Moniack recorded altitudes range from 5.95 m. to 8.33 m. and at Barnyards from 3.73 to 5.11 m. At Barnyards the layer is not recorded landward of BY10 yet the altitudinal range at Moniack suggests that the erosive transgressive overlap at BY14B (7.88 m) is within the range of this event. Pollen evidence from BY14B suggested this transgressive overlap is dated some time after c. 7200 B.P.

The cause of formation of the layer is not known. Theories advanced include a storm surge (D.E. Smith unpublished) or a minor transgressive episode succeeded by a slight regression (Smith *et al*. 1980).

A storm surge hypothesis is attractive. The sand layer is certainly a unique event in the mid-Flandrian history of the east coast of Scotland. Arguments in favour of a surge could include:-

- the layer is usually thin 20 cm. is uniform in grain size (a sandy silt) and often has an erosive lower contact.

- the age of the layer is remarkable uniform (if correctly correlated) being c. 7300 B.P. in the inner Moray Firth, 7555 - 7180 B.P. in East Fife and 7140 - 7050 B.P. at Fullerton near Montrose.

- it is precisely in the more landward positions relative to the contemporary tidal range that one would expect evidence for extreme events to be preserved, more seaward locations would be susceptible to later reworking by natural coastal processes.

- an extension of the former point, it could be suggested that the slowing in the rate of sea-level rise compared to the period 8200 B.P. - 7500 B.P. would initiate conditions more likely for the preservation of such a layer.

The search for modern analogues is probably meaningless with so much of the present coastline the product of man's activities, indeed it is doubted if a completely natural coastline showing a transition from intertidal → saltmarsh → reedswamp → freshwater Alnus or Quercus fen exists today.

Kumar and Sanders (1976) have described characteristics of modern and ancient storm deposits and consider them to contain a distinctive three part sequence; from the base upward consisting of (a) a basal lag containing coarse gravel (b) finely laminated sand up to 2 m. thick (c) burrow-mottled sand coarser than (b).

The lower two units (a) and (b) are considered to result from storms, the lag formed during maximum storm intensity and the overlying, finer sand is inferred to have been deposited rapidly under conditions of intense bottom shear as the storm waned. The upper unit is considered to result from fair weather processes creating wave-ripple laminae between the wave base and the breaker zone or burrow-mottled sediment further to seaward(p.145).

The environments studied by Kumar and Sanders are not strictly comparable to the predominatly low energy sedimentary environments in which the sand layer is preserved today. In these environments conditions leading to the creation of a gravel lag deposit would not operate. However, an attractive origin for the sand layer could be that of rapid deposition out of suspension. At M4B diatoms counted through the sand layer proper (zone M4BD1) show little variation in species content or species numbers, which could suggest rapid deposition.

Evidence from the 1953 storm surge shows no evidence that sediments such as those found at M4B were laid down extensively. In south-east England the only sedimentary evidence on the natural coast was a thin veneer of clay of limited extent and closely association with dune breaching (Tooley 1979). The sand layer is an exceptional event however and comparison with a storm surge with a return period of 10 years that affected a largely man-made coastline is probably invalid.

An alternative interpretation for the layer could include that it represents a minor transgressive episode within a general period of rising sea-level. At M4B the initial erosive phase represented by the sand layer is succeeded by a succession in diatoms from marine to brackish spectra. The thin overlying Phragmites peat contains no evidence for environmental succession that may be expected under conditions of falling sea-level and the sequence could be interpreted as an initial erosive event caused by a rise in sea-level followed by a fall or equally a decrease in the rate of rise allowing peat accumulation over brackish facies.

If the sand layer has an eustatic origin it should be capable of resolution in the available eustatic curves. Morner's eustatic curve (1979b) does show a distinct oscillation with a fall in sea-level recorded at c. 7000 B.P. as does the sea-level curve for north-west England (Tooley 1974).

In an uplifted area rises in sea-level are events of interregional significance but tend to record a shorter time span for the event than in areas of less isostatic uplift. Therefore a sudden increase or pulse in the rate of sea-level rise in an uplifted area, if it has a eustatic origin, should be capable of identification in areas of less isostatic uplift. It is perhaps indicative of the scale of resolution of the eustatic sea-level curves mentioned above that no increase in the rate of sea-level rise is shown at this time. Alternatively it could be argued as proof of a storm surge origin.

The culmination of the Flandrian rise in sea-level is recorded at an altitude of 9 m. and an age between 7100 ± 120 B.P. and 5775 ± 85 B.P. with a preferred age of 6100 - 6400 B.P. Table 8.3 compares age brackets and altitude information for the formation of the Main Postglacial Shoreline in eastern Scotland and the Flandrian maximum of sea-level rise for the Solway Firth area (Jardine 1975)

TABLE 8.3

Location	Altitude (m)	Preferred age (B.P.)	
East Fife	c. 8.3 m.	5900	(1)
Mid-Tay	9.7 - 11.5 m.	6100	(1)
Western Forth	14.4 m.	6600	(2)
Moray Firth	9m.	6100 - 6400	
Kirkcudbright	8.18 m.	4300	(3)

There is therefore some evidence for a diachroneity of the Flandrian culmination of sea-level away from the centre of isostatic uplift. The resolution afforded by the inner Moray Firth data is poor however since of the three ^{14}C dates on the upper regressive overlap, the Arcan Mains data is considered the most reliable and the site is some 5-6 km. north-west of Barnyards and Moniack. The dates are comparable to those published apart from the Solway Firth and together with the comparable altitudes and with no evidence of a higher Flandrian shoreline in the inner Moray Firth the maximum altitudinal limit of the Flandrian marine sequence at Moniack, Arcan and Barnyards is equated with the Main Postglacial Shoreline. More ^{14}C dates are needed to allow meaningful suggestions about diachroneity or synchroneity and much more care needs to be taken that similar features are being compared (see Section 8.5).

8.4 A preliminary isostatic curve for the Moray Firth area

Two isostatic curves are available for Scotland (Sissons and Brooks 1971, Cullingford et al. 1980). Their construction uses the relationship S + E = I where.

S = Relative sea-level
E = Eustatic sea-level
I = Isostatic recovery

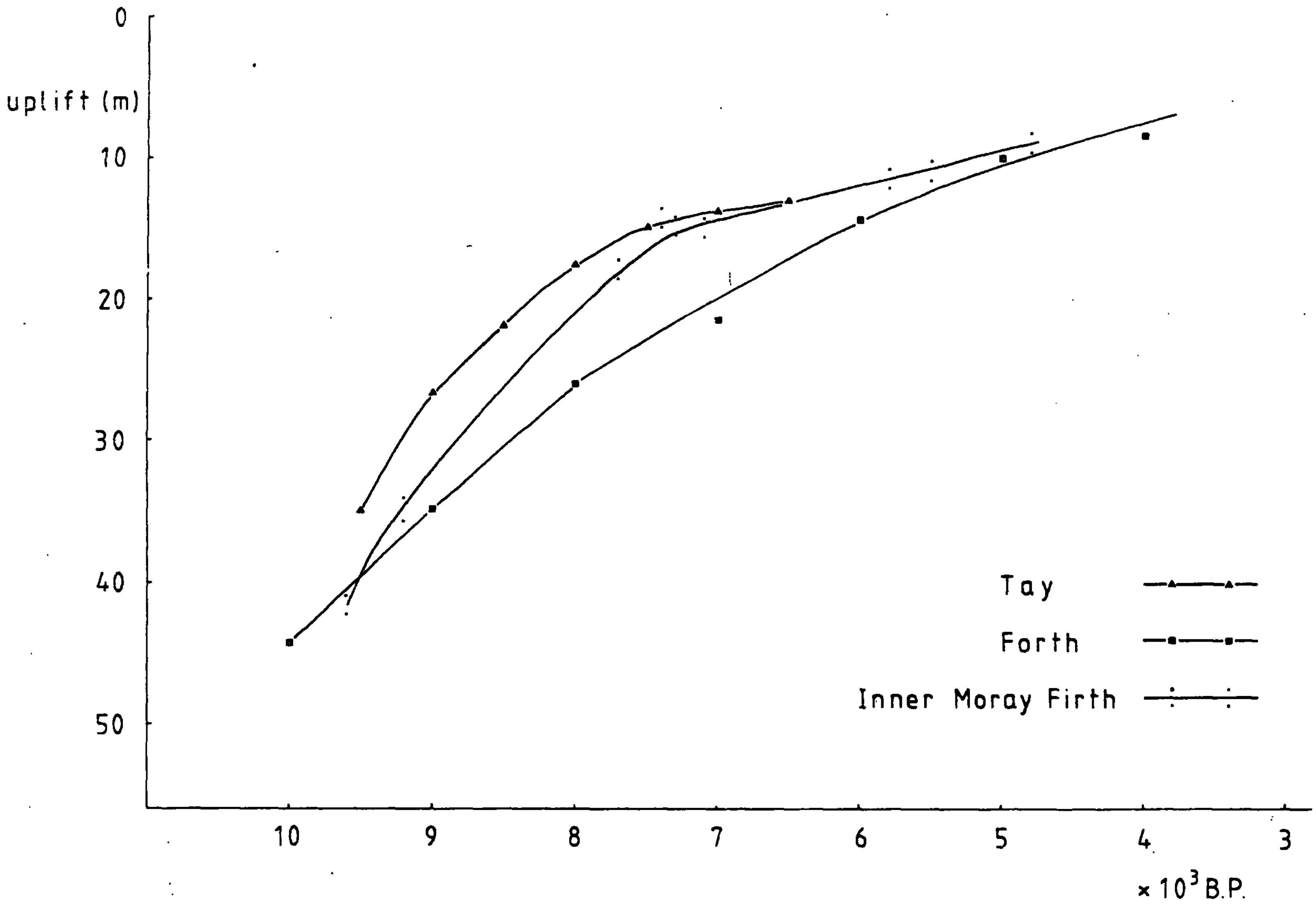
The eustatic factor used in the two curves, from the western Forth Valley and lower Strathearn was a mean value calculated through extrapolation from several 'eustatic' curves. For the inner Moray Firth area, as a first approximation, values were extrapolated from three 'eustatic' curves (Tooley 1974, Mörner 1979b and Kidson and Heyworth 1978) for each index point age, averaged and added to altitudes converted to MTL. Fig. 8.4 shows the preliminary isostatic curve. The comparable curves for the Forth and lower Strathearn are also shown.

The diagram shows that the inner Moray Firth area has an isostatic uplift history comparable to the Forth and Tay areas with c. 42 m. of total uplift since 9600 B.P. and 11.5 m. since 5800 B.P. These figures should only be seen as approximate since the construction of the diagram is prone to many errors especially in the determination of altitude, such as those relating to the accuracy of the original index point altitude, the accuracy of interpolation from the eustatic curve and the accuracy of the original eustatic curve. The isostatic curve for the inner Moray Firth is drawn within an altitudinal error band equal to the original error boxes of the index points. The total error is considerably larger.

Nevertheless several interesting features are apparent in the curve. Firstly, the initial amount of uplift in the inner Moray Firth

Fig. 8 .4 Isostatic recovery curves for Scotland I

Tay curve from Cullingford et al. (1980). Forth curve from Sissons and Brooks (1971). Inner Moray Firth curve calculated from original 9 index points reduced to MTL and with the eustatic component added. The eustatic component is calculated as the mean value of 3 'eustatic' curves (Mörner 1979, Tooley 1978a, Kidson and Heyworth 1978) at each corresponding age.


uplift (m)
0
10
20
30
40
50
10
9
8
7
6
5
4
3
× 10^3 B.P.
Tay
Forth
Inner Moray Firth

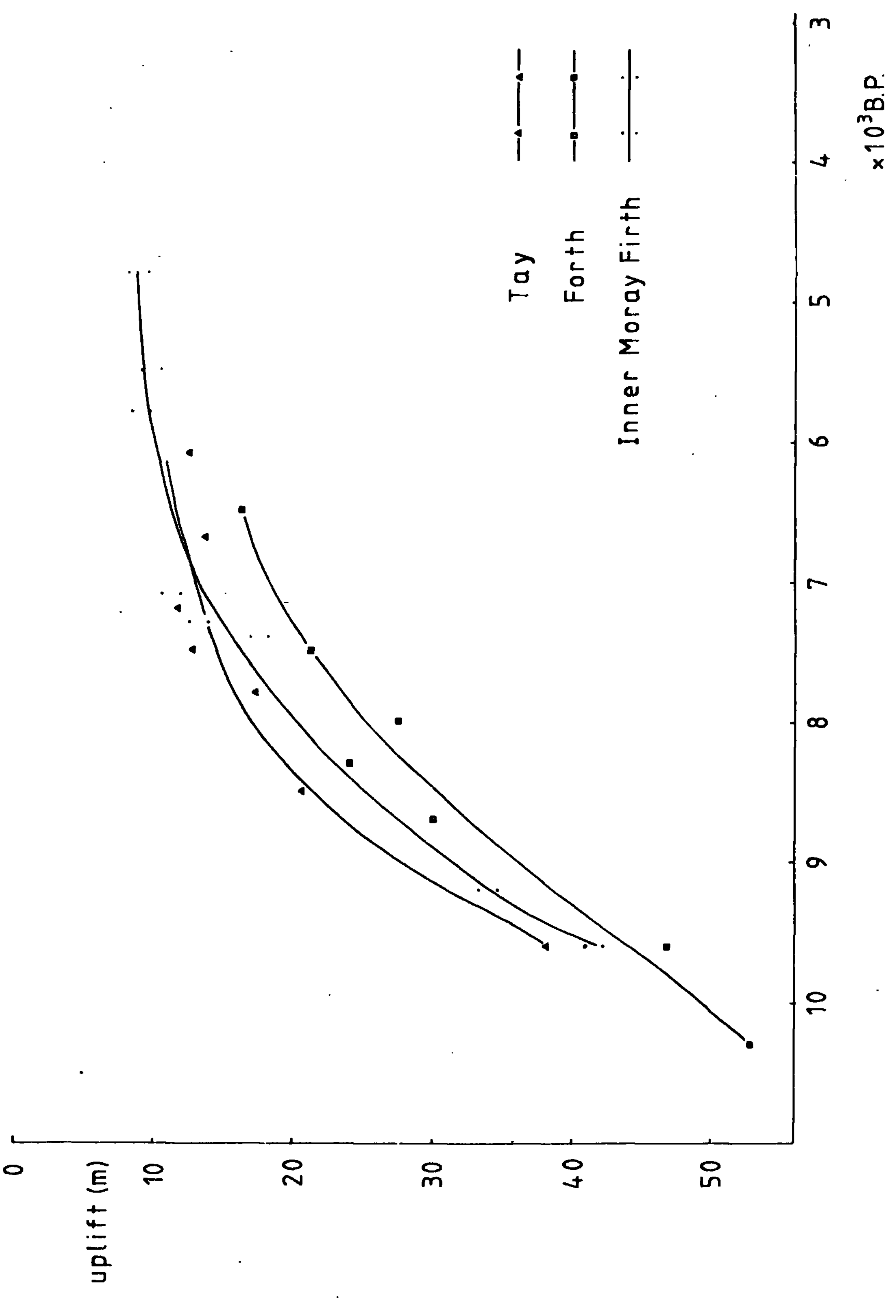
appears to have been greater than that of the Forth at c. 9200 B.P. Secondly, the rate of isostatic uplift for the inner Moray Firth appears to have been greater than in both the Forth and Tay until c. 7300 B.P. Thirdly, the inner Moray Firth and Tay curves appear to cross at c.6500 - 7000 B.P. with the Tay recording a greater amount of isostatic uplift since that date.

One possible explanation of these features is that they are real differences and give evidence for differential isostatic uplift caused by differing glacial histories and geological structure between the areas.

However it is thought probable that the differences are a phenomenon of the method of curve construction and lie within the error band for the resolution of the data. The uplift curves for the Forth and Tay were constructed at 1000 and 500 yr. intervals, respectively, whilst the Moray Firth area curve was based on the actual age of the original index points. Furthermore the eustatic calibration of the former two curves was derived from a number of 'eustatic' curves. The Forth curve includes data from the curves of Godwin et al. (1958), Shepard (1963), Schofield (1964), Moran and Bryson (1969) and Mörner (1969) (in Sissons and Brooks 1971) and the lower Strathearn curve - called here the Tay curve - includes data from all five of the above curves and in addition those of Kidson and Heyworth (1973) and Tooley (1974). The Moray Firth curve was derived only from these latter three. Recent work by Mörner (1976) has effectively halted the search for a global eustatic curve and therefore the Tay and Forth curves include data from eustatic curves that probably contain error from including data points from widely differing areas.

In an attempt to see if the differences in the isostatic curves given in fig. 8.4 could be explained by differences in construction, all three were redrawn in a similar way using an age for each individual

Fig. 8.5 Isostatic recovery curves for Scotland II. All curves derived from original data points related to MTL with the eustatic component derived from Mörner (1979), for each corresponding age.


uplift (m)
0
10
20
30
40
50
10
9
8
7
6
5
4
3
$\times 10^3$B.P.
Tay
Forth
Inner Moray Firth

index point used in the original sea-level curve or time altitude graph and a eustatic factor taken from the curve of Mörner (1979b) which is claimed to be the best approximation to the form of eustatic change in North West Europe. The result is shown in fig. 8.5. The variability of the data is great caused in part by the inaccuracy of interpolation from an oscillating curve and therefore no reliance should be placed on the curves shown in fig. 8.5, they are to be considered merely an exercise in assessing the isostatic factor.

The greater amount of isostatic uplift in the inner Moray Firth area for 9200 B.P. compared to the western Forth is seen as a phenomenon of curve construction. However, the curves for the inner Moray Firth and Tay still cross at c. 7000 B.P. suggesting a differential rate of isostatic recovery between the two areas. It may still be caused by the inclusion of data points from Barnyards 14B and Moniack which are minimal ages for the removal of marine conditions from the respective sites, the true age could be somewhat older and the dangers of circular argument must be stressed.

However there is some support in the geological record for a decrease in the rate of isostatic uplift in the inner Moray Firth area with respect to the Tay. At Hole of Clien, St. Michael's and Fullerton in the middle Tay valley, East Fife and near Montrose respectively, the grey silty sand layer described in section 8.1 below forms a distinct, separate, wedge into the coastal peat mosses. The wedge extends further landward relative to the later carse deposits. At Moniack the reverse is true and the grey silty sand layer, if correlation is correct, does not extend into the coastal peat further than the wedge formed by the blue-grey silty clay which is probably the correlative of the carse clay of the Forth and Tay. This could suggest a differential isostatic recovery, though again the errors inherent in the above speculation are large and depend greatly on the validity of lithstratigraphic correlation by chronostratigraphic means and the validity of Moniack as a site reflecting regional events since Moniack is a site open to local influences on sedimentation.

A further line of evidence supporting the speculation is the fact that the correlative of the Main Buried Shoreline in the inner Moray Firth is now at 6.59 m. compared to 3.2 m. in lower Strathearn and yet the present altitude of the correlative of the Main Postglacial Shoreline is c. 9 m. though probably slightly higher compared to a maximum of 11.5 m. in lower Strathearn. It is considered that while the speculation of differential rates of uplift between the Tay and Moray Firth area - due to the differences in glacial history and tectonic history - is an attractive one, the available data do not prove such a differential isostatic history at present.

8.5 Other Correlations

The registration of positive and negative tendencies between areas of uplift, stability and subsidence will depend greatly on the rate and direction of the eustatic and isostatic factors as defined in chapter 1. If a similar eustatic history can be assumed for Britain and perhaps even north-west Europe then differences in the date of initiation of positive and negative tendency periods will have an isostatic cause. It may therefore be suggested that in a subsiding area positive tendencies will predominate, begin earlier and last longer than in a stable or uplifting area; negative tendencies will probably reflect an inter-regional significant fall in sea-level. In an uplifting area negative tendencies will predominate, begin earlier and last longer than a stable or subsiding area; positive tendencies will probably reflect an inter-regional, significant rise in sea-level.

Given this theoretical background, correlation can be made between areas of different tectonic history to identify differences in the registration of positive and negative tendencies and to identify possible causes. This approach is not incompatible with previous research in Scotland which has tended to identify and name discrete features or shorelines. If the definition of a shoreline by Jardine (1981) is accepted - that of the intersection of mean tide level and the land surface at any given time in any given area - then any sea-level index point can be regarded as a shoreline for the scales of time and space within which it is considered to be representative. Shorelines such as the features described in the Forth and Tay would then only define the boundary conditions between the end of a positive tendency and the beginning of a negative tendency period.

In north-west England Tooley (1982) has identified twelve time periods characterized by transgressive overlap and twelve time periods characterized by regressive overlap. This new scheme, derived from a reassessment of the basic data for north-west England is considered to supersede the Lytham I - IX transgression sequences which used mixed criteria to establish the limits.

The time interval c. 9300 B.P. to 8600 B.P. corresponds to the first of Tooley's transgressive overlap periods. This interval is based on three ^{14}C dates from Heysham Harbour and two from deep boreholes in Morecambe Bay. Of the three dates from Heysham Harbour two are from the middle of peat layers and are disturbed samples. Only one date shows corroborating evidence for a rise in watertable, Birm. 140, 8925 ± 200 B.P. some 63 cm. below the transgressive overlap. The dates are not good evidence for the initiation of a transgressive episode prior to 9,000 B.P. and a later date of c. 8900 B.P. is preferred. This suggests the first period of transgressive overlap can be considered as c. 8900 B.P. to c. 8600 B.P. This time period is characterized by evidence for a negative tendency of sea-level change in the Moray Firth area. There are two possible reasons for the proposed opposite movements of sea-level between the areas at this time.

If the relationships mentioned above are valid, a positive tendency period should start earlier in NW England than the Moray-Firth. Due to lack of stratigraphic control provided by a shoreline sequence it is unknown as yet if the equivalent of the Low Buried Shoreline of the Forth and Tay exists in the Moray Firth area. Tooley's first transgressive overlap period and dates of 8800 B.P. and 8500 - 8600 B.P. for the Low Buried Beach in the Forth and Tay do suggest further research may enable further refinement of the chronological scheme during the time period 9000 - 8500 B.P. in the inner Moray Firth.

Alternatively the lack of a Low Buried Shoreline may reflect a higher rate of isostatic recovery in the inner Moray Firth producing continued negative tendencies. However, the dangers of a circular argument must be stressed here.

The second time interval of transgressive overlap in north-west England lasts from c. 8450 B.P. to c.7600 B.P. and corresponds to the period of positive tendency in the inner Moray Firth area which commenced c.8550 B.P. The rise in sea-level between these dates was dramatic, approximately 8-10 m. in north-west England and greater than this figure in the inner Moray Firth area. Tooley (1974) has suggested this dramatic restoration of sea-level correlates with the final catastrophic disintegration of the Laurentide ice sheet (Bryson _et al_. 1969) consequent upon the transgression of Hudson Bay.

Between c. 7400 B.P. and c. 7150 B.P. a second period of regressive overlap is recorded in north-west England. This might be taken as evidence to suggest that the thin peat layer above the thin silty sand layer at Moniack dated at 7200 - 7100 B.P. may represent a fall in sea-level. However the interval is based on only two radiocarbon dates in north west England and such a conclusion is premature.

A further interesting feature of the scheme is the alternation of transgressive and regressive overlap periods between 6750 and 5500 B.P. Approximate dates are given below in table 8.4

TABLE 8.4

	Transgressive Overlap (B.P.)		Regressive Overlap (B.P.)
4.	6400 - 6450	3.	6500 - 6750
5.	5950 - 6000	4.	6050 - 6300
6.	5490 - 5750	5.	5750 - 5900

It can be suggested that if the transgressive episodes have regional significance they may well be capable of recognition in areas with increased isostatic uplift. There are two time periods given in table 8.4 that provide optimum conditions for shoreline formation between 6300 and 6400 B.P. and between 5900 and 5950 B.P. In Scotland the Main Postglacial Shoreline is considered to have been formed c. 6400 B.P. in the western Forth Valley, c.6100 B.P. in the Tay and 5800 - 5900 B.P. in East Fife. If the transgressive episodes recorded in north-west England do have regional significance then there is the possibility that in Scotland the differences in date noted above may be caused by a clustering of ^{14}C dates resulting from a decrease in the rate of sea-level fall. Alternatively the diachroneity may result from the practice of dating the shoreline in different estuaries at differing distances from the centre of isostatic uplift.

The earliest ^{14}C dated overlaps in the Fenland are found at Adventurer's Land, Guyhirn (Shennan 1980) where an erosional transgressive overlap was dated at 6575 ± 95 B.P. (Hv 10.011, AL4), and therefore data from this area only provides slight overlap in time with the scheme outlined for the inner Moray Firth area. Interestingly however the boundaries between

Wash I, Fenland I and Wash II and Fenland II are considered c.6300 B.P. and c.5600 B.P. respectively, a slightly later end to transgressive episodes is suggested likely in a subsiding area such as the Fenland compared to an uplifted area. The data are possibly not incompatible therefore with the idea of two periods registering negative tendencies in parts of eastern Scotland at c. 6400 B.P. and c.5900 B.P. and great care is suggested when statements are made concerning the synchroneity or diachroneity of the Main Postglacial Shoreline in Eastern Scotland especially when the shoreline has not been traced between sites.

In Fennoscandia where total isostatic uplift has been approximately three times that of Scotland it is easier to distinguish between shorelines since isostatic uplift has raised and preserved features shortly after their formation.

The first Flandrian transgression (ALV-2) in Sweden began c.9280 B.P. and reached its maximum at 8850 B.P. (Mörner, 1969). Other postglacial transgression maximum (PTM) are given below where they overlap in time with the inner Moray Firth area (Table 8.5).

TABLE 8.5

Postglacial Transgression Maxima (after Mörner 1969) for the Kattegatt region 8800 - 5500 B.P.

ALV 2	8800 B.P.
PTM 2	6950 B.P.
PTM 3A	6450 B.P.
PTM 3B	6250 B.P.
PTM 4A	5850 B.P.
PTM 4B	5650 - 5500 B.P.

According to Mörner (1979) these oscillations are well dated and stratigraphically separated, the peaks representing shorelines. It is remarkable how these dates mirror the accepted dates for shoreline formation in south-east Scotland where the Low Buried Beach is considered to have been formed at 8800 B.P. (Sissons 1976). The 6950 B.P. date is close to that suggested fof the 'grey micaceous silty sand' layer in the Forth (Sissons, unpublished) and PTM 3A to 4A record three separate transgressions covering the time period assumed for the formation of the Main Postglacial Shoreline (Morrison et al. 1980), a greater resolution of events being possible in Fennoscandia due to the increased amount of uplift compared to Scotland.

Using diatom stratigraphy, Digerfeldt (1975) identified seven transgressions into a former lagoon at Barsebäckmossen, Western Skane, Sweden. The first is dated between 6750 - 7150 B.P., the second c. 6400 - 6200 B.P. and the third from c.5900 - 5700 B.P. While it is accepted that Digerfeldt's transgression scheme and of Mörner are constructed using different criteria the broad agreement in age (to an accuracy of c. ± 200 yrs) suggests similar processes were operating.

In Blekinge, Sweden, Berglund (1971) identified six marine transgressions, those that overlap in age with the inner Moray Firth include

TABLE 8.6

I	6950 - 6650 B.P.
II	6450 - 6250 B.P.
III	5850 - 5550 B.P.
IV	5450 - 5250 B.P.

In conclusion it is remarkable how closely many of the shorelines noted for Sweden mirror those of Scotland in time of formation. The greater degree of resolution afforded in Fennoscandia by the larger amount of uplift does suggest the possibility of two or perhaps three transgressions at or about the time of the formation of the Main Postglacial Shoreline which could suggest the Main Postglacial Shoreline is a complex feature in eastern Scotland. Ideally close ^{14}C dating of the regressive overlap associated with the fall in sea-level from its Flandrian maximum should be attempted from the centre of uplift outwards to identify the effects of positive tendencies found in other areas during the time period 6600 - 5800 B.P.

In conclusion the identification of time periods of positive and negative tendencies provides a flexible method of correlation between areas of differing and similar tectonic history. The use of this approach could lead to modelling the inter-regional resitration of events and enable statistical matching techniques to be employed (Shennan 1982). It is admitted however that in certain areas of Scotland this aim will be impossible to achieve through lack of datable material.

CHAPTER 9

CONCLUSIONS

9.1 Flandrian coastal evolution in the Moray Firth

Three new sites, at Barnyards near Beauly, Moniack near Kirkhill and Arcan Mains in Strathconon were investigated to provide altitude age and environmental information on sea-level movements during the Flandrian Age in an area with little or no previous research.

Pollen analysis was used to provide independent age corroboration of the radiocarbon method, as an indicator of possible unconformities in sedimentation and to identify environmental change consequent upon the addition and removal of marine conditions.

Diatom analysis provided data relevant to the study of the depositional environment of the clastic horizons that characteristically interfinger the peat layers.

Stratigraphic analysis allowed the identification of units within peat layers to provide additional information on water table movements and together with pollen analysis and ^{14}C dating allowed the time - transgressive nature of transgressive and regressive overlaps to be assessed as evidence for sea-level rise and fall.

An effort has been made to evaluate the errors inherent in age and altitude of index points used in the reconstruction of former sea-levels. It is suggested that the evaluation of such errors, especially in altitude is a prerequisite for further research in Flandrian sea-level change.

A preliminary chronological scheme for sea-level change within the study area suggests a period of falling sea-level from 9600 B.P. to later than 9200 B.P. The age of the subsequent rise in sea-level is unknown but it was probably under way by c. 8200 B.P. Further dates on the transgressive overlap formed by this rise are 7700 B.P. at Arcan Mains and 7400 and 7100 B.P. at Moniack.

The culmination of the Flandrian rise in sea-level is given an age limit of 7100 - 5800 B.P. but an age of 6100 - 6400 B.P. is preferred for the formation of the highest Flandrian Shoreline in the area which is correlated with the Main Postglacial Shoreline of eastern Scotland. However certain reservations about the formation of the Main Postglacial Shoreline have been expressed.

Prior to the culmination of the Flandrian rise in sea-level a thin but widespread grey silty sand layer was deposited. As in other areas in eastern Scotland the layer forms a distinct wedge into the coastal peat layers at Moniack and can be traced as a consistent horizon within the blue-grey and orange clay-silts of the clastic cover sequence at Barnyards, correlated with the carse deposits of eastern Scotland. An age of 7430 - 7270 B.P. is assumed for the layer, interpreted as being formed either by an increase in the rate of sea-level rise within a period of regionally rising sea-level or by a sudden event such as a storm surge. This age is quite comparable to other areas of Scotland where the layer has been identified.

Local factors on sedimentation affecting the suitability of ^{14}C dated index points have been assessed at Moniack and Arcan Mains.

Altitudinal information is considered less reliable with compaction and changes in palaeotidal range not resolved in this study. Errors involved in sampling, indicative range and conversion to a reference tide level have been studied to provide a minimum error for the vertical range of sea-level.

The altitude of the shoreline underlying the lower peat in the study area, dated at 9600 B.P. is given as 5.98 - 7.03 m. and it is correlated with the Main Buried Shoreline of the Forth and Tay. The altitude of the succeeding minimum is not known but extrapolation of data from transgressive and regressive overlaps at Barnyards and Moniack suggest a minimum value of +2 m. and -3 m. respectively with an age bracket of 9200 - 8200 B.P. at Barnyards. Peacock _et al_. (1980) suggest an altitude of c. -6 m. and an age of 8800 B.P. for this minimum. It is unknown if there is a feature comparable with the Low Buried beach of the Forth and Tay and at present the minimum referred to above encompasses the age 9200 - 8200 B.P. and may include an intervening rise and fall in sea-level. However if the increased rate of isostatic recovery between 9600 B.P. and 9200 B.P. compared to the Forth and Tay is valid, the registration of such a rise and fall which caused the formation of the Low Buried Beach in the Forth and Tay may be absent in the Moray Firth area.

The altitude of the limit correlated with the Main Postglacial Shoreline of eastern Scotland is at c. 9 m.O.D. in the inner Moray Firth comparable to the altitude for the Main Postglacial Shoreline in the Tay and Solway Firth areas but less than that recorded for the western Forth Valley. The age, 6100 - 6400 B.P., of its formation is too wide a period to assess arguments for the possible diachroneity of this feature. Certainly within the resolution of the ^{14}C method and sites investigated at present it is not possible to demonstrate diachroneity.

A preliminary isostatic curve suggests 42 m. of uplift at 9600 B.P. and 11.5 m. at 5800 B.P. The form of the curve is comparable to that of the Forth and Tay areas, though the inner Moray Firth curve and that of the Tay appear to cross at c. 7000 B.P. with the Tay showing a greater amount of uplift since this date. This feature of the two uplift curves may be incapable of resolution within the errors inherent in curve construction but it is felt there are some grounds in the geological record for supporting such a speculation.

9.2 Proposals for further research

More research is needed to refine the scheme of sea-level change in the inner Moray Firth area outlined in Chapter 7. An attempt has to be made to increase the data base to produce more ^{14}C dated index points for periods deficient in time control and to produce additional stratigraphic data to assess the altitudinal limits of marine activity for each rise and fall in sea-level. Periods deficient in time and altitude control include 9200 B.P. to 7700 B.P. and 7100 to 5800 B.P. which cover the period of minimum sea-level during the early Flandrian, the initiation of the succeeding rise in sea-level and the culmination of the rise represented by the Main Postglacial Shoreline.

In order to evaluate the inter-regional variation in altitude and timing sites are required at locations further from the centre of isostatic recovery. Three such sites at Munlochy Bay (NH 6351), Delny (NH 7372) and Rhynie - Mounteagle (NH 8478) do suggest a fall in altitude of, for instance, the highest postglacial shoreline, from a maximum at the head of the Beauly and Cromarty Firths. At Rhynie - Mounteagle it is suggested that no late Flandrian marine sediments are present, the only units attributable to marine activity lie at c. 4-6 m. O.D. and may relate to a Late Devensian or early Flandrian isolation of the site.

Further research is needed on the definition, recognition and dating of the 'Main Postglacial Shoreline' in eastern Scotland. In

Chapter 8 it was suggested that a serious limitation of shoreline studies lies in inter-regional correlation with areas of differing tectonic history. Because the later Flandrian shorelines in Scotland lie close to each other in altitude and have similar gradients the possibility of incorrect lithostratigraphic correlation is great. It is tentatively suggested that future research should, in areas with datable material, adopt a more flexible approach using periods of positive and negative tendencies derived from all available data, including shorelines. This would possibly enable the recognition of discrete events such as those noted in Southern Sweden where greater isostatic uplift means the shoreline sequence is capable of finer resolution.

The time altitude graph produced is the only one for Scotland to include an explicit altitudinal error component for measuring error and relationship of the index point to its contemporary sea-level. The investigation of other post-depositional influences on altitude such as consolidation is a priority for the future.

In Scotland as a whole the aim for future research must be to produce more ^{14}C dated index points with an assessment of the error in age and altitude. Sea-level curves drawn as a single line through index points are therefore to be regarded as only one possible scheme for sea-level change within a wider error band. Allochthonous material and ^{14}C dated points without good stratigraphic control are to be regarded as unsuitable for the production of sea-level curves.

Once reliable data have been synthesized for each area of Scotland according to similar operational definitions and procedures, an attempt can be made to assess the between-area differences in the altitude of sea-level change and to suggest reasons for the differences. Rates of change of sea-level could then be evaluated for specific time periods and linked to models of isostatic recovery.

A final stage in analysis would be the three-dimensional representation of variation in index point altitude with age. Trends of isostatic recovery could then be mapped by incorporating tidal and eustatic calibration. A preliminary study of this nature using the ^{14}C dated index points used in the histogram analysis is in progress.

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APPENDIX I

- Laboratory Schedule for Pollen Analysis

- Pollen counts for -

    Barnyards 3B
    Barnyards 14B
    Moniack 29B
    Arcan Mains

Laboratory Schedule for Pollen Analysis

Stages 1.2, 1.4 and 1.5 should be applied to peats. Gytjjas and lake marls may require the addition of stages 1.1 and 1.3 in strict order.

1.1 Solution of Carbonates and Disaggregation

Add 5 tablets of Lycopodium to 0.5 cm^3 material.

1.1.1 Add 10% solution cold HCl, leave until effervescence stops, stir.

1.1.2 Centrifuge, decant

1.2 Evacuation of Alkali-soluble organic compounds

1.2.1 Add KOH (10% solution), stir.

1.2.2 Heat in boiling water for 30 mins. Stir occasionally

1.2.3 Decant through 180 sieve. Wash residue

1.2.4 Centrifuge. Decant and wash until supernatant liquid unstained

1.3 Hydrofluoric acid digestion of siliceous material

1.3.1 Add HF (30% solution) to residue. Stir well. ½ fill tube.

1.3.2 Heat in boiling water until stratified sediment appears 1 hr.

1.3.3 Stir, centrifuge, decant

1.3.4 Add HCl (10% solution). Heat in boiling water 3-5 mins.

1.3.5 Centrifuge, decant, wash with distilled water, stir, centrifuge, decant

1.4 Acetylation. Evacuation of unaltered Lignin and Cellulose

1.4.1 Add Glacial Acetic Acid. Stir, centrifuge, decant

1.4.2 Add acetylation mixture. Stir well, 1:9 conc. H_2SO_4 - Acetic anhydride

1.4.3 Heat in boiling water, 1 minute. Stir occasionally

1.4.4 Centrifuge. Decant

1.4.5 Add Glacial Acetic Acid, Stir, centrifuge, decant

1.4.6 Add distilled water, stir, centrifuge, decant. 2X

1.5 Staining

1.5.1 Add Tertiary Butyl Alcohol, Centrifuge, decant

1.5.2 Add 1ml Tert. But. Alcohol + 2 drops safranin, place in small vials, centrifuge, decant.

1.5.3 Add silicone fluid, same volume as sample, stir, plug with cotton wool.

[illegible]ARNYARDS 38   POLLEN COUNTS

DEPTH	-355	-360	-365	-370	-371	-372	-373	-374	-375	-376	-377	-378	-379	-380	-381	-382	-383
BETULA	14	0	5	11	6	19	22	32	29	13	21	31	19	40	15	20	5
PINUS	14	15	17	8	15	20	17	12	13	8	12	5	4	4	9	10	6
ULMUS	0	0	0	0	1	1	0	1	1	1	1	2	0	0	1	1	0
QUERCUS	3	0	1	0	0	0	1	0	1	2	0	1	0	0	0	0	0
TILIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PICEA	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALNUS	0	0	0	1	0	0	0	1	0	2	0	0	0	0	0	0	1
CORYLOID	24	5	11	19	23	29	27	52	54	22	21	42	16	50	40	33	37
JUNIPERUS	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
SALIX	6	1	1	4	7	4	6	13	4	9	4	3	4	12	6	1	3
ERICALES	1	1	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1
CALLUNA	0	0	0	3	1	0	1	1	2	0	1	0	0	0	2	0	0
GRAMINEAE	37	11	25	45	55	127	67	87	173	37	39	105	33	118	70	47	43
CYPERACEAE	4	1	5	5	6	4	4	1	0	4	6	10	9	6	16	30	9
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible] TYPE	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
ARTEMISIA	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0
TARAXACUM TYPE	0	1	1	2	1	0	0	0	0	1	2	6	0	0	0	3	3
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible] TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE	1	0	2	0	0	4	1	1	3	1	1	3	1	3	7	3	4
FILIPENDULA	1	0	2	0	0	0	1	2	1	0	0	0	0	0	0	0	0
RUBUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAXIFRAGACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UMBELLIFERAE	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYGONUM	0	0	0	0	1	0	2	1	1	0	0	1	0	0	0	0	0
RUMEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. MARITIMA	0	0	0	0	0	0	1	2	2	0	0	0	1	0	0	0	0
RUBIACEAE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
VALERIANA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M. ALTERNIFLORUM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
POTAMOGETON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
TYPHA LAT.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TYPHA ANG.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTERIDIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYPODIUM	0	1	0	1	0	1	0	0	2	1	0	2	0	0	0	0	0
SPHAGNUM	5	5	5	5	6	5	3	3	6	4	6	7	3	5	0	2	1
FILICALES	27	22	27	31	37	45	32	17	33	31	35	29	20	28	12	27	16
CORRODED	2	1	0	5	15	9	10	5	13	10	1	2	2	10	8	7	0
CRUMPLED	5	1	1	0	2	5	1	2	2	5	1	2	1	7	3	2	4
BROKEN	0	0	0	1	4	5	5	2	9	1	0	2	0	7	1	2	0
FOLDED	3	0	1	4	14	3	6	5	16	2	4	10	1	26	11	6	6
INDET.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
LYCOPODIUM	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400

BARNYARDS 33 POLLEN COUNTS-CONTINUED

DEPTH	-384	-385	-386	-387	-388	-389	-390	-391	-392	-393	-394	-395	-396	-397	-400	-405	-410
BETULA	10	10	22	32	48	49	80	73	58	21	0	0	1	0	5	12	28
PINUS	4	15	8	15	9	11	18	26	21	31	4	4	4	3	4	3	2
ULMUS	0	1	0	2	4	0	1	0	0	0	0	0	0	0	0	4	1
QUERCUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TILIA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
PICEA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
ALNUS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CORYLOID	[illegible]	[illegible]	82	96	115	131	199	99	10	10	1	0	1	0	2	7	3
JUNIPERUS	[illegible]	0	[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	0	[illegible]	0	0	0	0	0	0	0
SALIX	[illegible]	0	[illegible]	4	[illegible]	5	[illegible]	[illegible]	7	5	1	2	1	3	2	3	4
ERICALES	1	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	4
CALLUNA	0	0	2	1	1	0	5	1	1	3	0	0	0	0	0	0	0
GRAMINEAE	58	59	84	88	131	90	65	59	129	63	11	5	10	8	19	5	8
CYPERACEAE	33	19	47	49	53	94	30	18	45	10	3	0	2	1	25	2	4
CLADIUM	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SENECIO TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ARTEMISIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TARAXACUM TYPE	0	0	1	0	0	1	1	0	29	3	0	0	0	0	1	0	1
CARYOPHYLLACEAE	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
SPERGULA TYPE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE	0	4	0	0	13	0	0	19	51	0	0	0	0	0	0	0	0
FILIPENDULA	1	0	0	1	0	1	25	5	0	1	0	0	0	0	1	1	6
RUBUS	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SAXIFRAGACEAE	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
UMBELLIFERAE	0	1	0	0	1	4	0	3	0	0	0	0	0	0	0	0	0
MERCURIALIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYGONUM	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0
RUMEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
PL. MARITIMA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
RUBIACEAE	0	0	2	0	10	2	1	1	0	0	0	0	0	0	0	1	0
PL. LANCEOLATA	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
CRUCIFERAE	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2	1
[illegible]FLORUM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POTAMOGETON	1	1	0	0	0	0	5	3	0	1	0	0	0	0	0	0	0
TYPHA LAT.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
TYPHA ANG.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYCOPODIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTERIDIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYPODIUM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SPHAGNUM	4	2	3	7	4	4	4	5	3	10	3	2	0	0	1	1	0
FILICALES	44	40	32	40	27	31	49	72	91	15	33	18	35	18	31	22	13
CORRODED	6	8	12	2	11	5	0	5	6	7	1	1	6	0	1	0	2
CRUMPLED	5	3	9	10	19	17	0	17	12	1	0	0	5	1	5	0	1
BROKEN	5	3	4	3	4	8	0	15	15	10	5	1	5	0	3	0	0
FOLDED	10	3	8	8	20	10	0	38	46	11	4	2	11	1	10	4	4
UNIDENT.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYCOPODIUM	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400

BARNYARDS 3B POLLEN COUNTS-CONTINUED

DEPTH	-415	-420	-430
BETULA	53	79	57
PINUS	7	1	1
ULMUS	1	0	0
QUERCUS	0	0	0
TILIA	0	0	0
[illegible]	0	0	0
ALNUS	2	4	14
CORYLOID	14	8	3
JUNIPERUS	3	3	10
SALIX	5	10	2
ERICALES	3	2	2
CALLUNA	1	0	0
GRAMINEAE	25	14	15
CYPERACEAE	5	1	4
CLADIUM	0	0	0
SENECIO TYPE	0	0	0
ARTEMISIA	0	0	0
TARAXACUM TYPE	0	0	0
CARYOPHYLLACEAE	0	0	0
SPERGULA TYPE	0	0	0
CHENOPODIACEAE	0	0	2
FILIPENDULA	0	1	5
RUBUS	0	0	0
SAXIFRAGACEAE	0	0	1
UMBELLIFERAE	0	0	0
MERCURIALIS	0	0	0
POLYGONUM	0	0	1
RUMEX	0	0	0
P. MARITIMA	0	4	1
[illegible]	0	0	0
VALERIANA	0	0	0
CRUCIFERAE	0	0	0
M. ALTERNIFLORUM	1	1	2
M. SPICATUM	0	0	0
TYPHA LATIF.	0	0	0
TYPHA ANG.	0	0	0
[illegible]	0	0	0
PTERIDIUM	0	0	1
POLYPODIUM	0	1	0
SPHAGNUM	1	0	1
FILICALES	25	21	16
[illegible]	0	7	5
CORRODED	3	1	5
BROKEN	2	10	5
[illegible]	1	11	15
[illegible]	0	0	1
LYCOPODIUM	400	400	400

BARNYARDS 145 POLLEN COUNTS

DEPTH	-90	-93	-95	-100	-110	-120	-130	-140	-146	-170	-200	-234	-236	-240	-252	-260	-270
BETULA	0	8	2	5	3	5	0	2	12	15	3	2	9	8	9	1	4
PINUS	0	3	8	9	9	15	2	25	114	255	12	25	40	19	4	7	2
ULMUS	1	2	0	0	0	1	0	8	12	6	0	2	2	0	0	1	0
QUERCUS	1	2	4	1	5	2	0	2	2	2	0	1	0	0	0	0	0
TILIA	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ALNUS	10	24	30	34	35	52	0	45	39	24	0	1	0	0	0	0	0
CORYLUS	0	57	22	38	24	11	1	13	29	59	2	30	44	34	73	122	57
JUNIPERUS	0	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	1
SALIX	0	1	0	0	0	0	0	0	1	0	1	6	25	14	27	22	8
ERICACEAE	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0
CALLUNA	0	0	2	1	1	0	0	0	0	1	0	0	0	0	0	0	0
VIBURNUM TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
GRAMINEAE	10	21	56	77	80	14	6	20	99	94	1	19	11	7	14	4	6
CEREALIA TYPE	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPERACEAE	1	5	117	83	49	5	4	1	2	2	0	11	6	13	9	2	19
SENECIO TYPE	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0
TARAXACUM TYPE	0	0	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0
RANUNCULUS TYPE	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
THALICTRUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
SPERGULA TYPE	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE	0	0	1	0	0	0	0	0	2	5	0	0	0	0	0	0	0
LOTUS TYPE?	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
ROSACEAE	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
FILIPENDULA	0	0	1	0	0	0	0	0	2	0	0	1	0	0	0	0	1
CRUCIFERAE	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	1	0
SAXIFRAGACEAE	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
UMBELLIFERAE	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
RUMEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLANTAGINACEAE	0	0	1	4	1	1	0	0	2	0	0	0	1	0	1	1	1
P.LANCEOLATA	0	0	4	1	3	0	0	0	0	0	0	0	0	0	0	0	0
P.MEDIA/MAJOR TY	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
MYRIOPHYLLUM.ALT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.SPICATUM	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
POTAMOGETON	0	0	0	2	0	0	0	0	1	0	0	0	0	17	12	8	0
T.ANGUSTIFOLIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
T.LATIFOLIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SELAGINELLA	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
EQUISETUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
PTERIDIUM	0	2	2	7	5	1	0	0	0	0	0	0	0	0	0	0	0
POLYPODIUM	1	0	0	2	1	4	0	1	5	1	1	1	0	0	0	0	0
SPHAGNUM	0	2	2	2	12	1	0	1	1	1	0	1	4	0	3	0	0
FILICALES	7	3	8	4	27	9	3	37	15	8	2	64	230	284	134	20	30
CORRODED	1	1	1	5	0	2	1	0	2	2	0	1	4	2	2	0	1
DEGRADED	2	14	5	6	10	8	0	9	8	8	0	13	6	12	23	4	8
BROKEN	2	15	10	6	3	2	1	3	5	6	0	5	6	7	5	11	7
FOLDED	1	9	4	7	11	0	0	1	10	3	1	5	3	6	6	3	4
CONCEALED	0	0	2	1	1	1	0	25	28	23	6	3	21	9	7	9	7
UNDIFF.	0	1	0	1	0	0	0	0	1	1	0	0	2	0	0	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYCOPODIUM	200	200	200	200	200	200	200	200	200	200	200	293	200	303	200	200	202

BARNYARDS 1-8 POLLEN COUNTS-CONTINUED

DEPTH	-280	-290	-300	-310	-319	-330	-340	-345	-355	-360	-362	-363	-364	-366	-380	-405
BETULA	2	5	4	32	2	55	6	12	15	10	19	5	4	29	10	0
PINUS	2	6	4	5	0	3	1	11	1	2	1	1	0	4	1	0
ULMUS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
QUERCUS	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
TILIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALNUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
CORYLUS	32	49	74	41	3	25	22	10	11	13	9	4	6	40	17	1
JUNIPERUS	0	1	0	0	0	3	6	16	14	29	21	2	0	1	1	0
SALIX	5	11	0	9	2	2	5	9	7	19	10	2	1	0	2	0
ERICACEAE	0	0	0	0	1	0	1	0	0	1	5	0	0	3	1	0
CALLUNA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
VACCINIUM TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAMINEAE	8	8	6	9	1	6	20	21	19	23	16	4	7	14	13	5
CEREALIA TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPERACEAE	19	13	10	7	1	13	32	13	38	7	20	6	11	4	9	0
SENECIO TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TARAXACUM TYPE	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
RANUNCULUS TYPE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
THALICTRUM	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPERGULA TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
LOTUS TYPE?	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROSACEAE	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
FILIPENDULA	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0	0
CRUCIFERAE	1	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SAXIFRAGACEAE	1	2	0	0	0	0	1	2	4	0	0	0	0	0	0	0
UMBELLIFERAE	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
RUMEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
PLANTAGINACEAE	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0
P.LANCEOLATA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P.MEDIA/MAJOR TY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRIOPHYLLUM.ALT	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
M.SPICATUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POTAMOGETON	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
T.ANGUSTIFOLIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T.LATIFOLIA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SELAGINELLA	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
EQUISETUM	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTERIDIUM	2	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
POLYPODIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPHAGNUM	2	4	3	0	2	4	3	3	0	1	0	0	1	1	0	0
FILICALES	65	44	17	27	3	30	51	105	10	47	27	12	2	3	2	0
CORRODED	1	2	0	1	0	9	5	1	2	2	0	0	0	2	3	1
DEGRADED	12	5	5	7	0	7	8	10	9	7	14	3	8	4	3	0
BROKEN	5	4	2	6	1	0	5	3	5	9	13	4	18	4	4	10
FOLDED	7	4	4	7	0	4	2	10	7	10	11	7	4	4	4	1
CONCEALED	7	5	2	5	3	7	1	6	2	5	1	10	12	20	15	0
UNDIFF.	0	0	0	1	0	0	0	1	1	2	0	0	0	1	0	0
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
LYCOPODIUM	200	433	406	221	200	200	330	355	200	353	306	200	200	294	200	200

MONIACK 29B POLLEN COUNTS

DEPTH	-270	-284	-285	-296	-297	-330	-333	-334	-395	-620	-625	-650	-655	-685
BETULA	3	44	14	5	6	14	25	23	25	8	4	85	6	2
PINUS	5	24	2	22	19	25	20	21	23	19	2	7	7	1
ULMUS	1	8	3	1	2	7	6	2	2	2	2	2	1	0
QUERCUS	14	11	14	1	8	12	14	9	10	0	0	0	0	0
ALNUS	19	40	29	13	11	76	80	86	238	0	0	0	0	0
CORYLUS	19	33	24	18	11	32	35	35	41	66	48	100	28	1
JUNIPERUS	0	0	0	0	0	0	0	1	0	2	2	1	0	0
SALIX	6	191	278	2	0	0	0	1	0	4	1	18	2	1
CALLUNA	0	0	0	0	0	1	0	1	1	0	1	2	0	0
GRAMINEAE	10	239	62	30	37	186	172	192	108	51	26	21	20	25
CYPERACEAE	21	0	3	8	18	19	18	21	15	13	7	231	25	258
SENECIO TYPE	0	0	0	0	0	0	0	0	1	2	0	0	0	0
RANUNCULUS TYPE	0	2	0	0	0	0	0	5	2	0	0	0	0	0
CALTHA	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	1	0	0	0	0	0	1
ROSACEAE	0	0	0	0	0	1	0	0	0	0	1	0	0	0
FILIPENDULA	0	3	1	0	0	1	2	1	0	2	0	14	11	0
UMBELLIFERAE	0	0	0	0	0	0	0	1	0	2	2	0	0	0
CRUCIFERAE	1	1	0	0	1	0	0	1	0	0	0	4	0	0
ARTEMISIA	0	0	0	0	0	0	0	0	3	0	0	0	0	1
PLATAGINACEAE	0	0	0	0	0	0	0	0	1	1	0	1	0	0
RUBIACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SUCCISA	0	0	0	0	0	0	0	0	0	0	1	0	0	0
M.ALTERNIFLORUM	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MENYANTHES	0	0	0	1	0	0	0	0	0	0	0	5	0	0
POTAMOGETON	0	0	0	0	0	0	3	3	0	0	0	0	0	0
T.ANGUSTIFOLIA	0	0	0	0	2	3	2	3	0	0	0	0	0	0
DRYOPTERIS	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SELAGINELLA	0	0	0	0	0	0	0	0	0	1	0	1	0	0
EQUISETUM	0	1	0	83	53	2	3	5	142	72	3	50	12	3
PTERIDIUM	1	1	0	1	2	0	0	2	0	0	0	0	0	0
POLYPODIUM	0	1	0	1	1	0	2	3	1	0	0	0	0	0
SPHAGNUM	0	0	1	1	0	0	0	1	0	3	7	4	3	0
FILICALES	11	5	5	1	4	22	9	17	4	15	19	15	15	2
CORRODED	0	1	0	0	1	3	2	1	0	3	0	3	0	0
DEGRADED	3	4	4	1	3	1	2	4	5	6	3	3	3	0
BROKEN	0	0	2	1	1	3	2	3	6	9	4	4	1	0
FOLDED	2	10	2	2	2	4	3	2	3	19	7	3	4	0
CONCEALED	0	2	0	0	4	0	0	0	2	1	1	2	0	0
UNKNOWN	0	0	0	0	0	0	0	0	0	0	0	1	0	0
LYCOPODIUM	200	200	200	267	200	200	200	200	200	200	209	200	419	200

ARCAN MAINS	POLLEN COUNTS										
DEPTH	-110	-150	-190	-300	-320	-380	-400	-420	-440	-460	-480
BETULA	18	18	32	5	6	150	168	141	131	114	91
PINUS	35	20	86	13	3	0	1	6	5	3	1
POPULUS	0	0	0	0	0	0	0	0	2	1	0
ULMUS	42	29	19	6	2	0	1	0	0	0	0
QUERCUS	3	6	3	0	0	0	0	0	0	1	0
TILIA	6	11	2	0	0	0	0	0	0	0	0
ALNUS	309	305	282	1	0	0	0	0	1	0	0
CORYLUS	90	75	144	33	36	4	3	2	0	2	2
JUNIPERUS	1	70	1	0	0	3	7	8	21	6	0
SALIX	15	7	32	5	2	4	8	5	11	4	4
ERICACEAE	0	0	0	0	0	3	2	6	2	1	6
CALLUNA	0	0	1	0	0	7	4	3	1	1	0
GRAMINEAE	50	49	31	15	14	9	10	16	20	14	17
CYPERACEAE	1	3	3	2	3	0	2	0	6	9	0
ROSACEAE	0	1	0	0	0	0	0	0	0	0	0
FILIPENDULA	29	43	5	0	0	8	6	5	6	5	9
EPILOBIUM	1	2	0	0	0	0	0	0	0	0	0
UMBELLIFERAE	1	0	0	0	0	1	0	1	0	2	1
CRUCIFERAE	1	1	0	0	0	0	0	0	0	0	0
MERCURIALIS	0	0	3	0	0	0	0	0	0	2	0
ARTEMISIA	0	0	0	0	0	0	0	1	0	0	0
SPERGULARIA	0	0	0	0	0	0	0	1	0	0	0
POLYGONUM	4	1	0	0	0	0	0	0	0	0	0
RUMEX	0	0	1	0	0	1	1	0	0	0	0
URTICA	2	10	4	0	0	0	0	0	0	0	0
P.MARITIMA	1	0	0	0	0	0	1	0	0	0	4
VALERIANA	0	1	0	0	0	0	0	0	0	0	0
M.SPICATUM	0	0	0	0	0	0	1	0	0	0	0
M.ALTERNIFLORUM	0	0	0	0	0	6	5	13	3	2	3
MENYANTHES	0	0	0	1	0	0	0	0	0	0	0
POTAMOGETON	1	5	3	0	0	0	2	0	0	0	0
T.LATIFOLIA	0	0	0	0	0	1	0	0	0	0	1
T.ANGUSTIFOLIA	0	0	1	0	0	0	1	0	1	0	0
DRYOPTERIS	0	0	0	0	0	0	1	0	0	0	0
EQUISETUM	0	0	0	0	0	1	1	1	0	0	0
PTERIDIUM	0	0	0	9	6	0	0	0	0	0	0
POLYPODIUM	2	5	1	1	1	0	0	3	3	0	1
SPHAGNUM	0	1	0	0	0	1	2	2	2	2	2
FILICALES	78	58	44	0	0	21	20	25	18	17	23
CORRODED	1	2	1	0	0	1	1	1	4	2	2
DEGRADED	17	30	20	0	0	4	4	3	7	11	13
BROKEN	15	5	7	0	0	0	0	0	2	1	3
FOLDED	57	40	42	0	0	18	18	22	9	22	27
UNKNOWN	3	1	0	0	0	1	1	1	0	1	0
LYCOPODIUM	200	200	200	100	100	200	200	200	200	200	200

APPENDIX II

- Laboratory Schedule for Diatom Analysis
- List of Diatom taxa with ecological notes
- Diatom counts for -

Barnyards	3B
Moniack	4B
Moniack	29B

Laboratory Schedule for Diatom Analysis

1. Place 1 cm^3 in 150 ml. Pyrex beaker

2. Add 30% solution of H_2O_2

3. Leave overnight, if reaction not complete, heat gently until effervescence stops

4. Disperse residue by agitation in remaining liquid, decant into centrifuge tubes

5. Add distilled water, centrifuge, decant 3X

6. Transfer random sample to cover slips on a hot plate. Evaporate liquid

7. Place a small amount of Microps 163 mountant on microscope slides on a gentle heat and invert microscope cover slips (22 x 22 mm.)

Achnanthes brevipes Agardh v. intermedia (Kutz) Cleve.	BM e
A. flexella (Kutz.) Brun.	Z (e)
A. lanceolata (de Brebisson) Grunow.	ZB e
Actinoptychus undulatus (Bailey) Ralfs.	MB P
Amphora marina W.Smith.	MB(b)
A. ovalis Kutz.	ZB b
Auliscus sculptus (W.Smith) Ralfs.	M b
Biddulphia aurita (Lyngbye) de Brebisson et Godey.	M e
Caloneis brevis Gregory.	M(b)
Caloneis formosa (Gregory) Cleve.	B(b)
Cocconeis clandestina A. Schmidt.	M e
C. distans Gregory.	M(e)
C.placentula Ehrenberg.	ZB e
C. scutellum Ehrenberg.	MB e
Coscinodiscus excentricus Ehrenberg.	MB p
Cyclotella comta (Ehrenberg) Kutz.	ZB p
Cymatosira belgica Grunow.	M e
Cymbella cistula (Hemprich) Grunow.	ZB e
C.cuspidata Kutz.	ZB(e)
C.hungarica (Grunow) Pantocsek.	(Z) e
C. sinuata Gregory.	ZB e
C. turgida (Gregory) Cleve.	ZB(e)
C. ventricosa Kutz.	ZB e
Diatoma hiemale (Lyngbye) Heiberg.	Z(p)
D. vulgare Bory	ZB p
Didymosphenia geminata (Lyngbye) M.Schmidt	Z e
Dimerogramma marina (Gregory) Ralfs.	Mb(e)
D. minor (Gregory) Ralfs.	Mb(e)
Diploneis didyma Ehrenberg.	MB b
D.interrupta (Kutz.) Cleve.	Bb(e)

D.lineata (Donkin) Cleve.	M b
D. ovalis (Hilse) Cleve.	ZB b
D. smithii (de Brebisson) Cleve.	MB e
D. stroemi Hustedt.	M e
Epithemia argus Kutz.	ZB e
E. turgida (Ehrenberg) Kutz.	ZB e
E. zebra (Ehrenberg) Kutz.	ZB e
Eunotia arcus Ehrenberg.	Z e
E. diodon Ehrenberg.	Z e
E. gracilis (Ehrenberg) Rabenhorst.	Z(e)
E. lunaris (Ehrenberg) Grunow.	ZB e
E. monodon Ehrenberg.	Z(e)
E. pectinalis (Dillwyn) Rabenhorst.	Z e
E. praemonos Ake Berg.	Z(e)
Eunotogramma marinum (W.Smith) Peragullo.	M -
Fragilaria bidens Heiberg.	ZB(e)
F. brevistriata Grunow.	ZB(e)
F. construens (Ehrenberg) Grunow	ZB e
F. construens (Ehrenberg) Grunow v. venter (Ehrenberg)Grunow	ZB(e)
F. pinnata Ehrenberg.	ZB e(p)
F. schulzii Brockmann.	B e
F. virescens Ralfs v. clavata Grunow.	B(e)
Frustulia rhomboides (Ehrenberg) De Toni.	Z(e)
Gomphonema acuminatum Ehrenberg.	ZB e
G.acuminatum Ehrenberg v.coronata (Ehrenberg) W.Smith.	ZB e
G. angustatum (Kutz.) Rabenhorst	ZB(e)
G. constrictum Ehrenberg.	ZB e
G. gracile Ehrenberg	ZB(e)
G. intricatum Kutz.	ZB e
Grammatophora oceanica (Ehrenberg) Grunow.	
v. macilenta (W.Smith) Grunow.	MB e

G. serpentina (Ralfs) Ehrenberg.	M e
Gyrosigma balticum (Ehrenberg) Rabenhorst.	B b
Meridion circulare Agardh.	ZB p
Navicula americana Ehrenberg.	Z(b)
N. avenacea de Brebisson	B b
N. cancellata Donkin	M b
N. cincta (Ehrenberg) Kutz.	ZB(b)
N. clementis Grunow	B(b)
N. dicephala (Ehrenberg) W. Smith	ZB(b)
N. digitoradiata (Gregory) A. Schmidt.	B b
N. elegans W. Smith.	B(b)
N. hennedyi W. Smith.	M b
N. hungarica Grunow.	ZB b
N. lanceolata (Agardh) Kutz.	ZB b
N. latissima Gregory.	M b
N. lyra Ehrenberg.	M b
N. marina Ralfs.	MB b
N. palpebralis De Brebisson	M b
N. peregrina (Ehrenberg) Kutz.	B b
N. pupula Kutz.var. rectangularis (Gregory) Grunow .	ZB b
N. pusilla W. Smith.	ZB b
N. radiosa Kutz.	ZB b
N. scoliopleura A. Schmidt.	M b
Neidium iridis (Ehrenberg) Cleve.	ZB(e)
N.productum (W.Smith) Cleve.	ZB(e)
Nitzschia acuminata (W.Smith) Grunow.	MB b
N. bilobata W. Smith	B(b)
N. circumsuta (Bailey) Grunow.	B(b)
N. navicularis (de Brebisson) Grunow.	B b

N. palea (Kutz.) W. Smith.	ZB(b)
N. palustris Hustedt.	Z(b)
N. punctata (W.Smith) Grunow.	BM b
N. scalaris (Ehrenberg) W.Smith	B(b)
N. sigma (Kutz.) W.Smith.	BZ b
N. tryblionella Hantzsch.	BZ b
Opephora pacifica (Grunow) Petit.	M e
Paralia sulcata (Ehrenberg) Kutz.	M p
Pinnularia borealis Ehrenberg.	ZB(b)
P. divergens W. Smith	Z(b)
P. gentilis (Donkin) Cleve.	Z(b)
P. gibba Ehrenberg.	Z(b)
P. interrupta W.Smith.	Z(b)
P. lata (de Brebisson) W. Smith	Z(b)
P. major (Kutz) Cleve.	ZB(b)
P. mesolepta (Ehrenberg) W. Smith	Z(b)
P.microstauron (Ehrenberg) Cleve.	Z(b)
P. nobilis Ehrenberg.	Z(b)
P. stauroptera (Rabenhorst) Cleve.	(Z)b
P. subcapitata Gregory.	Z(b)
P. viridis (Nitzsch) Ehrenberg.	ZB(b)
Plagiogramma staurophora (Gregory) Heiberg	M e
Podosira stelliger (Bailey) Mann	M e(p)
Rhabdonema arcuatum Kutz.	M e
R. minutum Kutz.	M e
Rhoicosphenia curvata (Kutz) Grunow.	ZB e
Rhopalodia gibba (Ehrenberg) O.Müller.	ZB e
R. gibberula (Ehrenberg) O. Müller	B e
Scoliopleura tumida (de Brebisson) Rabenhorst.	BM b

Stauroneis anceps Ehrenberg.	Z(b)
St. phoenicenteron Ehrenberg.	ZB(b)
St. smithii Grunow.	ZB(b)
Surirella biseriata de Brebisson.	ZB(b)
Surirella fastuosa Ehrenberg.	M b
Synedra Crystallina (Agardh) Kutz.	MB e
S. gaillonii (Bory) Ehrenberg.	MB e
S. pulchella (Ralfs) Kutz.	BZ e
S. tabulata (Agardh) Kutz.	BM e
S. ulna (Nitzsch.) Ehrenberg	ZB e
Tabellaria fenestrata (Lyngbye) Kutz.	ZB e
T. flocculosa (Roch) Kutz.	Z e
Trachyneis aspera (Ehrenberg) Cleve.	M b

Z - Fresh
ZB - Fresh-brackish
BZ - Brackish-fresh
B - Brackish
BM - Brackish-marine
MB - Marine-brackish
M - Marine

BARNYARDS 3B DIATOM COUNTS

DEPTH	-365	-370	-372	-374	-376	-378	-380	-392	-392	-394	-395	-400	-410	-415	-420	-430
P.SUBCAPITATA	0	0	0	0	0	1	0	45	2	0	0	0	0	0	0	0
P.NOBILIS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
T.FLOCCULOSA	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	3
F.LEPTOSTAURON	0	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0
[illegible]	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
A.OVALIS	4	1	1	0	0	0	0	0	0	0	0	0	9	0	3	5
N.AMPHIOXYS	0	0	0	0	0	0	0	2	0	0	1	1	0	6	0	0
N.CINCTA	0	1	0	0	0	0	1	0	0	0	0	0	0	7	2	0
N.PUSTULA	43	63	71	59	57	43	26	46	6	2	0	0	0	3	3	1
N.RADIOSA	0	0	4	11	10	7	19	0	0	0	0	0	12	0	0	0
A.LANCEOLATA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2
C.ASPERA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.ZEBRA	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	1
F.BREVISTRIATA	2	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0
F.PINNATA	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2
G.ACUMINATUM	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1
G.CONSTRICTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C.MARTYII	0	0	0	0	0	0	0	0	0	0	0	0	6	9	14	42
R.CURVATA	0	0	0	0	0	0	0	1	0	0	0	0	0	4	5	7
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	20	10	4	0
D.VULGARE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.CIRCULARE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
[illegible]	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
S.PULCHELLA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	18	2
C.FORMOSA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
D.INTERRUPTA	28	10	28	43	55	71	74	61	179	168	156	18	0	1	3	2
N.CLEMENTIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
N.DIGITORADIATA	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	23	12	5	4	3	18	37	13	0	0	0	0	3	5	1	0
N.BILOBATA	4	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
N.LANCEOLATA	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
N.NAVICULARIS	9	4	3	4	0	0	0	0	1	0	0	2	14	1	7	1
N.SCALARIS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
A.DELICATULA	0	0	0	0	0	0	0	0	0	0	0	0	0	16	35	85
F.SCHULZII	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
[illegible]	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
N.PUNCTATA	0	2	0	0	0	1	0	0	2	0	0	0	7	2	1	0
A.BREVIPES	0	0	0	0	0	0	0	0	0	0	0	0	7	7	0	0
C.TABULATA	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
[illegible]	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
N.HUMEROSA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
N.HASTA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C.CLANDESTINA	0	0	0	0	0	0	0	0	0	0	0	0	5	2	10	1
C.SCUTELLUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
C.SMITHII	44	17	19	42	21	24	35	0	0	0	0	0	2	2	0	0
R.STRIGELLA	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
A.UNDULATUS	0	0	0	0	0	1	0	0	0	0	0	1	3	2	6	2
C.EXCENTRICUS	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

BARNYARDS 3B

DIATOM COUNTS -CONTINUED

DEPTH	365	370	372	374	376	378	380	392	393	394	395	400	410	415	420	430
A.SCULPTUS	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
C.BREVIS	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0
D.MINOR	0	1	0	0	1	0	0	0	0	0	0	0	0	2	5	2
N.LATISSIMA	3	1	0	0	1	1	0	0	0	0	0	0	1	0	1	0
N.LYRA	0	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0
N.PALPEBRALIS	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
N.DISTANS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
N.SOCIALIS	0	0	0	0	0	0	0	0	0	0	0	0	17	7	6	3
T.ASPERA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
S.AURITA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	3
C.DISTANS	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
C.BELGICA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
D.STROEMI	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G.OCEANICA V.M.	1	9	0	0	0	0	0	0	0	0	2	0	2	1	1	0
G.SERPENTINA	0	2	0	0	0	0	0	0	0	0	2	7	6	1	1	0
D.PACIFICA	0	0	0	0	0	0	0	0	0	2	1	0	0	11	0	0
D.STAUROPHORA	0	0	0	0	1	2	0	0	0	1	0	0	1	5	1	2
P.STELLIGER	0	1	2	3	1	1	0	0	0	0	3	17	14	7	5	4
R.ARCUATUM	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
R.MINUTUM	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0
P.SULCATA	33	40	54	32	30	25	10	14	9	27	36	78	49	61	45	15
P.WESTII	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
C.CF.STRIATA	0	0	0	0	0	0	0	0	9	7	0	0	0	0	0	0
COSC.SP.UNDIFF.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
H.CUNEIFORMIS?	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
SYN.SP.UNDIFF.	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACHN.SP.UNDIFF.	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
ACHN.AURICULA?	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
ACHN.CF.HUNGARICA	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0
ST.CF.OBTUSA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
N.SP.UNDIFF.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N.SP.ABRUPTA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
N.CF.GRACILIS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PINN.SP.UNDIFF.	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PINN.CF.MINUTA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CAL.CF.PERMAGNA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
GYRO.SP.UNDIFF.	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
GYRO.CF.SCALPR.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
GOMPH.SP.UNDIFF.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GOMPH.CF.PARVULUM	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
NITZ.SP.UNDIFF.	3	7	4	0	1	0	0	0	0	0	0	0	0	0	0	0
NITZ.CF.APICULATA	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NITZ.CF.FILIFORMIS	0	0	0	0	0	0	1	14	0	0	0	0	0	0	0	0
NITZ.CF.VITREA	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
CAMP.SP.UNDIFF.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNK.SP.	2	3	3	2	2	0	0	0	0	0	0	0	2	5	4	2
UNK.VALVES	3	3	3	2	2	0	0	0	0	0	0	0	4	7	5	2
FRAGS.	20	32	18	26	23	32	35	63	0	0	9	29	49	23	60	35

MINI-CK 43 DIATOM COUNTS

DEPTH	-400	-410	-442	-443	-445	-450	-455	-460	-465	-469	-470	-471
A.FLEXELLA	0	0	2	0	0	1	0	1	1	0	0	0
A.OVALIS	0	1	4	7	0	0	0	0	0	0	0	2
[illegible].OVALIS	42	10	2	0	0	0	0	0	0	0	0	0
[illegible]	5	0	0	0	0	0	0	0	0	0	0	0
[illegible].PUSILLA	5	0	0	0	0	0	0	0	0	0	0	0
[illegible].RADIOSA	3	0	0	0	5	0	0	0	0	0	2	0
ST.PHOENICENTERON	1	0	0	0	0	0	0	0	0	0	0	0
S.BISERIATA	1	1	0	0	0	0	0	0	0	0	0	0
A.LANCEOLATA	0	0	0	0	0	0	0	0	0	0	0	30
C.VENTRICOSA	0	0	0	0	0	0	0	0	0	0	1	0
[illegible].ARCUS	0	0	10	12	0	0	0	0	0	0	0	0
[illegible].ZEBRA	0	0	0	1	0	0	0	0	0	0	0	0
[illegible]	2	0	0	0	0	0	0	0	0	0	0	20
F.BREVISTRIATA	1	237	0	0	0	0	0	0	0	0	0	5
F.CONSTRUENS V.V.	0	0	0	2	0	0	1	0	0	0	0	0
F.PINNATA	0	1	0	0	0	0	0	0	0	0	3	0
[illegible]	0	1	0	0	0	0	0	0	0	0	0	0
[illegible].CURVATA	0	0	0	0	0	0	1	0	0	1	0	0
[illegible].GIBBA	0	1	0	0	0	0	0	0	0	0	0	2
[illegible].ULNA	1	0	0	0	0	0	1	0	0	1	0	0
.FENESTRATA	0	0	0	0	0	0	0	0	0	0	1	0
N.SIGMA	14	1	0	0	2	0	0	2	1	0	0	0
N.TRYBLIONELLA	0	4	0	0	0	0	0	0	0	0	0	0
S.PULCHELLA	0	1	0	0	0	0	0	0	0	0	0	0
[illegible]	4	1	0	0	0	0	0	0	0	0	0	2
[illegible].INTERRUPTA	1	1	1	0	0	1	0	3	2	1	6	5
[illegible]	1	0	0	0	0	0	1	1	0	0	1	3
N.AVENACEA	0	0	0	0	0	0	0	0	0	0	0	4
N.DIGITORADIATA	5	1	3	3	6	3	2	2	1	2	1	6
[illegible].ELEGANS	0	1	0	0	0	0	0	0	0	0	0	3
N.PEREGRINA	7	13	165	166	56	0	0	0	0	0	0	12
[illegible]	13	0	0	0	0	0	0	0	0	0	0	1
[illegible]	0	2	0	0	0	0	0	0	0	0	0	2
[illegible].NAVICULARIS	0	1	0	2	0	0	0	0	2	1	4	6
[illegible].SCALARIS	7	0	0	0	0	0	0	0	0	0	0	0
[illegible].SCHULTZII	0	1	0	0	0	0	0	0	0	0	0	1
[illegible]	0	0	10	3	0	0	0	1	1	0	0	2
N.PUNCTATA	1	0	4	2	19	25	11	24	14	12	24	7
[illegible].TUMIDA	0	0	3	1	3	2	0	0	0	0	3	0
S.TABULATA	3	0	0	0	0	0	5	1	0	5	1	1

MONIACK -8

DIATOM COUNTS

DEPTH-	-400	-410	-442	-443	-445	-450	-455	-460	-465	-469	-470	-471
E.MARINA	0	0	0	0	0	0	1	2	0	1	0	0
D.DIDYMA	1	1	0	0	0	0	0	0	1	1	0	0
N.[illegible]	0	0	0	0	1	0	0	2	0	1	0	0
N.ACUMINATA	1	0	0	0	0	3	0	0	0	0	0	0
C.SCUTELLUM	13	2	2	1	3	12	37	33	25	66	45	15
C.SMITHII	20	0	0	0	3	4	0	3	4	1	2	6
G.OCEANICA V.M.	32	2	12	0	33	31	25	34	49	34	34	15
E.EXCENTRICUS	1	0	0	0	0	0	0	0	0	0	0	0
E.MINOR	0	0	1	0	1	0	1	0	0	0	3	2
C.LINEATA	0	0	0	0	1	0	1	1	1	0	0	0
N.CANCELLATA	0	0	0	0	0	0	0	0	0	0	1	0
N.SCOLIOPLEURA	0	0	0	0	0	0	0	0	0	1	0	0
S.FASTUOSA	0	0	0	0	2	2	0	0	0	1	0	0
T.ASPERA	0	0	1	0	1	0	0	0	0	0	0	0
B.AURITA	0	0	0	0	0	0	1	1	1	0	0	0
C.DISTANS	0	0	0	0	0	2	0	0	0	0	0	0
I.STRIATA	0	0	0	0	0	1	0	0	0	0	0	0
G.SERPENTINA	0	0	0	0	0	0	1	0	1	0	0	0
E.PACIFICA	0	0	0	0	1	0	0	1	0	0	0	0
N.STAUROPHORA	0	1	0	0	0	0	1	1	0	1	1	1
P.STELLIGER	0	1	1	0	6	4	1	1	1	4	3	1
R.ARCUATUM	0	0	0	0	0	0	1	0	0	0	0	0
E.CINCTUM	1	1	0	0	0	19	1	9	2	5	4	2
M.SULCATA	34	10	15	9	70	95	100	100	97	55	62	51
STAURONEIS UNDIFF.	9	0	0	0	0	0	0	0	0	0	0	0
PINNULARIA UNDIFF.	1	0	1	1	0	0	0	0	0	0	0	2
GYROSIGMA UNDIFF.	1	0	0	3	0	0	0	0	0	4	1	0
NAVICULA UNDIFF.	1	0	1	0	10	0	0	0	0	0	0	1
NITZSCHIA UNDIFF.	0	2	0	0	0	1	1	0	0	3	4	0
CYMBELLA UNDIFF.	0	0	1	0	0	0	0	0	0	0	0	0
GOMPHONEMA UNDIFF.	0	0	0	1	0	0	0	0	0	0	0	0
SYNEDRA UNDIFF.	0	0	0	0	0	0	0	2	0	0	0	0
SPONGE SPIC.	12	0	0	1	44	25	29	20	25	6	9	14
UNK.VALVES	0	0	1	0	1	0	0	1	0	2	4	2
UNK.SP.	0	0	1	0	1	0	0	1	0	4	6	2

WINIACK 232 DIATOM COUNTS

DEPTH	-259	-285	-290	-334	-340	-350	-359	-380	-390	-393	-400	-420	-440	-460	-480	-500	-520
[illegible]	0	3	0	1	0	1	0	0	0	2	0	0	0	0	0	0	0
[illegible]LIS	3	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible].DIVERGENS	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
[illegible].GRACILIS	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
[illegible]	1	0	2	0	0	1	1	2	2	0	0	0	0	0	0	0	0
[illegible].INTERRUPTA	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible].LATA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P.MESOLEPTA	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
[illegible]STAURON	4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible].SUBCAPITATA	0	0	0	0	1	3	2	0	0	0	0	0	0	0	0	0	0
ST.ANCEPS	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0
[illegible].HUNGARICA	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
E.ARCUS	5	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
E.DIODON	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.PECTINALIS	50	22	24	24	0	20	7	41	43	38	0	0	0	0	0	0	0
[illegible]	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0
[illegible]S	0	0	0	0	0	2	0	1	0	2	0	0	0	0	0	0	0
[illegible]SA	0	0	0	9	6	7	3	4	0	2	0	0	0	0	0	0	0
[illegible]	0	4	5	1	1	1	2	2	0	0	0	0	0	0	0	0	0
[illegible].OVALIS	0	1	5	1	0	1	2	1	0	1	0	0	1	0	0	0	0
[illegible]	0	1	4	0	0	0	1	0	0	0	0	3	0	0	0	0	0
[illegible]A	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]CA	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
[illegible].LANCEOLATA	0	0	0	4	0	2	2	1	2	2	4	0	0	0	0	0	0
[illegible]	1	1	0	6	0	1	2	1	2	0	0	0	0	0	0	0	0
[illegible]	1	2	5	1	0	17	16	0	0	0	0	10	11	0	0	0	0
[illegible]	1	0	0	7	0	0	0	1	0	0	0	0	0	0	0	0	0
[illegible]	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0
[illegible]LIS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	1	5	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0
[illegible].VIRIDIS	11	2	2	0	1	2	4	0	0	0	0	0	0	0	0	0	0
[illegible]CENTERON	1	0	0	4	2	1	4	0	0	0	0	0	0	0	0	0	0
ST.[illegible]	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
[illegible]A	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
[illegible]ATA	0	0	0	0	0	1	1	0	0	3	0	0	0	0	0	0	0
[illegible]	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
[illegible]	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]TA	1	2	0	0	2	0	4	2	4	1	0	0	0	0	0	0	0
[illegible]	5	4	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0
[illegible]	1	[illegible]	6	1	1	0	7	0	1	0	0	0	0	0	0	0	0
[illegible]OSA	23	20	31	0	1	0	6	22	1	1	0	0	0	0	0	0	0
[illegible]	0	0	0	0	13	7	0	0	15	11	0	0	0	0	0	0	0
[illegible]	2	4	2	3	0	0	0	1	1	0	0	0	0	1	0	0	0
[illegible].SP.	2	[illegible]	3	3	0	2	0	5	2	1	0	0	1	0	3	0	0
UNK.VALVES	2	4	3	3	0	2	0	0	0	2	0	0	1	0	0	0	0
SPONGE.SPIC.	0	0	0	0	0	0	0	0	0	0	26	40	19	81	83	54	51

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VONIACK 298          DIATOM COUNTS-CONTINUED

DEPTH                 -540-560-580-600
N.AMERICANA              0    0    0    0
N.PALPEBRALIS            0    0    0    0
P.DIVERGENS              0    0    0    0
P.GENTILIS               0    0    0    0
P.GIBBA                  0    0    0    0
P.INTERRUPTA             0    0    0    0
P.LATA                   0    0    0    0
P.MESOLEPTA              0    0    0    0
P.MICROSTAURON           0    0    0    0
P.NOBILIS                0    0    0    0
P.SUBCAPITATA            0    0    0    0
ST.ANCEPS                0    0    0    0
S.HUNGARICA              0    0    0    0
G.GEMINATA               0    0    0    0
E.ARCUS                  0    0    0    0
E.DIODON                 0    0    0    0
E.GRACILIS               0    0    0    0
E.MONODON                0    0    0    0
E.PECTINALIS             0    0    0    0
E.PRAEMONDS              0    0    0    0
E.[illegible]IDES        0    0    0    0
T.FLOCCULOSA             0    0    0    0
D.HIEMALE                0    0    0    0
C.OVALIS                 0    0    0    0
A.OVALIS                 0    0    0    0
N.CRYPTOCEPHALA          0    0    0    0
N.HUNGARICA              0    0    0    0
N.LANCEOLATA             0    0    0    0
N.PUPULA                 0    0    0    0
N.PUSILLA                0    0    0    0
N.RADIOSA                0    0    0    0
N.PELLA                  0    0    0    0
P.BOREALIS               0    0    0    0
P.MAJOR                  0    0    0    0
P.VIRIDIS                0    0    0    0
ST.PHOENICENTERON        0    0    0    0
A.[illegible]            0    0    0    0
A.LANCEOLATA             0    0    0    0
C.PLACENTULA             0    0    0    0
C.CISTULA                0    0    0    0
C.CUSPIDATA              0    0    0    0
C.SINUATA                0    0    0    0
C.TURGIDA                0    0    0    0
C.VENTRICOSA             0    0    0    0
E.LUNARIS                0    0    0    0
E.TURGIDA              0    0    0    0
UNK.SP.                  2    1    0    1
UNK.VALVES               3    2    0    1
SPONGE.SPIC.            53   51   59   36
```

MONIACK 292 DIATOM COUNTS -CONTINUED

DEPTH	-263	-284	-290	-334	-340	-350	-359	-380	-390	-393	-400	-420	-440	-460	-480	-500	-520
F.CONSTRUENS	0	2	0	15	0	5	1	0	0	0	0	0	0	0	0	0	0
F.CONSTRUENS.V.V.	0	0	1	11	3	0	1	0	1	0	0	0	0	0	0	0	0
F.PINNATA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G.ACUMINATUM	1	2	0	2	1	1	3	1	1	0	0	0	0	0	0	0	0
G.ACUMINATUM.V.C	4	1	4	0	3	2	2	3	3	7	0	0	0	0	0	0	0
G.ANGUSTATUM	37	27	40	9	6	3	5	35	35	28	0	0	0	0	0	0	0
G.CONSTRICTUM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G.INTRICATUM	7	13	4	3	0	4	4	1	0	3	0	0	0	0	0	0	0
G.GRACILE	0	0	0	0	1	0	0	1	1	2	0	0	0	0	0	0	0
N.IRIDIS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
A.PRODUCTUM	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0
[illegible]	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SY.ULNA	14	27	33	7	13	19	14	15	15	7	0	0	0	0	0	0	0
T.FENESTRATA	2	10	0	92	145	169	143	84	84	105	0	0	0	0	0	0	0
D.VULGARE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.CIRCULARE	0	0	2	0	0	2	1	2	1	1	0	0	0	0	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0
C.FORMOSA	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	6	1
C.INTERRUPTA	0	0	0	0	0	0	0	0	0	0	191	182	185	10	0	3	1
G.BALTICUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	1
N.DIGITORADIATA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
N.PEREGRINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N.NAVICULARIS	0	0	0	2	0	0	0	0	0	0	0	0	0	11	2	0	1
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	1
N.PUNCTATA	0	0	0	0	0	0	0	0	0	0	0	0	1	20	5	5	15
A.BREVIPES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S.TABULATA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0
N.ACUMINATA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	3
D.SMITHII	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	4
[illegible] V.M.	0	0	0	0	0	0	0	0	0	0	0	1	0	27	35	44	29
S.CRYSTALLINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C.EXCENTRICUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible].SCULPTUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
N.HENNEDYI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.FASTUOSA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible].ASPERA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
[illegible].CLANDESTINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	15	4
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
[illegible].SERPENTINA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
[illegible].STAUROPHORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P.STELLIGER	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	2	1
[illegible].ARCUATUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
[illegible].MINUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	2	6
P.SULCATA	0	0	0	0	0	0	0	0	0	0	2	4	7	140	119	131	147
ACHNANTHES	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
CYMBELLA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GYROSIGMA	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

-338-

MONIACK 293 DIATOM COUNTS-CONTINUED

DEPTH	-5-0-560	-580	-600	
F.CONSTRUENS	0	0	0	0
F.CONSTRUENS.V.V	0	0	0	0
F.PINNATA	0	0	0	0
G.ACUMINATUM	0	0	0	0
G.ACUMINATUM.V.C	0	0	0	0
G.ANGUSTATUM	0	0	0	0
G.CONSTRICTUM	0	0	0	0
G.INTRICATUM	0	0	0	0
G.GRACILE	0	0	0	0
N.IRIDIS.	0	0	0	0
N.PRODUCTUM	0	0	0	0
R.GIBBA	0	0	0	0
S.ULNA	0	7	0	0
T.FENESTRATA	0	0	0	0
M.VULGARE	0	0	0	0
M.CIRCULARE	0	0	0	0
N.SIGMA	0	0	0	0
A.FORMOSA	0	1	1	1
P.INTERRUPTA	7	2	5	5
G.BALTICUM	0	0	0	0
N.SUBRADIATA	0	0	0	0
N.PEREGRINA	0	0	0	1
N.PELLUCIDA	0	0	0	0
N.CIRCUMSUTA	1	0	0	0
N.NAVICULARIS	0	1	3	0
P.BICUSPIDULA	5	2	1	0
N.PUNCTATA	3	7	5	4
B.BREVIPES	0	0	0	0
S.TABULATA	0	0	0	0
C.CUSPIDATA	0	0	1	0
N.ACUMINATA	3	0	0	0
T.SMITHII	2	2	1	1
C.SCUTELLUM V.M.	35	28	25	11
S.CRYSTALLINA	0	2	0	0
C.EXCENTRICUS	1	0	0	0
A.SCULPTUS	0	0	0	0
D.MARINA	1	1	2	2
D.MINOR	0	1	2	5
N.HENNEDYI	0	0	0	0
S.FASTUOSA	1	0	0	0
T.ASPERA	1	1	0	0
C.CLANDESTINA	3	15	5	0
C.BELGICA	0	0	0	0
G.SERPENTINA	1	0	0	1
P.PACIFICA	1	0	0	0
P.STAUROPHORA	0	1	0	1
C.STELLIGER	0	1	0	2
R.ARCUATUM	0	0	1	0
R.MINUTUM	1	0	3	1
P.SULCATA	146	143	196	196
ACHNANTHES	0	0	0	0
CYMBELLA	0	0	0	0
GYROSIGMA	0	0	0	0

APPENDIX III

\- Particle size and loss on ignition determinations for -

Barnyards 3B

Barnyards 14B

Arcan Mains

Barnyards 3B. Particle Size (%)

Depth	Gravel	Coarse Sand	Med. Sand	Fine Sand	Coarse Silt	Med. Silt	Fine Silt	Clay
415-20	0	0.05	0.39	3.09	79.46	7.37	2.54	7.10
410-15	0	0	0.20	3.28	63.67	13.41	4.86	14.10
405-10	0	0	0.63	3.01	64.77	15.21	3.92	12.36
400-05	0	0.07	1.19	9.08	41.31	25.54	8.64	14.24
395-400	0	0	0.89	7.12	41.41	21.20	10.19	19.19
393-75	0	0	1.00	4.10	43.70	23.97	10.87	16.36
365-70	0	0	0.10	0.20	44.80	19.77	11.20	23.93
360-65	0	0	0.15	0.31	38.66	27.98	12.37	20.53
355-60	0	0	0.77	1.64	20.75	34.71	21.27	20.86

Loss on ignition (%)

430 - 35	1.60
425 - 30	1.34
420 - 25	1.39
415 - 20	1.49
410 - 15	1.43
405 - 10	1.47
400 - 05	1.62
395 - 400	1.86
393 - 95	2.29
365 - 70	12.42
360 - 65	8.06
355 - 60	8.44

BY14B Particle Size (%)

Depth	Gravel	Coarse Sand	Med. Sand	Fine Sand	Coarse Silt	Med. Silt	Fine Silt	Clay
520-5	35.73	6.42	9.77	19.18	19.34	4.06	2.45	3.06
515-20	28.66	7.12	9.37	21.29	24.17	3.64	2.42	3.32
510-15	57.05	3.62	4.26	13.31	15.46	2.90	1.42	1.98
505-10	36.97	5.36	7.86	17.80	21.77	4.80	2.12	3.32
500-05	15.24	2.54	7.87	33.60	34.13	3.21	1.38	2.03
495-500	7.89	4.57	10.98	36.90	25.95	7.62	0.30	5.79
490-95	0	0.91	30.36	40.43	25.09	0.92	0.77	1.52
485-90	0	0	4.67	47.31	41.76	2.74	0.77	2.75
480-85	8.15	0.61	3.65	14.70	46.47	12.82	4.79	8.81
475-80	2.35	0.86	3.16	9.95	58.68	9.98	3.08	11.94
470-75	0.78	0.62	0.99	3.18	37.01	35.36	3.05	19.01
465-70	4.85	4.50	5.25	9.61	45.59	8.22	3.93	18.05
460-65	21.85	4.86	5.40	8.78	38.32	6.15	2.27	12.37
455-60	60.29	6.03	5.30	7.65	14.20	1.94	0.67	4.02
450-55	7.00	3.18	2.74	4.45	76.8	2.35	0.66	2.82
445-50	23.97	8.41	7.75	16.03	30.15	5.82	2.28	4.89
440-45	0.73	0.71	0.85	3.64	47.66	19.64	5.87	20.90
435-40	2.04	1.98	2.31	4.89	62.63	5.06	3.05	18.42
430-35	0	0.58	0.77	3.37	66.3	7.82	3.17	17.99
425-30	0	0	0.75	5.82	57.85	10.26	4.04	21.28
420-25	0	0.73	1.02	8.79	59.93	10.21	3.05	16.23
415-20	0	0.77	0.92	2.30	38.79	10.86	3.93	21.42
410-15	0	0.62	0.83	1.63	47.39	16.67	6.75	26.11
405-10	0	0	0.10	0.95	36.51	23.12	13.29	26.03
400-05	0	0	0.30	1.13	63.32	5.97	2.39	26.89
395-400	0	0	0.27	0.96	64.73	6.83	4.04	23.17
390-95	0	0.56	1.00	6.94	65.44	7.44	1.95	16.67
385-90	0	0.63	0.83	3.14	57.83	24.61	5.30	7.66
380-85	0	0	1.19	1.74	76.82	5.98	1.74	12.53
375-80	0	1.23	1.85	1.85	33.58	34.81	2.46	24.22
370-75	0	0.87	0.87	1.41	25.85	23.01	20.89	27.10
364-70	0	0.34	0.87	3.12	9.78	28.17	32.62	25.10
225-30	21.24	7.90	16.95	29.63	15.39	5.09	0.65	3.15
220-25	8.34	5.91	19.66	35.84	11.53	9.07	1.87	7.78

BY14B	Loss on ignition (%)
520 - 25	0.1
515 - 20	0.13
510 - 15	0.14
505 - 10	0.17
500 - 05	0.09
495 - 500	0.12
490 - 95	0.08
485 - 90	0.17
480 - 85	0.21
475 - 80	0.27
470 - 75	0.39
465 - 70	0.55
460 - 65	0.38
455 - 60	0.32
450 - 55	0.45
445 - 50	0.53
440 - 45	0.73
435 - 40	0.25
430 - 35	0.56
425 - 430	0.46
420 - 25	0.51
415 - 20	0.70
410 - 15	0.68
405 - 10	0.70
400 - 05	0.86
395 - 400	0.63
390 - 95	0.63
385 - 90	13.43
380 - 85	25.71
375 - 80	28.59
370 - 75	5.47
364 - 70	3.29
225 - 30	2.19
220 - 25	2.25

Arcan Mains. Particle Size (%)

Depth	Gravel	Coarse Sand	Med. Sand	Fine Sand	Coarse Silt	Med. Silt	Fine Silt	Clay
570-75	0	0.58	3.52	87.65	0.116	1.66	1.294	5.180
565-70	0	0.38	4.06	75.85	16.341	1.405	1.263	0.701
560-65	0	0.40	6.22	65.82	24.01	1.91	0.82	0.820
555-60	0	0.45	4.48	49.99	26.598	12.112	1.874	4.496
552-55	0	1.14	10.51	53.59	27.409	3.678	2.622	1.051
548-52	0	0.45	1.30	60.84	30.273	3.141	2.853	1.143
520-25	0	0	0.36	0.76	55.14	18.222	4.661	20.855
515-20	0	0	0.52	8.49	70.36	5.741	2.017	12.872
510-15	0	0	0.51	8.93	65.57	9.153	1.886	13.949
505-10	0	0	0.69	4.21	38.29	23.29	12.467	21.053
500-05	0	0	0.28	4.26	53.35	14.572	7.992	19.546

Loss on ignition	(%)
570 - 75	0
565 - 70	0
560 - 65	0
555 - 60	0
552 - 55	0
548 - 52	0
520 - 25	0.006
515 - 20	0.004
510 - 15	0.005
505 - 10	0.005
500 - 05	0.004

APPENDIX IV

- New ^{14}C dates for the inner Moray Firth area

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. BY14B : 141-6

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

BEAULY, INVERNESS — geographic region or town or county

2a. Coordinates

Longitude	Latitude	
·042748W	572928N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
5226	4708	coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:.......NH..........

2b. Altitude of sample / indicator

8.81 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

1 / ±0.05 — altitude measured (1) derived from map (2) / estimated error (in metres)

☐ . ☐ — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

± ☐ . ☐ — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

1.41 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

0.05 — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 — geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "O".

local factors:

? — local faulting

0 — halokinetic movements

± ☐ . ☐ — total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

☐ . ☐ — amount in metres

± ☐ . ☐ — estimated error

regional factors:

? — epoirogenic movements — others:

1 — glacio-isostasy — ....

? — hydro-isostasy — ....

± ☐ . ☐ — total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

-0.09 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± ☐ . ☐ — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

5 — specify the water level, which is represented by the indicator:

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

1 2

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

1 1

01.wood:....................
02.shells:....................
03.bones:....................
04.corals:....................
05.stromatolites:...............
06.coralline algae:...........
07.charcoal:....................
08.limnic muds:..................
09.soils:.......................

10.peat:......................
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 1
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+ [ ][ ][ ].[ ] ± [ ].[ ] amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

[ ][4].[1] modern tidal range at closest point of open sea

8. Paleocoast

5 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast

5 type of actual coast (look for no. from list above)

10. Lower sediment contact to indicator

2 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

7 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample PROVISIONAL

B ± R 1 1 2 2 laboratory-code and -number

1 9 8 1 year of dating

5 5 7 0 half-life of 14C

[ ][ ].[ ] δ 13C value (‰) used for correction

[ ] SUESS-correction=1 other corrections=2

5 5 1 0 ± 8 0 result in years BP

[ ] specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

1 ion exchange
[ ] recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
[ ] others:....................

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

0 3

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others:.................
10.indirect

result:..................
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

[ ]
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

[ ][1].[0] distance of site to actual coastline of open sea (in kilometres)

Institute: Date: Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

internal programming no.

sample no. BY14B : 358-63

1. Geographic locality of sample

SCOTLAND	country, state or sea and sector
BEAULY, INVERNESS	geographic region or town or county

2a. Coordinates

Longitude	Latitude	
042748 W	5 2928 N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
5226	4708	coordinates of national rectangular grid (optional)

internal code for national grid; national grid designation:.........NH..........

2b. Altitude of sample / indicator

6.64	altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)
/ ±0.05	altitude measured (1) / estimated error derived from map (2) / (in metres)
.	altitude of local zero datum above (+) or below (-) mean sea level mark (metres)
± .	estimated error in identification of the mean sea level mark and relation to local zero datum (metres)
3.58	if sample is taken from below land surface, give in depth of sample-top from surface (metres)
0.05	thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "O".

local factors:

?	local faulting
0	halokinetic movements
+ . −	total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

.	amount in metres
± .	estimated error

regional factors:

1	epeirogenic movements	others:
1	glacio-isostasy	....
?	hydro-isostasy	....
+ . −	total amount of regional m. (give estimation, if possible)	

4. Relation of sample/indicator to an ancient water level

0.20	thickness of interval within which the fossil water level occurred = indicative range (metres).
+0.20	vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.
± .	minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: 5

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator 1 2

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species) 1 3

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 1
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

± ☐☐.☐ ± ☐.☐ amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

4.1 modern tidal range at closest point of open sea

8. Paleocoast 5

type of ancient coast
1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast 5

type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator 2

nature of underlying material
1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator 2

if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample

B I R 1 1 2 3 laboratory-code and -number
1 9 8 1 year of dating
5 5 7 0 half-life of 14C
☐☐.☐ δ 13C value (‰) used for correction
☐ SUESS-correction=1 other corrections=2
9 6 1 0 · 1 3 0 result in years BP
☐ specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

1 ion exchange
1 recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
☐ others: ....

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination 0 3

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

☐
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

1.0 distance of site to actual coastline of open sea (in kilometres)

Institute:

Date:

Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

internal programming no.

sample no. BY3B : 388-93

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

BEAULY, INVERNESS — geographic region or town or county

2a. Coordinates

Longitude	Latitude	
42704W	573008N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
5283	4673	coordinates of national rectangular grid (optional)

internal code for national grid; national grid designation:....NH.............

2b. Altitude of sample / indicator

+1.99 altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

1 / ±0.05 altitude measured (1) derived from map (2) / estimated error (in metres)

. altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

± . estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

3.88 if sample is taken from below land surface, give in depth of sample-top from surface (metres)

0.05 thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

? local faulting

0 halokinetic movements

± . total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

. amount in metres

± . estimated error

regional factors:

2 oepirogenic movements — others:

1 glacio-isostasy ....

? hydro-isostasy ....

± . total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 thickness of interval within which the fossil water level occurred = indicative range (metres).

-0.09 vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± . minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator:

5

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

12

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

11

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 1
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+/− ☐☐☐.☐ ± ☐.☐ amount of ancient local tidal range with error interval or tendency (+ or −) of changes since deposition of material.

4.1 modern tidal range at closest point of open sea

8. Paleocoast

5 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others:
....

9. Modern coast

5 type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator

2 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

2 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample

HV10010 laboratory-code and -number
1980 year of dating
5570 half-life of 14C
−27.2 δ 13C value (‰) used for correction
0 SUESS-correction=1 other corrections=2
9200 · 100 result in years BP
1 specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

☐ ion exchange
☐ recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
☐ others: ....

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

03

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

☐
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

0.5 distance of site to actual coastline of open sea (in kilometres)

Institute:

Date:

Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. M4B : 283-288

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

MONIACK INVERNESS — geographic region or town or county

2a. Coordinates

Longitude: 042601W
Latitude: 572746N
geocoordinates E or W of Greenwich and N or S of the equator (required)

Right: 5421
Up: 4393
coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation: NH

2b. Altitude of sample / indicator

8.76 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

☐ / ±0.05 — altitude measured (1) derived from map (2) / estimated error (in metres)

. — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

± . — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

2.83 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

0.05 — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 — geotectonic influences
1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

? — local faulting

0 — halokinetic movements

± . — total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

. — amount in metres

± . — estimated error

regional factors:

1 — epeirogenic movements

1 — glacio-isostasy

? — hydro-isostasy

others: ....

± . — total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

-0.09 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± . — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: 5
1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

1 2

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

1 3

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 1
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

± [.] ± [.] amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

4.1 modern tidal range at closest point of open sea

8. Paleocoast

3 type of ancient coast
1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast

5 type of actual coast (look for no. from list above)

10. Lower sediment contact to indicator

2 nature of underlying material
1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

7 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample PROVISIONAL

BIR 1124 laboratory-code and -number
1981 year of dating
5570 half-life of 14C
[.] δ 13C value (‰) used for correction
[ ] SUESS-correction=1 other corrections=2
4760 ± 90 result in years BP
[ ] specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

[ ] ion exchange
[ ] recrystallisation
1 hard water effect
1 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
4 older material included
1 artificial contamination by younger material
[ ] others: ....

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

[ ][ ]
01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

[ ]
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

4.0 distance of site to actual coastline of open sea (in kilometres)

Institute: Date: Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. M4B :419-424

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

MONIACK, INVERNESS — geographic region or town or county

2a. Coordinates

Longitude	Latitude	
042601 W	572746 N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
5421	4393	coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:.....NH.............

2b. Altitude of sample / indicator

7.40 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

☐ / ±0.05 — altitude measured (1) derived from map (2) / estimated error (in metres)

. — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

± . — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

4.19 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

0.05 — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

☐ geotectonic influences
1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

? local faulting

0 halokinetic movements

± . — total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

. — amount in metres

± . — estimated error

regional factors:

1 epeirogenic movements

1 glacio-isostasy

? hydro-isostasy

others:

....

....

± . — total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

± +0.20 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± . — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: 5
1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator 1 1

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species) 1 1

01.wood:....................
02.shells:..................
03.bones:...................
04.corals:..................
05.stromatolites:...........
06.coralline algae:.........
07.charcoal:................
08.limnic muds:.............
09.soils:...................

10.peat:....................
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 3
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

± [.] ± [.] amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

4.1 modern tidal range at closest point of open sea

8. Paleocoast 3

type of ancient coast
1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast 5

type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator 2

nature of underlying material
1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator 2

if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample PROVISIONAL

BIR 1125 laboratory-code and -number
1981 year of dating
5570 half-life of 14C
[.] δ 13C value (‰) used for correction
[ ] SUESS-correction=1 other corrections=2
7100 ± 120 result in years BP
[ ] specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

	ion exchange	1.not checked, possible
	recrystallisation	2.checked, not possible
1	hard water effect	3.checked, contaminated
1	penetrated by roots	4.pretreated, contamination partly eleminated
1	infiltration of humic acids	5.contamination reduced by calculation
1	fungi, bacteria, algae	
4	older material included	
1	artificial contamination by younger material	
	others:.................	

14. Other kinds of age determination [ ]

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others:................
10.indirect

result:..................
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation: [ ]

1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

4.0 distance of site to actual coastline of open sea (in kilometres)

Institute: Date: Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

internal programming no. ☐

sample no. M4B : 426 - 431

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

MONIACK, INVERNESS — geographic region or town or county

2a. Coordinates

Longitude 042601W — Latitude 572746N — geocoordinates E or W of Greenwich and N or S of the equator (required)

Right 5421 — Up 4393 — coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:....NH............

2b. Altitude of sample / indicator

7.23 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

☐ / ±0.05 — altitude measured (1) / derived from map (2) / estimated error (in metres)

. — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

±4.26 — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

0.05 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

. — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 — geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

? — local faulting

0 — halokinetic movements

± . — total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

. — amount in metres

± . — estimated error

regional factors:

1 — epeirogenic movements — others:

1 — glacio-isostasy — ....

? — hydro-isostasy — ....

± . — total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

+0.09 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± . — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: 5

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

1 2

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as
1.remnant, isolated
2.patch 3.wide spread

3

6. Material sampled (type/genus/species)

1 1

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material:

1

1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ, possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+ ☐☐☐.☐ ± ☐.☐ amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

4.1 modern tidal range at closest point of open sea

8. Paleocoast

3 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast

5 type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator

2 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

2 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample PROVISIONAL

B I R 1 1 2 6 laboratory-code and -number

1 9 8 1 year of dating

5 5 7 0 half-life of 14C

☐☐.☐ δ 13C value (‰) used for correction

☐ SUESS-correction=1
other corrections=2

7 2 7 0 ± 9 0 result in years BP

☐ specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

☐ ion exchange
☐ recrystallisation
1 hard water effect
1 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
4 older material included
1 artificial contamination by younger material
☐ others: ....

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

☐☐

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator, give an age estimation:

☐

1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

4.0 distance of site to actual coastline of open sea (in kilometres)

Institute: Date: Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

[ ] internal programming no.

sample no. M4B : 472-77

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

MONIACK, INVERNESS — geographic region or town or county

2a. Coordinates

Longitude: 042601 N

Latitude: 572746 N

geocoordinates E or W of Greenwich and N or S of the equator (required)

Right: 5421

Up: 4393

coordinates of national rectangular grid (optional)

[ ] internal code for national grid; national grid designation:.......NH..........

2b. Altitude of sample / indicator

6.82 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

[ ] / ± 0.05 — altitude measured (1) derived from map (2) / estimated error (in metres)

[.] altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

± [.] estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

4.72 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

0.05 — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 — geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

? — local faulting

0 — halokinetic movements

± [.] total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

[.] amount in metres

± [.] estimated error

regional factors:

1 — epeirogenic movements — others:

1 — glacio-isostasy ....

? — hydro-isostasy ....

± [.] total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

± -0.09 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± [.] minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator:

5

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

1 1

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 3
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

1 1

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 3
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+/− ☐☐☐.☐ ± ☐.☐ amount of ancient local tidal range with error interval or tendency (+ or −) of changes since deposition of material.

☐☐.☐ modern tidal range at closest point of open sea

8. Paleocoast

type of ancient coast 3

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary

6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others:
....

9. Modern coast

type of actual coast 5
(look for no. from list above)

10. Lower sediment contact to indicator

nature of underlying material 2

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)

6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

2 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample PROVISIONAL

BIR 1127 laboratory-code and -number

1981 year of dating

5570 half-life of 14C

☐☐.☐ δ 13C value (‰) used for correction

☐ SUESS-correction=1
other corrections=2

7430 ± 170 result in years BP

☐ specify sigma-interval of result
(sigma 1 = 1, sigma 2 = 2)

13. Contamination

☐ ion exchange
☐ recrystallisation
1 hard water effect
1 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
4 older material included
1 artificial contamination by younger material
☐ others: ....

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

☐☐

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

☐

1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

4.0 distance of site to actual coastline of open sea (in kilometres)

Institute:

Date:

Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. AM : 126-131

1. Geographic locality of sample

SCOTLAND	country, state or sea and sector
STRATHCONON	geographic region or town or county

2a. Coordinates

Longitude	Latitude	
43037 W	573230 N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
4963	5358	coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:.....NH..............

2b. Altitude of sample / indicator

9.05	altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)
☐ / ± 0.05	altitude measured (1) / derived from map (2) / estimated error (in metres)
.	altitude of local zero datum above (+) or below (-) mean sea level mark (metres)
± .	estimated error in identification of the mean sea level mark and relation to local zero datum (metres)
1.26	if sample is taken from below land surface, give in depth of sample-top from surface (metres)
0.05	thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "0".

local factors:

?	local faulting
0	halokinetic movements
+ . −	total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

.	amount in metres
± .	estimated error

regional factors:

1	epeirogenic movements	others:
1	glacio-isostasy	....
?	hydro-isostasy	....
+ . −	total amount of regional m. (give estimation, if possible)	

4. Relation of sample/indicator to an ancient water level

0.20	thickness of interval within which the fossil water level occurred = indicative range (metres).
- 0.09	vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.
± .	minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: 5

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

12

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 2
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

13

01.wood:......................
02.shells:....................
03.bones:.....................
04.corals:....................
05.stromatolites:.............
06.coralline algae:...........
07.charcoal:..................
08.limnic muds:...............
09.soils:.....................

10.peat:......................
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 1
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+/- +[.] ± [.] amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

3.7 modern tidal range at closest point of open sea

8. Paleocoast

5 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast

5 type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator

2 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

7 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample

HV10012 laboratory-code and -number

1980 year of dating

5570 half-life of 14C

-26.7 δ 13C value (‰) used for correction

0 SUESS-correction=1
other corrections=2

5775 ± 85 result in years BP

[ ] specify sigma-interval of result
(sigma 1 = 1, sigma 2 = 2)

13. Contamination

☐ ion exchange
☐ recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
☐ others:..................

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

03

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others:................
10.indirect

result:..................
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

[ ]
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

7.0 distance of site to actual coastline of open sea (in kilometres)

Institute: Date: Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. AM : 303-8

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

STRATHCONON — geographic region or town or county

2a. Coordinates

Longitude	Latitude	
043027 W	573230 N	geocoordinates E or W of Greenwich and N or S of the equator (required)
Right	**Up**	
4963	5358	coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:....NH..............

2b. Altitude of sample / indicator

7.28 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

☐ / ±0.05 — altitude measured (1) / derived from map (2) / estimated error (in metres)

☐☐.☐☐ — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

±3.03 — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

0.05 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

☐.☐☐ — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

1 — geotectonic influences
1.strong uplift
2.slight uplift
3.slight subsidence
4.strong subsidence
5.area can be looked upon as stable
6.absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "O".

local factors:

? — local faulting

0 — halokinetic movements

+/− ☐☐☐.☐ — total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

☐☐.☐☐ — amount in metres

±☐.☐☐ — estimated error

regional factors:

1 — epeirogenic movements — others:

1 — glacio-isostasy — ....

? — hydro-isostasy — ....

+/− ☐☐☐.☐ — total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.20 — thickness of interval within which the fossil water level occurred = indicative range (metres).

+0.20 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± ☐.☐☐ — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator:

5
1.groundwater table
2.mean high tide level
3.mean sea level
4.mean low tide level
5.mean high spring tide
6.mean low spring tide
7.mean high neap tide
8.mean low neap tide
9.storm flood levels
0.unspecified sea level

5. Type of water level indicator

11

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural leveé(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as 2
1.remnant, isolated
2.patch 3.wide spread

6. Material sampled (type/genus/species)

12

01.wood: ....
02.shells: ....
03.bones: ....
04.corals: ....
05.stromatolites: ....
06.coralline algae: ....
07.charcoal: ....
08.limnic muds: ....
09.soils: ....

10.peat: ....
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material: 3
1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

\+ [ ][ ][ ].[ ] ± [ ].[ ] amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

[ ] 3.7 modern tidal range at closest point of open sea

8. Paleocoast

5 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others: ....

9. Modern coast

5 type of actual coast (look for no. from list above)

10. Lower sediment contact to indicator

?8 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

3 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample

HV 10013 laboratory-code and -number

1980 year of dating

5570 half-life of 14C

-26.2 δ 13C value (‰) used for correction

[ ] SUESS-correction=1
other corrections=2

7700 · 80 result in years BP

[ ] specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

[ ] ion exchange
[ ] recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
[ ] others: ....

1.not checked, possible
2.checked, not posaible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

03

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others: ....
10.indirect

result: ....
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent wator level indicator,give an age estimation:

[ ]
1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

7.0 distance of site to actual coastline of open sea (in kilometres)

Institute:

Date:

Signature:

SEA-LEVEL DOCUMENTATION

COMPUTER-FORM FOR THE COLLECTION OF SAMPLE DATES (second edition)

☐☐☐☐ internal programming no.

sample no. AM : 484-90

1. Geographic locality of sample

SCOTLAND — country, state or sea and sector

STRATHCONON — geographic region or town or county

2a. Coordinates

Longitude 043037W — Latitude 573230N — geocoordinates E or W of Greenwich and N or S of the equator (required)

Right 4963 — Up 5358 — coordinates of national rectangular grid (optional)

☐ internal code for national grid; national grid designation:......NH............

2b. Altitude of sample / indicator

5.47 — altitude of sample above (+) or below (-) local zero datum -if a water level is not indicated by the sample itself, fill in altitude of indicator. (metres, measured from top)

☐ / ±0.05 — altitude measured (1) derived from map (2) / estimated error (in metres)

☐☐.☐☐ — altitude of local zero datum above (+) or below (-) mean sea level mark (metres)

±4.84 — estimated error in identification of the mean sea level mark and relation to local zero datum (metres)

0.06 — if sample is taken from below land surface, give in depth of sample-top from surface (metres)

☐.☐☐ — thickness of sampled interval (metres)

3. Secondary influences on altitude of data point since sampled material was formed

☐ geotectonic influences

1. strong uplift
2. slight uplift
3. slight subsidence
4. strong subsidence
5. area can be looked upon as stable
6. absolutely no information

If reasons for movements can be specified, check the list and indicate the direction by "+" for uplift or "-" for subsidence. For questionable movements fill in "?" and for no indication write "O".

local factors:

? local faulting

0 halokinetic movements

± ☐☐☐.☐ total amount of local m. (fill in, if possible)

Consolidation, compaction of underlying sediments (from comparing the geology of neighboring data points or from determination of underlying material):

☐☐.☐☐ amount in metres

± ☐.☐☐ estimated error

regional factors:

1 epeirogenic movements — others:

1 glacio-isostasy — ....

? hydro-isostasy — ....

± ☐☐☐.☐ total amount of regional m. (give estimation, if possible)

4. Relation of sample/indicator to an ancient water level

0.80 — thickness of interval within which the fossil water level occurred = indicative range (metres).

-0.40 — vertical distance of midpoint of indicative range to top of indicator in metres above (+) or below (-) top.

± ☐☐.☐☐ — minimum value for which the ancient water level was higher(+) or lower(-) than top of sample (metres).

specify the water level, which is represented by the indicator: ? 3

1. groundwater table
2. mean high tide level
3. mean sea level
4. mean low tide level
5. mean high spring tide
6. mean low spring tide
7. mean high neap tide
8. mean low neap tide
9. storm flood levels
0. unspecified sea level

5. Type of water level indicator

1 2

10.organic layer
position of sample:
11.top of layer
12.base of layer
13.middle of layer
14.full interval of layer
15.in upper part of layer
16.in lower part of layer
17.contact to top of layer
18.contact to base of layer
19.others: ....

40.structures
41.sedimentory structures

20.erosional feature
21.cliff face
22.cliff foot
23.cliff overhang
24.biotic solutional notch
25.biotic borehole(s)
26.sea cave
27.marine platform (solid)
28.marine terrace (gravel)
29.others: ....

42.bioturbation structures
43.archeological structures
44.dessication fissures

30.constructional feature
31.beach
32.dune barrier
33.salt marsh surface
34.tidal flat surface
35.natural levee(undiff.)
36.river or creek levee
37.fringing coral reef
38.barrier coral reef
39.others: ....

Indicator occurs as
1.remnant, isolated
2.patch 3.wide spread

2

6. Material sampled (type/genus/species)

1 6

01.wood:...................
02.shells:..................
03.bones:...................
04.corals:..................
05.stromatolites:...........
06.coralline algae:..........
07.charcoal:.................
08.limnic muds:..............
09.soils:....................

10.peat:.....................
11.phragmites peat
12.sedge peat
13.wood fen peat
14.moss peat
15.raised bog peat
16.highly decomposed peat
20.hydrothermal sediments
21.volcanic ashes
22.varve clay
23.beachrock
24.ooids
25.mangrove, undiff.
26.Rhizophora mangrove
27.Avicennia mangrove
28.Sonneratia mangrove

30.archeological material:
31.worked wood
32.worked shells
33.worked bones
34.worked rocks
35.tools
36.manure
37.charcoal
38.others: ....

In-situ nature and undisturbance of sampled material:

1

1.certainly in situ, not eroded
2.certainly in situ, top eroded
3.certainly in situ,possibly eroded
4.probably not in situ, not sure
5.not in situ, but still suitable

7. Tidal range

+ ☐☐☐ . ☐ ± ☐ . ☐ amount of ancient local tidal range with error interval or tendency (+ or -) of changes since deposition of material.

−

☐ 3 . 7 modern tidal range at closest point of open sea

8. Paleocoast

5 type of ancient coast

1.high coast
2.dune barrier coast
3.lagoon coast
4.open bay
5.river estuary
6.delta coast
7.open tidal flat
8.sheltered tidal flat
9.others:
....

9. Modern coast

5 type of actual coast
(look for no. from list above)

10. Lower sediment contact to indicator

?8 nature of underlying material

1.marine-subtidal
2.marine-intratidal
3.marine-supratidal
4.brackish (lagoonal)
5.limnic (lake sediment)
6.semiterrestrial (peat)
7.pedological (soils)
8.fluvial, eolian
9.bed rock

11. Upper sediment contact to indicator

2 if sample is taken from below land surface, fill in no. for nature of overlying material from list above.

12. 14C-dating of sample

☐ H V 1 0 0 1 3 laboratory-code and -number

1 9 8 0 year of dating

5 5 7 0 half-life of 14C

- 2 7 . 2 δ 13C value (‰) used for correction

☐ SUESS-correction=1
other corrections=2

☐ 5 4 2 0 ± ☐ 2 8 0 result in years BP

☐ specify sigma-interval of result (sigma 1 = 1, sigma 2 = 2)

13. Contamination

☐ ion exchange
☐ recrystallisation
1 hard water effect
4 penetrated by roots
1 infiltration of humic acids
1 fungi, bacteria, algae
1 older material included
1 artificial contamination by younger material
☐ others:...................

1.not checked, possible
2.checked, not possible
3.checked, contaminated
4.pretreated, contamination partly eleminated
5.contamination reduced by calculation

14. Other kinds of age determination

0 3

01.varve
02.dendro
03.pollen
04.fauna,flora
05.archeology
06.potassium-argon
07.thorium-uranium-methods
08.tephra
09.others:................
10.indirect

result:..................
(transform into years BP, and enter under no.12)

15. Age of water level indicator

-if dated sample itself does not represent water level indicator,give an age estimation:

☐

1.indicator is older than dated sample
2.indicator is slightly older
3.indicator is practically of same age
4.indicator is slightly younger
5.indicator is younger than dated sample

16. Additional data

☐ 7 . 0 distance of site to actual coastline of open sea (in kilometres)

Institute:

Date:

Signature:

APPENDIX V

- A method of representing Flandrian coastal sequences

The newly developed scheme for the description and lithological classification of Flandrian coastal sequences developed by Barckhausen et al. (1977) is hierarchical in character. There are three levels in the hierarchy - complexes, sequences and facies units. Each level contains a number of profile types. Complexes, described in chapter 3, contain 3 profile types - X, Y and Z. Sequences comprise the middle level of the hierarchy and are subdivisions of complexes. They are themselves composed of one or more facies units. Streif (1978) outlines ten sequences.

(1) clastic sequence (qhk) : clastic sedimentary succession without intercalated peat layers.

(2) organic basal sequence (qhOB) : succession of peat and limnic muds or soil horizons at the base of clastic Flandrian (Holocene) deposits.

(3) organic cover sequence (qhOD) : succession of peat or limnic muds which occur at the present surface and which is underlain by clastic Flandrian (Holocene) deposits.

The qhOB or qhOD sequences can occur in the clastic (X) complex as well as in the interfingering (Y) complex and may also be absent. The following sequences are found only in the Y complex and are characteristic of it:-

(4) lower clastic sequence (qhKU) : clastic sedimentary unit > 5 cm. which underlies lowermost intercalated peat layer and may be underlain by an organic basal sequence.

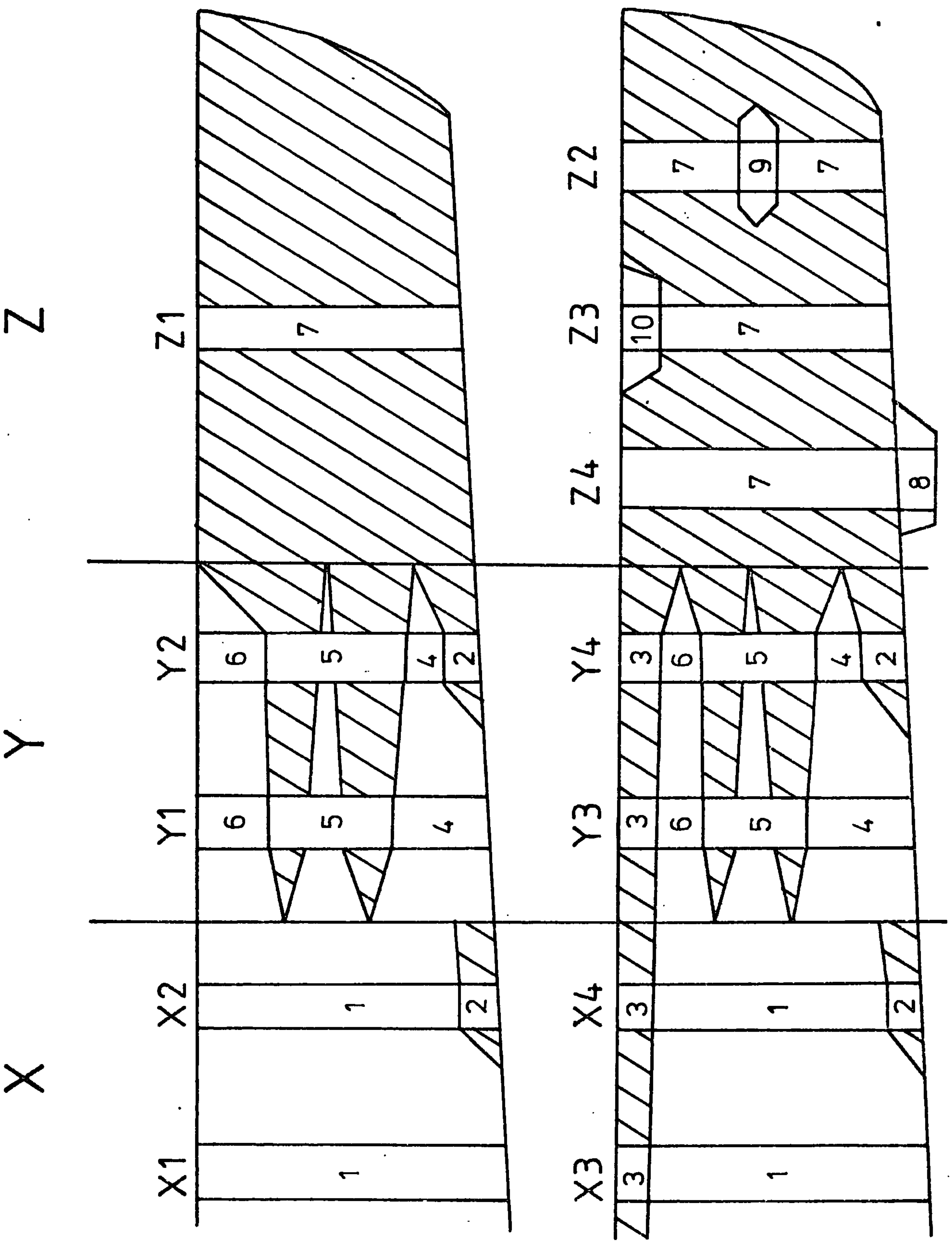
(5) Splitting up sequence (qhA) : sedimentary succession between the bottom of the lowermost intercalated peat layer and the top of the uppermost one.

(6) upper clastic sequence (qhKO) : clastic sedimentary unit > 5 cm.

Fig. AV-1. Schematic cross-section through the coastal deposits with lables for principal profile types (X1, X2, X3, X4, Y1, etc.). Numbers refer to sequences described in text.

1 = Clastic sequence (qhK)
2 = Organic basal sequence (qhOB)
3 = Organic cover sequence (qhOD)
4 = Lower clastic sequence (qhKU)
5 = Splitting up sequence (qhA)
6 = Upper clastic sequence (qhKO)
7 = Organic sequence (qhO)
8 = Clastic basal sequence (qhKB)
9 = Clastic interbedded sequence (qhKE)
10 = Clastic cover sequence (qhKO)

Source : Streif (1978)


X
Y
Z
X1
X2
Y1
Y2
Z1
X3
X4
Y3
Y4
Z4
Z3
Z2
1
2
3
4
5
6
7
8
9
10

thick which overlies the uppermost intercalated peat and may be overlain by an organic cover sequence.

The remainder are characteristic of the peat (Z) complex.

(7) organic sequence (qhO) : succession of peat and limnic mud with at least one interbedded layer of clastic sediments > 5 cm. thick.

(8) clastic basal sequence (qhKB) : clastic sedimentary unit which occurs in the basal parts of the coastal Holocene deposits and which is covered by an organic sequence. The thickness of the clastic basal sequence is less than that of any covering organic sequence.

(9) clastic interbedded sequence (qhKE) : unit of clastic sediments which is interbedded in the organic sequence unrelated to an upper or lower clastic unit of a splitting up sequence. This clastic interbedded sequence may not exceed 50% of the total thickness of the organic sequence. The qhKE unit may consist of one individual layer and/or of several thin layers 5 cm. thick.

(10) clastic cover sequence (qhKD) : clastic sedimentary unit which occurs at the present surface and which is underlain by the organic sequence. The thickness of the clastic cover sequence must be less than that of the underlying organic sequence.

In a coastal context there are a finite number of interrelationships these ten sequences can hold. Streif (1978, fig.1) outlines twelve 'subordinate profile types' incorporating all possible combinations of sequences. These are shown in fig. AV-1 and the numbers 1-10 denote sequences numbered in the text.

Facies units are the lowest division of the hierarchy and have a variable number of 'special profile types' which are defined individually with regard to specific objectives. In this study 'special profile types' are used to distinguish between clastic layers of marine and non-marine origin. A schematic diagram of the most commonly encountered 'special profile types' is given in Chapter 3, fig.3.4 and they are described below -

X, XI , 1 - marine clastic sedimentary succession without intercalation of peat layers. Definition of marine origin based on lithology, stratigraphic relationships and micropalaeontological analysis. No internal differentiation of marine sequences are made.

X,X2, 18 - terrestrial clastic sedimentary succession without intercalation of peat layers.

X, X2, 16 - terrestrial clastic sequence (qhK) underlain by thinner organic basal sequence (qhOB)

X,X3,17 - organic cover sequence (qhOD) overlying thicker terrestrial clastic sequence.

X,X4, 15 - terrestrial clastic sequence underlain and overlain by organic basal and cover sequences.

Y,Y1, 2 - marine clastic upper and lower sequences, separated by a single organic splitting up sequence (qhA).

Y ,Y3, 3 - organic cover sequence (qhOD) underlain by upper marine clastic sequence, single organic layer comprising a splitting-up sequence and a lower marine clastic sequence.

Y,Y3, 4 - as special profile 3 above save the splitting up sequence comprises two peat layers and are marine clastic layer.

Y,Y 5 - as special profile 4 above save the splitting up sequence has three peat layers and two minerogenic layers, the upper of which is non-marine in origin.

Y,Y3, 6 - as special profile 5 above save the splitting up sequence has three peat layers and two minerogenic layers, the upper of which is non-marine in origin.

Y,Y3, 7 - as special profile 6 above except the splitting up sequence has four peat layers and three minerogenic layers only the lower of which is marine.

Y, Y3,8 - as special profile 7 above save the lower minerogenic layer of the splitting up sequence is part marine, part non-marine.

Y,Y3, 9 - as special profile 6 above except the lower minerogenic layer of the splitting up sequence is part marine, part non-marine.

Y,Y1,10 - the profile type is characterized by an upper clastic sequence (qhKO) of non-marine origin underlain by a splitting up sequence of two peats and a single minerogenic layer of non-marine origin with a lower marine clastic sequence at the base.

Y,Y1,11 - as special profile type 10 above except the single minerogenic layer within the splitting up sequence is marine in origin.

Y,Y1,12 - as special profile type 10 above save the splitting up sequence comprises a single peat layer.

Y,Y1,13 - as special profile type 12 above except the splitting up sequence comprises three peats and two minerogenic layers, all of non-marine origin

Y,Y1,14 - as 13 above except there are four peatsand three minerogenic layers.