THE LATE QUATERNARY HISTORY OF THE RIVER ERME, SOUTH DEVON

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ABSTRACT

This thesis examines a typical 'drowned' river valley of south-west England. The River Erme drains southern Dartmoor and, in common, with other rivers of the region, has a buried channel graded to c. -50m OD. The channel has been infilled with a variety of sediments, of which the top 6-7m have been analysed for this study. Augered cores have been collected from the modern floodplain and salt marsh areas in the lower part of the valley and have been studied using particle size, diatom, molluscan and radiocarbon analyses.

The main sediment types recovered include a fine silt unit representing the most recent phase of fluvial deposition, which overlies variable horizons of fluvial granitic sands and gravels and brackish organic sands and silts. These are, in places, replaced at depth by shelly silts, sands and gravels deposited under more estuarine and marine conditions. The organic layer has been radiocarbon dated to between 1000 and 2000 years BP and has been correlated with a former area of marshland recorded in the tithe maps of the region. It is suggested that the Erme valley was previously more estuarine than today and that alluviation and infilling of the Erme's channel in the last 1000-2000 years has been aided by forest clearance and tin mining on Dartmoor.

All of the sediments recovered from the buried channel are derived from local sources of bedrock and have probably been deposited in the last 4000-6000 years. Evidence from the tithe maps suggests that the channel has been stable in the past 200 years.

This work seeks to contribute to the Quaternary knowledge of the south-west of England, and because of the paucity of data concerning these buried rock channels, makes this study of the River Erme a preliminary model against which other rivers in the South West may be compared.

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CHAPTER 1 INTRODUCTION

During the Quaternary[1] growth and decay of ice sheets caused oscillations in sea level. There were traditionally thought to be a maximum of four or five cold stages in the Quaternary but oxygen isotope analysis of deep sea sediments suggests at least eight in the last 700ka, and in the whole of the Quaternary at least 17 (Bowen 1978). In East Anglia West (1980) considered there to be seven cold stages of which five are confirmed by evidence of permafrost and periglacial sediments and three by glacigenic sediments. This therefore suggests there have been marked changes in sea level throughout the last two million years at least. It has been estimated that with the growth of the last ice sheet, during the Devensian, sufficient water was removed from the world's oceans to produce a eustatic lowering of sea level by over 100m.

With these numerous oscillations of sea level, one should expect to find evidence of river channels graded to lower levels than today. Many examples worldwide have been cited of lower sea levels and in the UK these include the Thames estuary (Devoy 1979, Conway *et al.* 1984), the Bristol Channel (Kidson and Heyworth 1973), north-west England (Tooley 1978) and the Fens (Shennan 1982a). This particular study concerns the south-west of England where in the drowned coastlines of the south-west peninsula, there is indisputable evidence of rock channels in the river valleys with 'floors' at c. 150ft (45m) below sea level (e.g. Codrington 1898, McFarlane 1955, Durrance 1971). These 'buried rock channels', as they have been termed, have been infilled with suites of sediments, the age of which can only be considered to range across part of the Quaternary; and may include sediments that have not been reworked during the Holocene.

As Orme (1964) stated there has been little work carried out on the buried channels of the West Country. Although Codrington (1898) presented some fairly detailed descriptions from nineteenth century engineering works of the depth and shape of rock channels in the South Devon area, there has been little study on the nature and age of sediments filling these valleys. Previous research in the area has been more concerned with the mapping of planation surfaces and attempting to assess the impact of any glacial action. The research presented in this thesis will attempt to redress the balance by an analytical study of some of these valley sediments. This study will focus on a typical river in South Devon, the Erme, drowned during the rise in sea level following the melting of the last ice sheets at the end of the Devensian cold stage. The location of the River Erme is shown in figure 1.1 and the mouth of the river at low tide in plate 1.1. Although this is not a study of denudation chronology, it may be possible to link the sediments found in the Erme channel with the older geomorphological studies of South Devon to form a more complete understanding of Quaternary events that have affected the south-west peninsula. In addition, because of the lack of data relating to these buried rock channels, this study of the Erme may present an initial model against which others may be compared.

The buried channel of the Erme was first positively identified using geophysical techniques by McFarlane (1955). The course of the River Erme (figure 1.2) begins at c. 480m OD on the Dartmoor granite and descends steeply to the town of Ivybridge on the edge of the moor. It continues through floodplain and terrace deposits, salt marsh flats and finally tidal flats at the mouth of the river at Mothecombe over a distance of 24km. The channel must have been cut at a time when sea level(s) were lower than today, either in the last cold stage, the Devensian, or in previous cold stages. With the Flandrian rise in sea level, new sediments have infilled the channel and thus the channel is likely to include estuarine and river sediments of varying ages. The aims of this study are to examine the sediments filling the buried channel, and derive some conclusion(s) on the episodes that have affected the development of the River Erme and its valley.

Because of the difficulties involved in extracting sediment from the channel, we were forced to accept shallow cores to a maximum depth of 7m. They were obtained from fairly regular intervals from the lower half of the Erme

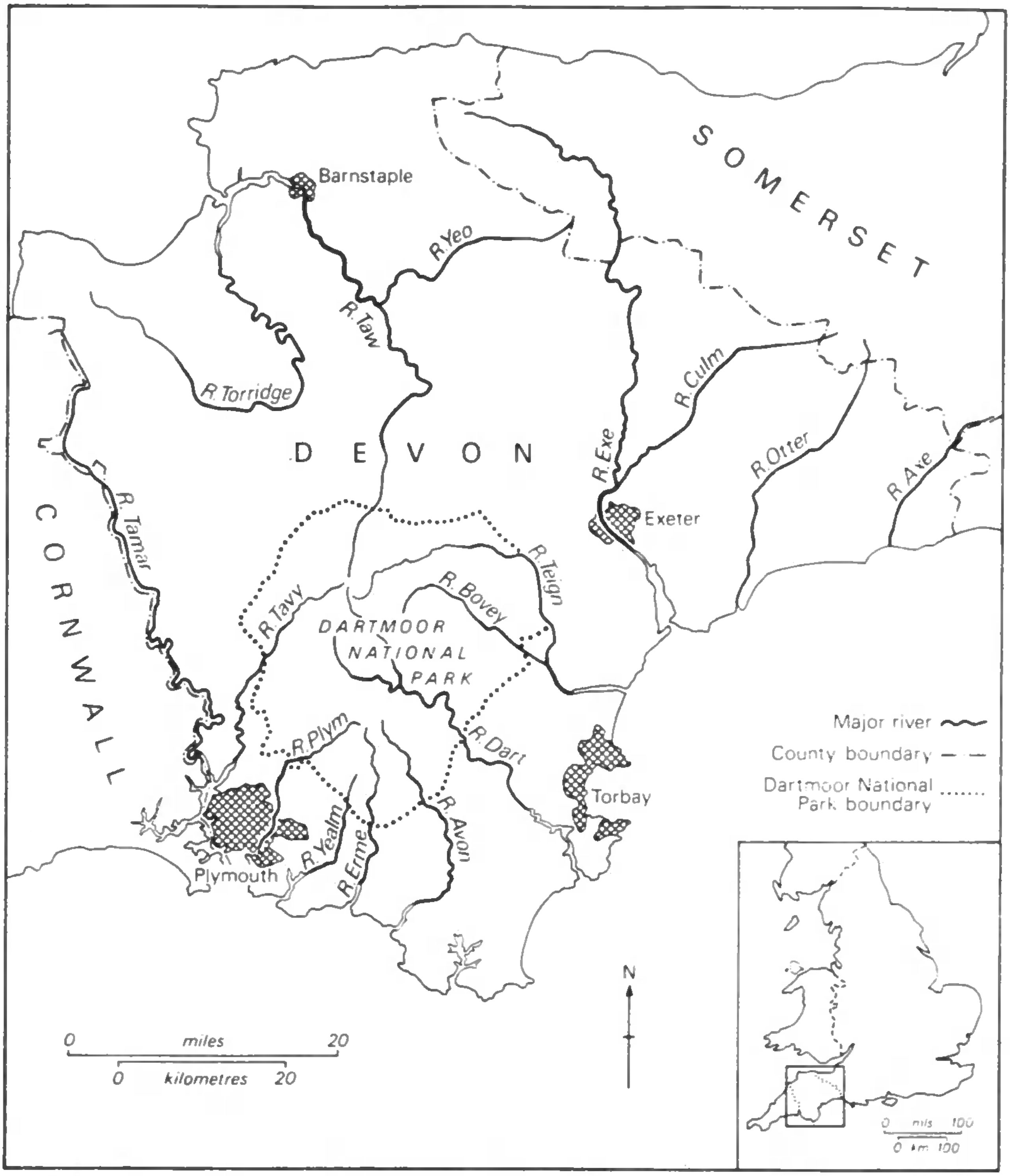

Fig 1.1 The Rivers of Devon

PLATE 1.1

An aerial view of the mouth of the River Erme,
South Devon, England

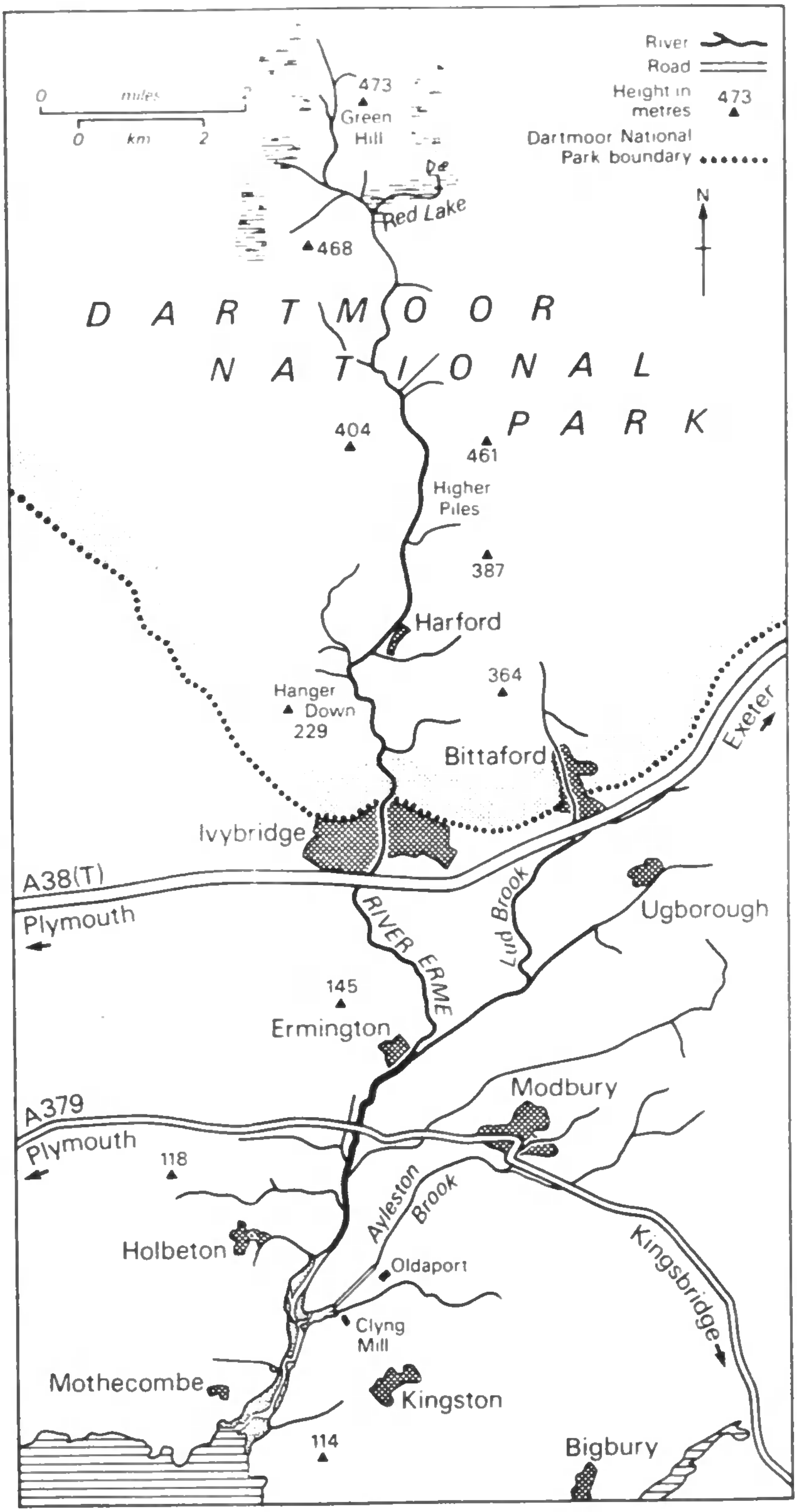

Fig 1.2 General location map

valley and cover a range of environments such as floodplain, reclaimed marsh and present day salt marsh.

The aims of this study can be summarized here as follows:

a) To examine the sediment collected from boreholes at a number of sites covering a range of environments.

b) The analysis of the sediments recovered from the boreholes where particle size analysis demonstrates changes in lithology of the channel deposits, which may aid correlation between the sediments obtained from different cores.

c) To differentiate between deposits of marine, estuarine and fluvial origin by a study of molluscan shells and diatoms preserved in the sediments.

d) To determine the relationship between sediments recovered from the channel and events that have occurred in prehistoric and historic time using documentary records from the Erme valley and evidence of tin mining and forest clearance on Dartmoor.

e) To assess the effect of the Flandrian rising sea level upon the River Erme, and the magnitude of fluvial activity in the channel during the late Flandrian.

f) To derive a series of conclusions relating to the development of the Erme valley and other river valleys in the south-west of England during the Flandrian stage and also in relation to events from earlier stages of the Quaternary.

In Chapter 2 the evidence available to support the former existence of 'high' and 'low' sea levels in the study area during the Quaternary will be reviewed. The Flandrian marine transgression in the UK and subsequent alluviation are considered. The geological and geomorphological characteristics of the study area are examined in Chapter 3. Chapter 4 highlights the field methodology employed in the collection of samples from the study area. This section includes a description of the core-augering locations and the lithology of the cores. Details of the particle size distribution and the possible origin of the gravels in the sediment are examined. Chapter 5 considers the use of diatom analysis in an attempt to separate deposits of fluvial, estuarine and marine origin and the mollusc shells and shell fragments identified in the deposits are discussed in chapter 6. Chapter 7 reviews historical changes in the Erme estuary which includes a study of old tithe maps of the Erme and archaeological changes in the catchment such as the effects of tin mining on Dartmoor. All these aspects are considered in Chapter 8 as a discussion of the origin and relative age of the sediments filling the buried channel of the River Erme in relation to the evolution of the surrounding landscape over time. The conclusions of this research and suggestions for future work are presented in Chapter 9.

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[1]The term 'Quaternary' is used throughout to include the Pleistocene and Holocene epochs. 'The geological status accorded to the Quaternary has varied. Charlesworth (1957) for example, referred to it as an Era, thus logically continuing the classification of Primary (Palaeozoic), Secondary (Mesozoic) and Tertiary. 'Tertiary' and 'Quaternary' are in a sense anachronistic because Primary and Secondary are no longer used: instead both are incorporated within the Cenozoic Era.' (Bowen l978).

It is however recognised (as suggested by eg. Flint 1957, West 1968, 1977, Stuart 1982, Lowe and Walker 1984) that there is no need for a geological or climatic differentiation between the Tertiary and Quaternary Periods, nor the Pleistocene and Holocene Epochs, as many believe that the current warm period is part of a long term climatic cycle and comparable to previous warm episodes of the Quaternary. The Pleistocene should therefore be considered as the most recent epoch of the Tertiary, and the Holocene as the most recent stage of the Pleistocene rather than as a separate series. This would make the terms Quaternary and Holocene redundant. The term Flandrian will be used here to replace the name Holocene, and Quaternary and Pleistocene will be used interchangeably, but to abandon totally the use of 'Quaternary' may be misleading, as it is already entrenched in the literature.

CHAPTER 2 A CONSIDERATION OF THE FACTORS CONTROLLING THE FORMATION AND DEVELOPMENT OF RIVER VALLEYS IN SOUTH-WEST ENGLAND

2.1 Introduction

The geographical extent of this review mainly relates to Devon, but other areas of the south-west of England are included as are parts of the English Channel coastlands including Brittany. The probable conditions that affected the Erme valley during the course of its development are discussed. As much of south-west England is believed to have been beyond Quaternary ice limits, the most important controls on river valleys in Devon have been the effects of periglacial climatic change, sea level variations over time and Flandrian fluvial activity. These changes have affected the depths to which rivers have incised their valleys, and their sediment infill. This chapter will consider the causes of such sea level variations and their effects on the area of study, incorporating evidence for higher and lower sea levels than today. The most recent rise in sea level following the melting of the Devensian ice sheets and changing fluvial conditions during the Flandrian are also considered in detail. These processes have had considerable influence on the development of the Erme and neighbouring river valleys; it is hoped to identify the most important of these processes which contribute to the present landscape.

2.2 The Effect of Quaternary Glaciations on the Area of Study

Much of the south-west of England has long been held to lie outside the limits of glaciation. Figure 2.1 shows the conventionally held views of ice sheet limits in the western part of Britain. It shows the Devensian ice limit to pass through Shropshire, South Wales and across the Irish Sea, and an earlier ice limit to impinge upon the north coasts of Devon, Cornwall and Somerset. The terminology used by Bowen (1973) in this diagram shows that most discussion concerning glaciation has been related to whether glacial deposits are seen above or below the raised beach that is generally thought of as Ipswichian and which occurs around much of the coastline of Wales and southern England.

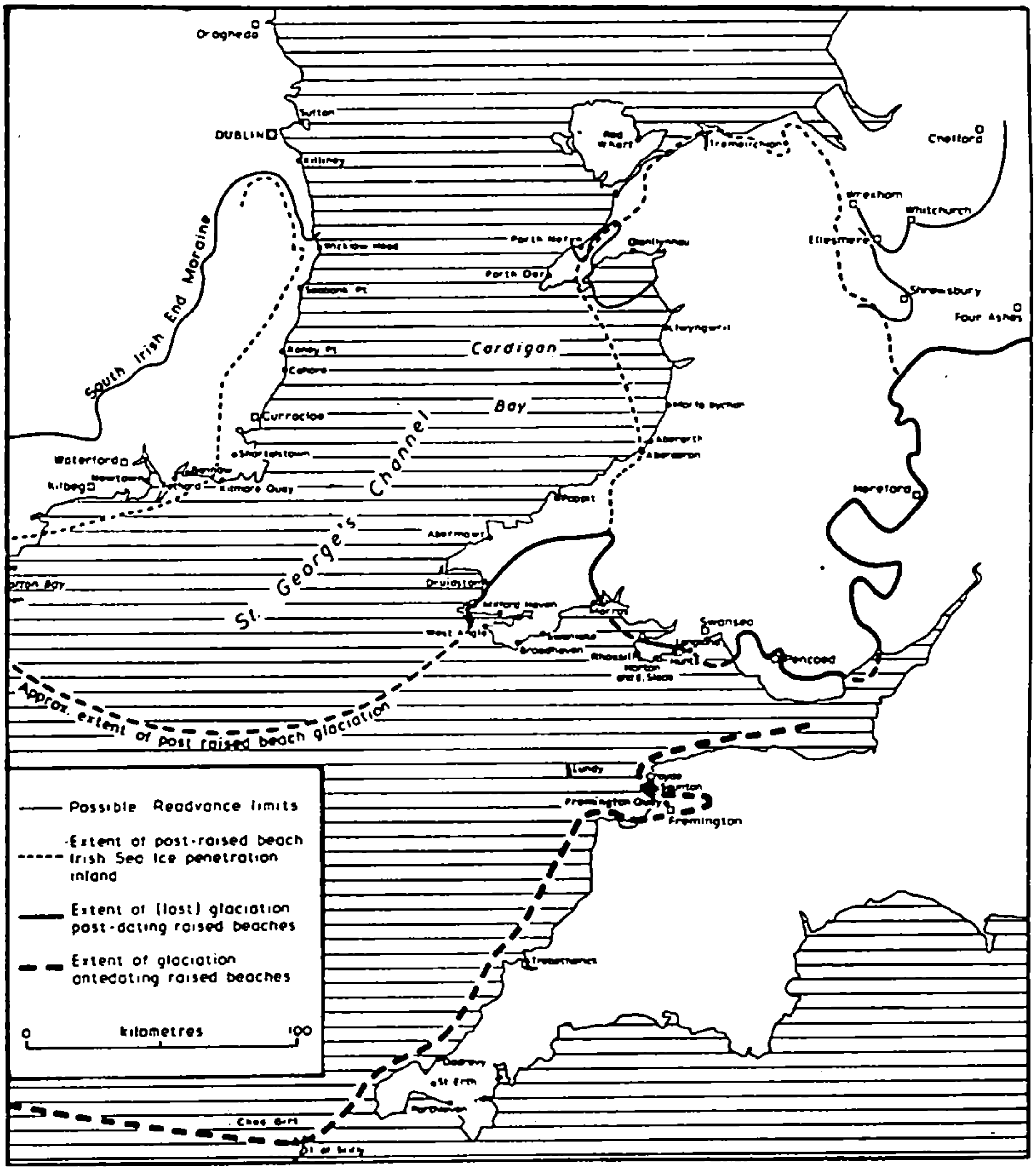


FIG 2.1 Glacial Ice Limits in the Western British Isles (from Bowen 1973)

The timing of this earlier glaciation is open to dispute and some, for example Scourse 1984, have suggested that all glacial deposits in the South West can in fact be thought of as Devensian in age. The evidence for glacial deposits in Devon, Cornwall and Somerset will be considered below.

Since the 1960s evidence for such an ice advance has been provided at a number of locations. Glacial deposits have been proposed at Barnstaple Bay (Maw 1864, Mitchell 1960, Stephens 1966, 1974a, Kidson and Wood 1974, Bowen 1977), the Isles of Scilly (Barrow 1906, Mitchell and Orme 1967, Scourse 1984, 1985a), Trebetherwick Point, North Cornwall, (Dewey 1913, Arkell 1943) and Kenn in Somerset (Gilbertson 1974). More speculatively ice is said to have penetrated by way of the Somerset Levels to southern England (Kellaway 1971) with one or more glacial advances taking place along the English Channel (Kellaway *et al.* 1975).

2.2.1 North Devon and the Isles of Scilly

There is some dispute over the evidence for and dating of an ice advance in North Devon. At Fremington, sediments have been likened to a glacial till and various glacial deposits have been described inland and at the coast. These include a red till overlying a stoneless till named the 'Fremington Clay' and glacial erratics at Croyde and Saunton. Mitchell (1960) and Stephens (1966) both considered that raised beaches are overlain by glacial deposits and Mitchell (1960) proposed that the 'Fremington Till' was of Wolstonian age and hence the underlying raised beach was attributed to the Hoxnian or an older interglacial. Others (eg. Zeuner 1959, Kidson 1971) considered that nowhere do glacial deposits overlie raised beach deposits and Kidson and Wood (1974) considered that lenses of till had been incorporated in head deposits at Croyde by solifluction processes and that they are not comparable to the Fremington Till in terms of texture or microfauna. Furthermore they stated that, at Saunton, the glacial suite is overlain by raised beach deposits. Kidson and Wood (1974) also attributed the gravels under the Fremington clay at

Brannam's clay pit to be of glacial outwash rather than raised beach origin and thus sequences could not be directly traced to the coast.

More recently, Croot (1987) examined an eleven metre exposure of the Fremington deposits, and described 7m of clay over 2m of river gravels topped by 2.5m of head. He attributed the structures in the clay to a marine or lacustrine rather than glacial origin.

Mitchell and Orme (1967) described a section in the Isles of Scilly of two raised beaches interbedded with glacial and periglacial deposits. However, it is commonly thought the sequence is more one of Devensian solifluction incorporating beach material and till overlying a raised beach (Kidson 1971). Recently Scourse (1984) has stated that the sequence includes till of Devensian age and has dated it to the Late Devensian maximum by organic deposits above and below the till. If correct, this has important consequences for the rest of the deposits in south-west England. Indeed the presence or absence of Wolstonian deposits in the Midlands and East Anglia has been debated in the last few years (Sumbler 1983, Rose 1987).

Arber (1977) described straight-tusked elephant remains from a probable interglacial deposit at Summerland Street brickworks in the terrace deposits of the Taw valley in North Devon; she considered these to be of Ipswichian age. This evidence suggests that the Taw valley was cut prior to the Devensian cold stage. The relationship of these deposits to the Fremington Till has not been identified, but because there are so few interglacial sites in the region, this site could form an important link between deposits in establishing the Quaternary chronology of the North Devon area.

2.2.2 The English Channel and South Devon

Evidence for glaciation of the area was put forward as early as 1872 by Pycroft who described erratics with occasional flat polished sides around Dawlish and by Inglis (1877) who attributed the deep closed depression on the floor of Plymouth Sound to glacial action. Inglis was later supported by Codrington (1898), Worth (1898) and Kellaway *et al.* (1975) but Ussher (1907) was not convinced of the glacial origin of 'stiff red clay with granite boulders' adhering to bedrock. Yet Kellaway *et al.* (1975) pointed out that the bedrock profile of the Tamar above Saltash is almost flat for 3.2km while below this it drops to the Hamoaze and Plymouth Sound where depths of 52-55m have been recorded. Worth (1898) remarked that the profile does not differ from Welsh valleys known to have been glaciated, and described the shape of the rock channels of other rivers in Devon (steep valley sides and flat bottoms) as being indicative of a glacial origin. According to Kellaway *et al.* (1975) there is little doubt that ice at some time flowed off Dartmoor as deeps occur where the erosive power of the ice would have been greatest. Similarly Durrance (1971) noted the negative gradient on the buried rock floor of the Teign which Clark (1970) considered to be consistent with glacial action, either ice erosion or the presence of a sub-glacial tunnel valley.

It may be that at some time in the Quaternary, ice sheets had a greater influence in the South West than is generally supposed. Deposits of such episodes may have been removed or reworked into later periglacial deposits, but the evidence so far presented is at best debatable and incomplete.

2.3 Periglacial Deposits

With most of the south-west of England and all of the Erme valley lying beyond former ice margins, the area probably experienced severe periglacial conditions during the Quaternary. The most extensive periglacial deposits consist of soliflucted material, for which de la Beche (1839) proposed the term 'head'. This overlies most of the raised beaches and wave cut platforms in Devon and Cornwall. A typical section through the Devon coast is shown in figure 2.2. Mottershead (1971) carried out an extensive study of the head on the South Devon coast. The mean particle size of 18 samples was -1.28Phi with a standard deviation of 2.21Phi showing the variable size distribution. In many places head was found to be coarsest at the bottom and much finer at

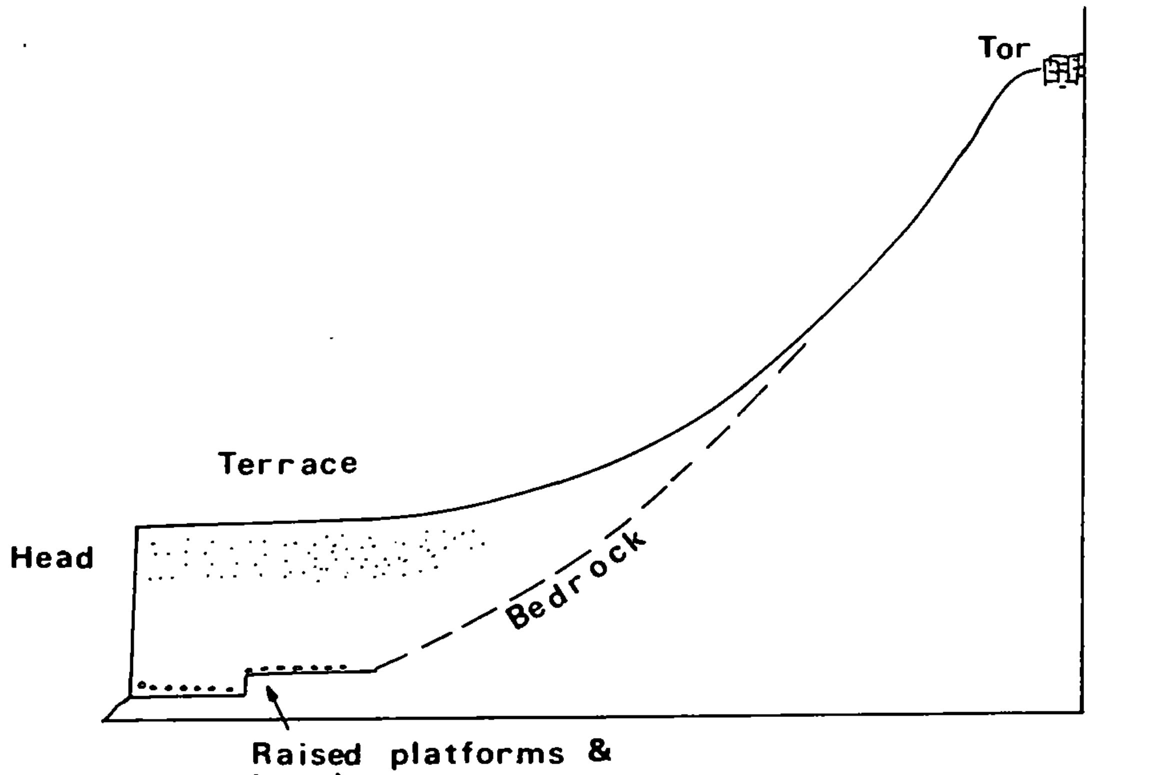


Fig 2.2

A Schematic Section through the Devon Coast the top. This is in common with many of the deposits in south-west England which has led to naming the deposits the Main head and an Upper head (Mitchell 1960, 1972, Stephens and Synge 1966). This is obviously a very simple model and there are exceptions, for example, Stephens (1966) noted coarse layers at the top of a head section in North Devon. The head sections are similar to those described in the Isles of Scilly (Mitchell and Orme 1967) and the Lizard peninsula (Combe *et al.* 1956, Roberts 1985). In some places head is reported as being interbedded with raised beach material. Some authors have ascribed the two head deposits to belong to different cold stages but without conclusive evidence of an intermediate 'warmer' stage.

These head deposits are generally considered to have formed during the latter part of the Devensian, and in the Isles of Scilly, twenty one radiocarbon dates indicate that solifluction deposits were formed between 34,000 and 21,000 years ago (Scourse 1987).

Loess sediments have been incorporated into the head that has been mapped in the Isles of Scilly (Barrow 1908), the Lizard (Combe *et al.* 1956) and in East Devon (Harrod *et al.* 1973). Roberts (1985) described the head in the Lizard area and suggested that the fine head deposits are probably thin loess sediments although in some places the loessic silt might be a weathering product derived *in situ.* Catt and Staines (1982) suggested that the Cornish loess is derived from the Irish Sea, the sea floor of which would have been dry in places and covered in glacial deposits. Wintle (1981) however, stated that loess sediments are derived from the North Sea since they show a decrease in particle size westwards across the southern part of England. Wintle (1981) has dated loess on the Lizard peninsula to 15,900 years BP.

Further evidence of periglacial conditions in south-west England is given by Guilcher (1950), Waters (1961), Palmer and Nielson (1962), Dineley (1963), Stephens (1966), Hamblin (1973, 1974), Jenkins and Vincent (1981) and Scourse (1987). There has been much debate as to whether the granite tors of the south-west were formed by periglacial processes (Palmer and Nielson

1962) or deep chemical weathering in the Tertiary (Linton 1955). Eden and Green (1971) stated that many tors have been exhumed and modified by periglacial processes and suggested the degree and depth of any chemical weathering to be far more limited than described by Linton (1955). They have at least been modified by periglacial processes and widespread clitter and solifluction deposits on the slopes and valley bottoms below tors are evidence of frost action.

Scourse (1987) identified some possible ice wedge casts from around the River Camel area in West Cornwall, which if Late Devensian, indicate the presence of permafrost further south and west in Britain then previously considered.

There are few examples of periglacial river deposits in the south-west of England. Valley gravels of the River Axe in East Devon have been described either as fluvio-glacial, derived from meltwater flowing from an ice margin north of the Chard Gap (Stephens 1970, 1974b, 1977) or largely derived from gravel patches of Tertiary age on the interfluves and head deposits of slopes (Green 1974). Shakesby and Stephens (1984) suggested the latter is more likely since the valley gravels contain no far travelled erratics and because of the lack of glacial deposits in the Somerset Levels. They were attributed to a Mid-Late Pleistocene cold environment with pollen evidence (Scourse in Shakesby and Stephens 1984) indicating some deposition within a Mid-Pleistocene interglacial or interstadial.

Thus in the south-west peninsula there is little evidence of direct glacial action where studies rather indicate a former extensive periglacial climate which most probably represents the Devensian stage. The recognition of periglacial deposits older than this depends on the finding and confirmation of dateable interglacial deposits.

2.4 Quaternary Sea Level Changes

As many previous studies in south-west England have evoked high Quaternary sea levels in the creation of planation surfaces and low Quaternary sea levels to explain the buried channels of many rivers, the reasons for the sea level changes with particular reference to the likely effects on the River Erme and its valley will be discussed. Actual evidence for higher and lower sea levels than today will be discussed in later sections.

There are a number of principal factors that govern sea level variations over time; of most importance are long term tectonic changes, glacial isostasy, hydro-isostasy, geoid changes and glacial-eustatic movements. These will all have affected the study area to varying extents.

2.4.1 Long Term Tectonic Changes in the Earth's Crust

An overall regression of the sea is said to have occurred in the Late Cenozoic due to continental collision and shortening of countries' coastlines. Bloom (1971) calculated that due to sea floor spreading (estimated at 16cm/year by Bullard (1969); in Bloom (1971)), oceans have grown by 2.6 x 10^6 km^3 over the last 100,000 years. He suggested that this expansion in ocean water has accommodated 6% of the returned meltwater from the last glaciation and therefore if correct, Holocene shorelines should be 8m lower than the interglacial shorelines of 125ka. One could extrapolate from this that early and middle Quaternary shorelines may be found at relatively higher altitudes. However, Donovan and Jones (1977) considered that the rate of increase in the capacity of the ocean basins to be too slow and Donn *et al.* (1962) concluded that sea level has been stable rather than there being a secular lowering during the Pleistocene, a conclusion supported by Bowen (1978) and Stienstra (1983).

2.4.2 Glacial Isostasy

Isostasy is the state of balance existing in the earth's crust, so depression of the crust by adding a load of sediment, water or ice in one location will be compensated for in another by a rise of the crust elsewhere. This state of approximate equilibrium is maintained by flowage of material at depth in the earth's mantle. The most important isostatic movements are those that have resulted from expansion and contraction of Quaternary ice sheets with the direct effect of the load of ice caps on land. For example, Walcott (1972) suggested that maximum loading occurs near the centre of an ice sheet, with a gradual rise in crust level towards the ice sheet margins. It has been suggested that marginal displacement of the crust involving a degree of upward bulging may be one aspect of compensation, in which case the effects of glacial loading may have extended for tens/hundreds kms beyond the ice sheet margin (Andrews 1975). In many areas, isostatic recovery is not complete in spite of total ice removal.

Therefore, even though it is generally believed that south-west England did not experience direct glacial action during the Devensian, the region may still have been affected by considerable isostatic loading as a result of the ice sheet on the north of the country. Isostatic adjustment probably produced a depression of the crust in the south of Britain because of localised tilting or crustal warping. Churchill (1965) placed the tilt line between Pembrokeshire and the Tees in accordance with the distribution of submerged forests seen only at exceptionally low spring tides. However this simple picture of tilting by which Scotland rises and the South East subsides is inadequate. Flemming (1982) used 143 sea level index points to derive a map of the UK showing rates of vertical isostatic displacement showing different movements for the South East, East Anglia, Scotland and the South West, although his study confirmed that the current data base is inadequate to produce anything other than general trends (Shennan 1983b).

2.4.3 Hydro-Isostasy

Walcott (1972) suggested that melting of the ice and release of large quantities of water into the oceans, would lead to crustal warping through the process of hydro-isostasy. Chappell (1974) estimated that following deglaciation in the last 7000 years, ocean basins were depressed by about 8mm on average and that hydrostatic upwarping could have introduced differences of up to 30% in estimates of marine transgression rates between ocean islands and continental crusts. At the same time continents rose 16m relative to the centre of the earth. It has been suggested that although total melting of Antarctic ice would raise world sea levels by about 60m, the compensatory hydrostatic sinking of ocean floors would reduce this figure to about 40m.

2.4.4 Geoid Changes

It has been generally assumed that the free ocean surface parallels that of the equator but as the earth is not spherical irregularities exist caused by gravitational variations determined by the earth's rotation and its structure and gravity. Of particular significance is that change in the distribution of ice in glacial and interglacial periods results in gravitational changes which lead to variations in the geoidal surface (Mörner 1976). Therefore the suggestion that the geoidal ocean surface can intersect different land masses simultaneously at different absolute altitudes (Tooley 1978) cannot be upheld.

Mörner (1976) suggested that the geodetic sea level (the equipotential surface of the geoid) varies by as much as 180m as the present geoid configuration is not stable, and therefore sea level changes can no longer be taken as a priori evidence of glacial volume changes. This does not affect sea level curves for individual localities, but does raise questions of applicability of such curves to areas other than for which they were derived.

2.4.5 Eustatic Sea Level Changes

World wide sea level changes resulting from fluctuations in the amount of water held in the ocean basins are termed eustatic. Of most importance are the glacio-eustatic changes caused by ice sheet variations. These oscillations are believed to be superimposed on a long term trend of falling sea level throughout the Tertiary and Quaternary, but bearing in mind Mörner's (1976) observations as stated above.

Various authors have put sea level during the last glaciation at 160m (Donn *et al.* 1962), 130m (Stride 1962) and 100m (Fairbridge 1962, Curray 1961) below present (D'Olier 1972). It has been suggested that sea level was close to the present day in the Mid-Devensian interstadial at 30000 years ago (Thom 1973), but a depth of -40 to -50m seems more realistic as temperature conditions, the vegetation cover in Europe and deep sea records do not show interglacial conditions (Goudie 1983).

Glacial eustatic changes are known in greatest detail for the last 15000 years during which the Laurentide, Fennoscandian and British ice sheets disappeared completely, with details provided by a considerable literature (eg. see Godwin *et al.* 1958, Shepard 1963, Jelgersma 1966, Kidson 1982).

Minor eustatic changes have resulted from the addition of sediments to the ocean basins, which tends to lead to a sea level rise. The addition of juvenile water from the earth's interior, variation of water level according to temperature and isostatic decantation may also effect minor sea level changes.

2.4.6 Miscellaneous Causes of Changes in Sea Level

These include orogenic activity such as caused by seismic activity, volcanism and mountain building, compression of sediments such as peat by the weight of overlying material, and growth of Pleistocene ice sheets causing sufficient gravitational attraction for sea level to rise locally relative to the land.

All these factors may have influenced the development of the Erme valley, although the recent sea level changes in the area of study are most likely due to eustatic changes of sea level during the last glacial-interglacial cycle and to a lesser extent isostatic adjustments caused by the weight of glacial ice to the north. Changes of sea level in the Early Quaternary and Tertiary may be due to a combination of the above factors.

2.5 High Quaternary Sea Levels

It is generally believed that there has been a long term trend of falling sea level throughout the Tertiary and Quaternary (Colquhoun and Johnson 1968, Mercer 1968), most probably as a result of sediment deposition and tectonic activity from continent movement (Lowe and Walker 1984). Consequently, various workers have identified a series of planation surfaces at descending levels on the hills of south-west England. Evidence for sea levels higher than today is said to be seen in planation surfaces on Dartmoor and South Devon and in raised wave cut platforms and beaches along the coastline. Others (Waters 1961, Guilcher 1950) have invoked a periglacial origin for the 'high shorelines' rather than high Tertiary or Quaternary sea levels. The evidence for these features in the Erme valley will be discussed here.

2.5.1 Planation Surfaces

Planation surfaces are shaped by either prolonged wave action or a combination of subaerial processes in which rivers, weathering and slope recession are important (Orme 1964). The type area for recognising higher stands of sea level is the Mediterranean/Morocco region against which other localities have been compared. Fairbridge (1961,1971) outlined a model where sea level descended from Early Pleistocene elevations in a series of glacio-eustatic oscillations imposed on a longer term fall. This was based primarily on the Mediterranean data and reflected the pioneer work of de Lamothe and Deperet (Hey 1971). These early twentieth century workers proposed a suite of characteristic high levels which could be related to glacial events; Sicilian (80-100m), Milazzian (55-60m), Tyrrhenian (30-35m), Monastirian (15-20m, 0-7m) and Flandrian. This work by Deperet (1918-1922) was used by many to correlate levels over wide areas. Data from Mediterranean coast shorelines and terraces of European rivers were correlated with the Alpine glaciations and this led Zeuner (1959) to recognise at least 13 shorelines from the Calabrian to the Postglacial. However, Guilcher (1969) objected to this model on the grounds that it is inapplicable to the whole world as some areas are subject to isostatic recovery whilst others are subsiding.

Fairbridge (1971) used his model to suggest that low 'glacial' sea levels of the earlier glaciations may have coincided with the position of the modern coastline and thereby emplaced exotic erratic pebbles on the British coastlines. He further suggested that wave cut rock platforms of these and other mid latitude coasts were fashioned under cold climates.

Some workers, however, consider that sea levels have not dropped during the Quaternary. Frenzel (1973) pointed out that total melting of the two main current ice caps, Greenland (2480 km^3) and Antarctica (22,100km^3) would raise world sea level by 7m and 59m respectively but since deep sea core evidence suggests that they did not melt in the Pleistocene sea level would have been only a few metres higher than today. Oxygen isotope curves also imply that at stage 5e, assigned to the Ipswichian interglacial, sea level was higher than on any other previous or subsequent occasion during the Quaternary (Shackleton and Opdyke 1973) and therefore any raised shoreline features higher than last interglacial must have been raised to their present positions by tectonic uplift (Shackleton 1975). The highest fossiliferous Middle Pleistocene intertidal deposits in the British Isles have been described by Holyoak and Preece (1983). They identified Middle Pleistocene estuarine deposits at 38-40m OD from a site at Bembridge on the Isle of Wight and did not rule out Pleistocene upwarping to account for the height of the deposits.

2.5.2 Evidence for Former High Sea Levels in South-West England

Many studies have attempted to trace Early Quaternary and Tertiary stands of sea level in the south-west of England; Green (1949), Wooldridge (1954), Waters (1960) on Dartmoor; Brunsden (1963) for the River Dart; Kidson (1962) for the River Exe and Orme (1961,1964) in the South Hams. There is no agreement on the number of shorelines present or their manner of fashioning. For example, Brunsden noted 17 different shorelines in the vicinity of the River Dart. Extensive discussion will not be entered into here, although surfaces in the study area, the 690' Calabrian Shoreline (at c.210m) and sites where there is depositional evidence will be considered.

In the River Erme area, between the Dart and the Yealm, Orme(1960) mapped the erosion surfaces. He considered that the summit plain at 1620-1520 ft (494-463m) was shaped in Early Tertiary times and later tilted south by the Alpine earth movements. The summit plain is flanked by a less extensive 1350-1300ft surface (412-396m) and outlying summits to descend to 1050ft (320m). Two unwarped subaerial surfaces of probable Late Tertiary age are preserved on the granite and metamorphic aureole rocks of Dartmoor near South Brent and Ivybridge at 930-875ft (284-267m) and 820-730ft (250-223m). Orme also supported the concept of a 690ft (210m) sea drowning the surface. In the north-east the South Hams drained eastwards to a proto-Harbourne river and the western sector drained eastwards to the Erme and Yealm rivers. Later Pleistocene still-stands were recorded at 600ft (183m), 550ft (168m), 460ft (140m), 327ft (100m), 150ft (46m) and 25ft (7.6m). Strandlines less than 690ft (210m) are considered horizontal, thus suggesting the movements in base level were eustatically controlled. Orme (1964) suggested the Erme and Yealm probably united south of Hanger Down to flow south-west to an extended Tamar estuary. Other surfaces in the South Hams noted by Orme are at 675ft (206m), 650ft (198m), 627ft (191m), 530-480ft (162-146m), 475ft (145m), 430ft (131m), 400ft (122m), 375ft (114m), 350ft (107m), 300ft (91m), 280ft (85m), 126ft (38m) and 14ft (4.3m).

The most universally recognised of these erosion surfaces is the Calabrian shoreline; it is believed to have been formed at the time of the Pliocene-Pleistocene boundary and has been correlated to the marine Crag deposits in the south-east of England at Netley Heath at an altitude of 183m (Chatwin 1927, Dines and Edmunds 1933, West 1972). It has been mapped by Wooldridge and Linton (1937) over much of the chalk at heights generally over 550ft (168m) and tends to a shoreline at 690ft (210m). It is regarded by many as Early Pleistocene age and equivalent to the 600ft (183m) platforms of Wales, Dorset and the Bath-Radstock areas (Wooldridge 1961). Kidson (1962) stated that a comparison with the Calabrian sea level of the Mediterranean, dated to the Pliocene-Pleistocene boundary was not unreasonable, hence the 690ft sea platform became known as the Calabrian shoreline.

This has been contested by Simpson (1964) who believed the sea was probably never higher than 400ft (122m) in Devon after the Tertiary Alpine Earth movements. Simpson suggested the 690' surface to be a sub-Mesozoic, probably Upper Cretaceous, surface and the 690' shoreline to be an exhumed Upper Cretaceous shoreline.

A 430ft (131m) surface was recognised in 1907 by Reid and Flett and called the 'Pliocene platform ' to which the only undoubted marine deposits have been related. If however the 690ft surface is Early Pleistocene this calls into question the age of the 430ft surface and other lower surfaces.

Kidson (1977) summed up the difficulty with planation surfaces as follows:

> "It is the paucity of supporting depositional evidence which leaves the Pleistocene chronology of the South West in such an imprecise state and makes untenable the correlations with Mediterranean stages".

2.5.3 Depositional Evidence Of Higher Sea Levels in South-West England

Deposits indicating high sea levels have been described from two sites in south-west England; at St. Erth and St. Agnes in West Cornwall.

i) St. Erth

At St. Erth in Cornwall deposits described as marine Pliocene by Reid (1890) partially conceal a degraded cliff face marking the 430ft (131m) platform. Sections show sand and clays overlain by head. The marine fauna of the clays showed strong Mediterranean affinities and had many extinct species. Reid compared the assemblage to the Lenham Beds of south-east England and suggested they were deposited in a water depth of 91m due to the dominance of deep water species. Although the deposit is found at 30m OD he suggested they were laid down by a sea cutting a platform at 131m.

They were re-examined by Mitchell (1965) who suggested they were deposited in the Cromerian interglacial and the lenses of 'boulder clay' would have been thrust into them during disturbance by glacial ice. If the marine clay is in its primary position he calculated sea level would have been at 56m. Earlier workers suggested the deposit was partly glacial. A later investigation by Mitchell (1973) of the mollusca, foraminifera, ostracoda and plants showed the deposit to be of Pliocene age and no younger than the Boytonian unit of the Coralline Crag in East Anglia. A water depth of 10m was suggested and therefore a sea level 45m above present OD.

Mitchell (1960) considered gravels at Hele near Barnstaple (56m) and in the Isles of Scilly to be equivalent to the St. Erth Beds, however, Kidson and Wood (1974) considered that they were more likely to belong to a sequence of glacial outwash deposits.

ii) St. Agnes Beacon

High level sands and clays were described by Reid and Scrivenor (1906) around St. Agnes Beacon in Cornwall at a height of 128-107m OD and were described as an old shore deposit. Atkinson (1980) described an exposure from Beacon Cottage Farm Pits and Dobban Pits of an upper sand/clay unit overlying a clay layer over a lower sand deposit resting on an iron pan. Mitchell (1965) identified microfauna of Oligocene age in a piece of lignitic clay from these deposits. If the lignite is not derived and the underlying sands are indeed of marine origin, then it is possible that the erosion platform and the overlying deposits are of Pliocene age. This would suggest a greater age than the St. Erth Beds even though there are considerable mineralogical affinities between the two sets of deposits.

Atkinson *et al.* (1975) suggested the beds are Middle-Upper Oligocene in age and the upper sands are fluvial in origin. Boulter, (in Atkinson *et al.*), by looking at the flora of the lignitic clay, suggested the deposit to be a basal remnant of a mainly fluvial deposit of Late Oligocene age. Atkinson (1980) considered a third possibility that the lignite was derived and washed into deposits of Coralline Crag age, making it comparable to the St. Erth Beds.

2.5.4 The Problems of Identifying and Mapping Erosion Surfaces

Some of the difficulties associated with the correct identification and mapping of these so called planation surfaces are considered here. One of the biggest sources of inaccuracy in mapping and correlating high level platforms is the field methodology employed. For example field mapping with an aneroid barometer (as undertaken by Orme 1960, for example) will not give precise heights above OD and thus this renders correlations between sites meaningless. Problems also exist in using the long profiles of rivers to estimate base levels since 'long profiles demonstrate the polycyclic nature of stream erosion without revealing the location of successive base levels' (Kidson 1962). Similarly use of river terrace levels are not indicative of base level changes; they are attributed more to structural variations in the Palaeozoic sediments and the granite and arise from the multiplication of knick points associated with rejuvenation to which creation of the lower surfaces are due (Brunsden *et al.* 1964).

The question must also be asked whether periglacial conditions in the Pleistocene have had more influence on present day morphology than older marine stillstands. Extensive head deposits mask low level wave cut platforms, block river valleys and smooth interfluves, as emphasized by Waters (1971). He stated:

> "the broad 'flat' topped interfluves of Bodmin and Dartmoor can no longer be interpreted as the trimmed surfaces of pre-Pleistocene planations; they are rather surfaces at the base of their zone of weathering stripped of their mantles of waste".

Guilcher (1950) supported this concept and related all minor forms of hills in Brittany and North Devon, that rise to around 300m, to Pleistocene frost action. He considered that they display snow shaped notches and altiplanation terraces as seen in periglacial environments today. These nivational landforms were described as being a few meters to 120m in width and 40-200m in length.

Scourse (1987) stated that:

> "aside from the underlying structural control almost all the major geomorphological features of the Isles of Scilly and West Cornwall owe their existing form to cold climate processes.....With the exception of the Lizard and north Penwith platforms, almost all flat surfaces are solifluction or cryoplanation terraces and not erosion surfaces as Wooldridge (1950) suggested."

Thus high Quaternary and pre-Quaternary sea levels are difficult to recognise, map and correlate between areas, and either periglacial processes were of such intensity that they contributed to the lack of depositional evidence of high sea levels as suggested by Kidson (1977) or the slopes of south-west England depict a relict periglacial landscape rather than a relict marine-formed landscape. As mentioned previously the deep sea record does not imply a falling sea level throughout the Quaternary. Without dateable deposits, no precise chronology of Early Quaternary sea level changes in south-west England can be developed.

2.5.5 Raised Beaches

Raised beaches are evidence of sea levels at or higher than modern sea level. Unlike the planation surfaces described earlier in this chapter, they are generally attributed to the later stages of the Quaternary and are easier to recognise in the field. The number of raised beaches represented on the Devon and Cornwall coasts is open to dispute. The most commonly referred to beaches occur at '65ft' (19.8m), '24ft' (7.3m) and '14ft' (4.3m) OD.

The '65ft' (19.8m) raised beach is revealed on Plymouth Hoe on a limestone shelf (Hennah 1817) and at Mousehole in Cornwall. The '24ft' (7.3m) shoreline is the most extensively mapped and is commonly known as the Patella beach due to the occurrence of *Patella vulgata* in its sediments. It runs for approximately 1000 miles along the British and French coasts (Everard *et al.* 1964) and in South Devon it is well developed between Plymouth Hoe and Hope's Nose, Torbay. Cut into this is the '14ft' (4.3m) raised wave cut platform best seen at Great Matchcombe Sands and Lannacombe Bay in the South Hams (Orme 1960).

Mitchell (1977) suggested the 24' beach is probably Late Hoxnian in age and that erratics, present in the beach sediments in the North Devon area, are from the Wolstonian cold stage. Hence Mitchell considered that ice floes deposited the erratics before the sea level fell too low. Zeuner (1959) however, dated the higher two beaches to the Ipswichian; the '65ft' (18m) beach was related to an early part of the last interglacial (Main Monastirian) and the '24ft' (7.5m) to the Late Monastirian, later on in the interglacial. The '14ft' beach was related to an early interstadial of the Devensian (Epi-Monastirian).

Two raised beaches have also been found in Cornwall (James 1968), Brittany, Normandy (Dangeard and Graindor 1956, Guilcher 1969, Mitchell 1977) the Channel Islands (Keen 1980), at Angle in west Wales,(Bowen 1973) and in the Clevedon-Brean Down area in Somerset (Gilbertson and Hawkins 1974). They have been assigned to the Hoxnian and Ipswichian by some (Mitchell 1960, 1972, Stephens 1966, 1974a) or the Ipswichian only by others (Zeuner 1959, Kidson 1971, Kidson and Wood 1974). Bowen (1971) considered that on faunal, floral, stratigraphic, geomorphic and palaeosolic grounds all the beaches are Ipswichian in age, although the wave cut platform may be older, and that all overlying deposits are Devensian in age. Miller (1979) distinguished two other beaches that may be younger than Hoxnian in age as well as an Ipswichian beach.

The situation is further complicated by recent excavations in the Gower caves of Minchin hole and Bacon Hole in South Wales where two beaches have been found. Sutcliffe and Kowalski (1976) described an Inner beach believed to relate to a warm stage not previously recognised between the Hoxnian and Ipswichian, and a Patella beach believed to be Ipswichian in age. They have been differentiated on the basis of faunal deposits, although their pollen records are similar. The Inner Beach has been dated to 210ka by Davies (1983) and the two beaches have been attributed to stages 7 and 5e of the deep sea record by Sutcliffe and Kowalski (1976). Amino acid dating of shells from the two beaches also suggest a considerable time separation (Bowen in Sutcliffe 1981). Similarly, Davies and Keen (1985) mapped two distinct raised beaches on different sides of Portland Bill in Dorset and attributed them to stage 5e (c. 125,000 BP) and stage 7 (c.210,000 BP). Like those from the Gower, they have different lithologies and fauna. Davies (1984) also dated the raised beaches at Saunton and Godrevy to stage 7, which may have implications to the age of glacial deposits in the North Devon area. Since many beaches along the southern coasts remain undated, and the stage 5e and 7 beaches occur at similar altitudes, they cannot be assigned automatically to the Ipswichian (5e) stage.

2.6 Low Quaternary Sea Levels

Evidence for lower sea levels than present in the south-west of England, can be seen in the form of drowned river valleys (termed rias where the geological structures are parallel to the coast), drowned shorelines and submerged forests.

2.6.1 Buried River Channels

Nineteenth century engineering works for railway bridges and tunnels, and more recent studies have revealed many buried rock channels. The earlier studies (Jones 1882, Codrington 1898) included the Severn, the Dart, the Tamar and the Fal and later studies examined the valleys of the Erme and Taw-Torridge (McFarlane 1955), the Exe (Durrance 1969, Clarke 1970), the Teign (Durrance 1971), the Bristol Avon (Hawkins 1962), the South Wales valleys (Anderson and Blundell 1965; Al-saadi and Brooks 1973) and the English Channel (Dingwall 1975, Dyer 1975). On the north coast of France, studies of the Somme, Meuse and Seine show similar features to the river valleys of the South West (Comment 1910; Lamothe 1965; Larsonneur 1971a,b), as do the Rivers Loire and Vilaine in southern Brittany (Horn *et al.* 1966). More recent studies of buried channels have generally been away from the South West, as in the case of the Crouch/Roach river system in Essex (Conway *et al.* 1984).

Borehole records from engineering works of the railway bridges for the Laira, Millbay and the Hamoaze in the Plymouth area (see figure 2.3) were investigated by Codrington (1898) and interpreted by Worth (1898). The rock valley of the Laira was found to have side slopes as steep as 1 in 2, a rock base at 87ft (27m) below the level of Low Water Spring Tides (LWST) and a practically level floor for 212ft (65m) at the centre of the channel. A rock bottom of 73ft (22m) below LWST was found in Millbay. The greatest depth found between Millbay and Drakes Island was 108ft (33m). A depth of 138ft (42m) has been recorded opposite Eastern King Point, 150ft (46m) in nearby Firestone Bay and a deeper place outside the entrance to the Hamoaze. The Hamoaze channel follows the western shore to opposite Drakes Island and then bends north passing by Eastern King Point, Millbay and the Hoe to the mouth of Cattewater where it turns south. Soundings of 20-23 fathoms occur along this line opposite Millbay and 14-15 fathoms opposite the Hoe. Outside this, to the breakwater, the Sound is nowhere deeper than 9 fathoms with a bottom of blue clay which Codrington considered to cover deeper channels in

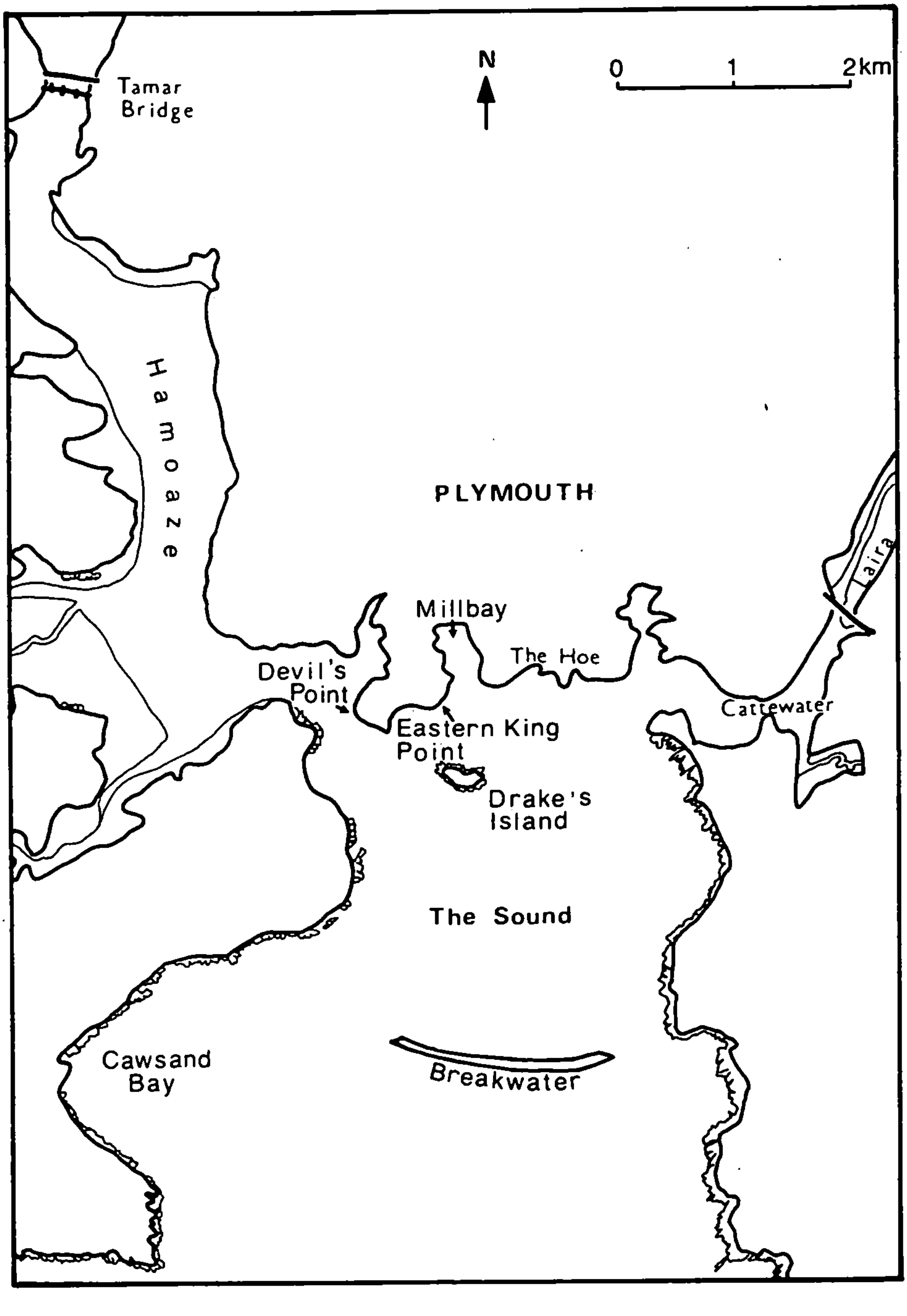


FIG 2.3 Location map of Plymouth Sound

the rock; the 10 fathom line lies 0.75 miles (1.2km) outside the Sound and it is not until 1.5 miles (2.4km) outside the breakwater before a depth as great as at the entrance to Homoaze is reached.

The greatest depth to the rock bottom of the River Dart was found to be 110ft (34m) below LWST at Maypool. This was buried beneath 85ft (26m) of mud and silt with the slope of the valley side being 1 in 3. At Kingswear Jetty, rock was proved at 71-73ft (21.6-22.3m) below LWST. The depth of the rock at Maypool is not reached again until about 2miles (3.2km) outside the mouth of the Dart (Codrington 1898).

McFarlane (1955) carried out a seismic survey of the Erme in South Devon and the Taw-Torridge in North Devon. His seismic lines for the River Erme investigation are shown in figure 2.4 and a longitudinal profile of the channel in figure 2.5. The greatest depth of the Erme was found to be 88ft (27m) near Owens Point at the mouth of the river. He suggested this represented a sea level of 150-140ft (46-43m) lower than today. Greater than one mile from shore echo sounding failed to detect any channels in the Red Sandstone. This can be compared to McFarlane's study of the Taw-Torridge where at the mouth, 100ft (30.5m) of recent sediment overlies the Lower Culm. A gradient of 1 in 600 was calculated and from this McFarlane calculated the shoreline was probably 13km (8 miles) out into Bideford Bay.

A more complex picture emerges for the Exe estuary. Using a 12 geophone shallow seismic refraction unit, Durrance (1969) produced a diagram of contours of the New Red Sandstone under Dawlish Warren (see figure 2.6). Buried channels appear to be cut into the solid rock and gravels of older periods of channelling were also detected (figure 2.7). Durrance suggested this represents two episodes of terrace formation and channelling. Older terraces occur at -25m, -31.4m and -36m and later episode terraces at -5.8m, -10.4m, -13.7m, -17.1m, -22m and -27.1m. The youngest group imply a gradient of 1 in 150. The older channels are cut to depths in excess of -52m and the younger to -30m. Where the younger channels have re-excavated the

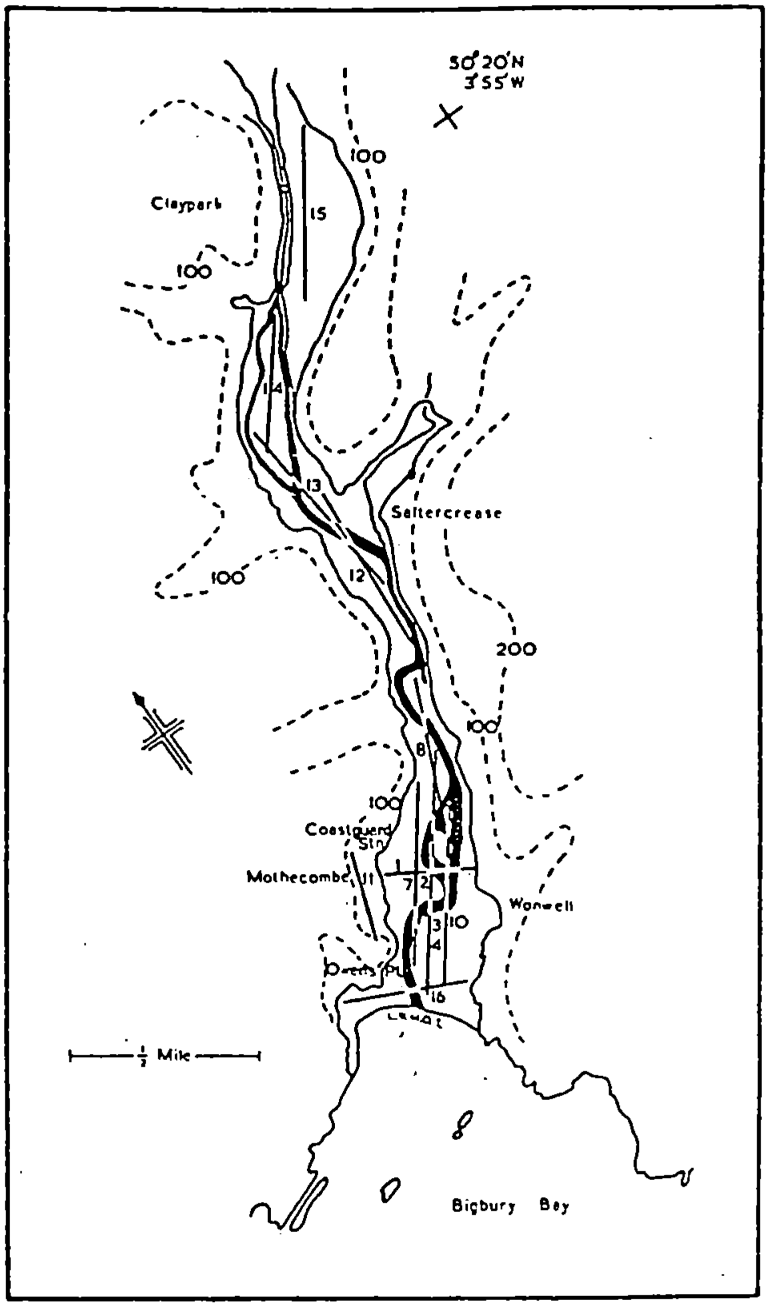


FIG 2.4 Seismic lines used by McFarlane (1955) to discover the depth to bedrock in the lower Erme valley

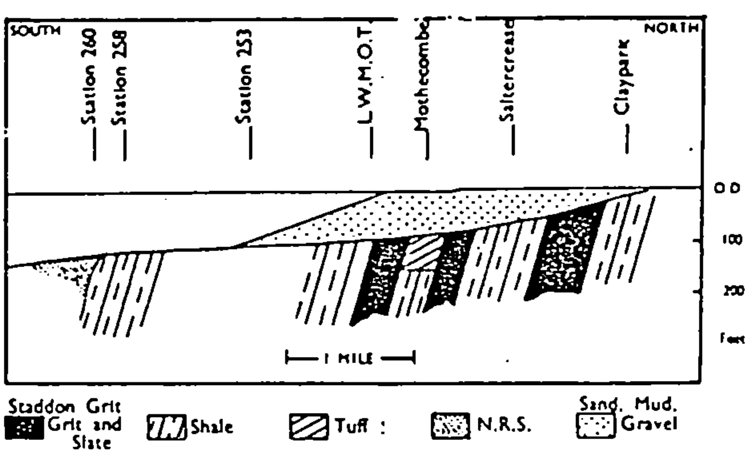


FIG 2.5 Seismic results showing the buried channel profile (from McFarlane 1955)

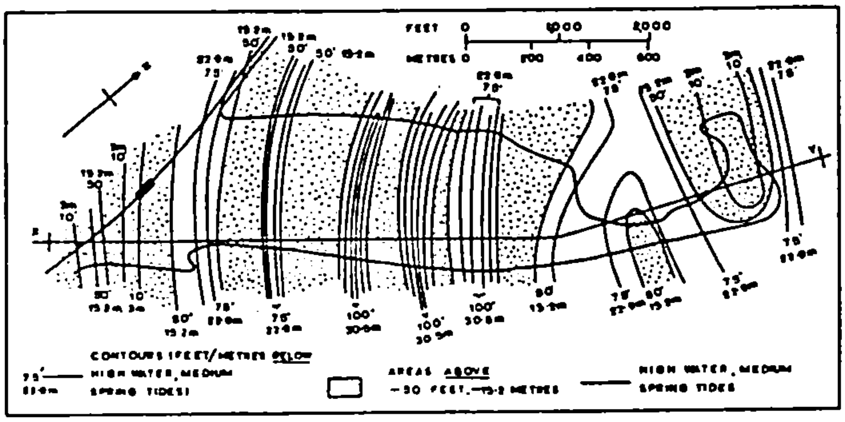


FIG 2.6 Contour map of the base of the Recent sands and clays beneath Dawlish Warren (from Durrance 1969)

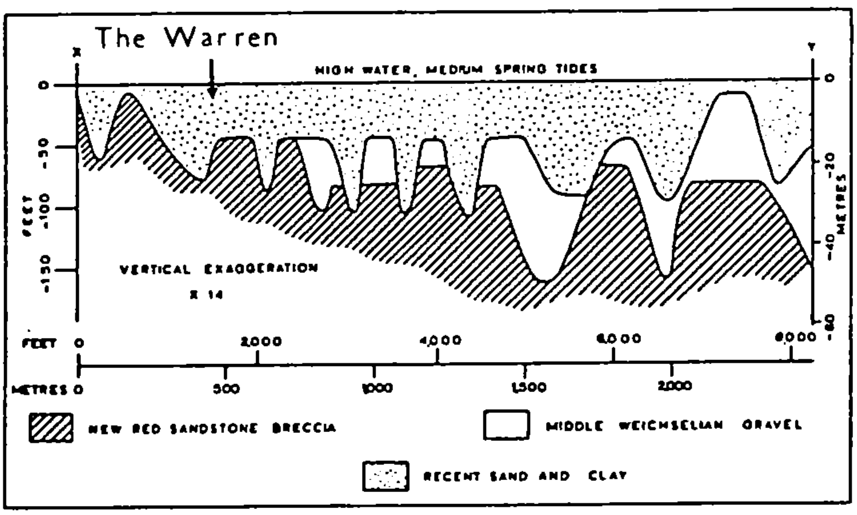


FIG 2.7 Section illustrating the relationship between the New Red Sandstone surface and the base of the Recent sands and clays beneath Dawlish Warren, drawn along the line X-Y in Figure 2.5 (from Durrance 1969)

older channels, they have always deepened even further into the New Red Sandstone. Durrance suggested this was either a result of lower sea level or regrading more easily through the gravels than the solid rock. Durrance suggested the -52m channels were cut during either a penultimate cold stage or the Early Devensian and the -30m channels to the Late Devensian. Towards the head of the estuary at Exeter, Durrance (1969) found the channel to be 10m deep, and suggested that the deeper channels at the mouth of the river are not as extensively developed as the younger channel since they do not extend as far upstream.

Thirteen shell and auger boreholes for the Newton Abbot by-pass were studied at the head of the Teign by Durrance (1971). The buried channel drops from -10.2m at the head of the estuary to -22.9m at Teignmouth, with a gradient of 1 in 470 (Durrance 1975). He compared this to Clarke's (1970) study of the Exe where bedrock was found at -22.5m. Clarke suggested that a negative gradient for a distance of 4.2km in the Teign was therefore necessary before it meets the Exe. Durrance (1975) however, considered this as unreasonable. He correlated the -10.1m and -14.3m terraces of the Teign to the -10.4m and -13.7m terraces of the Exe and agreed with Clarke that the Teign had a lesser influence in the Early Devensian than the Exe. The gradient of the Exe was found to be 1 in 540.

Similar studies have been undertaken on buried channels in northern France. Comment (1910) noticed the Seine and Somme were eroded to deep levels and suggested a Late Tertiary or possibly Miocene age with aggradation in the Quaternary. Larsonneur (1971b) and Robert (1969) thought that many of the north flowing rivers off the north coast of France have offshore infill channels which are probably tributaries of the Seine palaeovalley. North of the Cotentin peninsula, Dingwall (1975) identified a major system of buried erosion channels with 'large areas of overdeepened steep sided linear hollows - long and sinuous valley like forms' and a large variation in infill material. The buried channel of the Seine also shows two erosion levels upon which rest pebbles and gravels overlain by post-glacial deposits. The upper level -3.7--20.7m

NGF (French Ordnance Datum) was considered to be Early Weichselian and the lower level, -24m NGF at Tancarville to -50m NGF at Le Havre, related to the last part of the Weichselian (Hault *et al.* 1975).

A number of palaeovalleys have been recognised in the English Channel. Seismic profiling in the Hampshire basin (Dyer 1975) showed Southampton Water and the Solent were once part of a larger river which flowed eastwards as a continuation of the present Frome and Hampshire Avon, through the Solent into the English channel. Figure 2.8 shows the Frome-Solent system linking up with the Seine in the English Channel as described by Dingwall (1975). Dyer considered the Proto-Solent-Frome river developed with rising land in the Pleistocene, thereby supporting the concept of a Tertiary drainage pattern.

Two important infill systems meet north of Cherbourg and converge on Hurd Deep. Trending east-west is the English Channel palaeovalley and ESE-WNW the Seine palaeovalley. The greatest width at the confluence is 14km and material occurs to a depth of 200m below the sea bed. At least three periods of deposition occur in places. Dingwall (1975) suggested some of the valleys are fault guided and are remnants of two major river systems eroded in low Quaternary sea levels and swollen by glacial meltwater, which etched out the principal structural and stratigraphic weaknesses. Destombes *et al.* (1975) and Kellaway *et al.* (1975) described channels in the Fosse-Dangeard system as being characteristic of subglacial channels.

Some of the south trending valleys in South Wales also have deep buried channels. Anderson and Blundell (1965) described the Rhymney, Ely and Taff valleys in the Cardiff area as being mostly filled by estuarine clays and covered by glacial deposits. The greatest depth of the Taff is -42ft (12.8m) OD and probably -50ft (15.7m) OD near Cardiff docks. This is of similar order to the -65ft (19.8m) given by Hawkins (1962) for the maximum depth of the buried valley of the Bristol Avon, on the opposite side of the channel. Anderson and Blundell proposed the Taff, Ely and Rhymney join up to form an

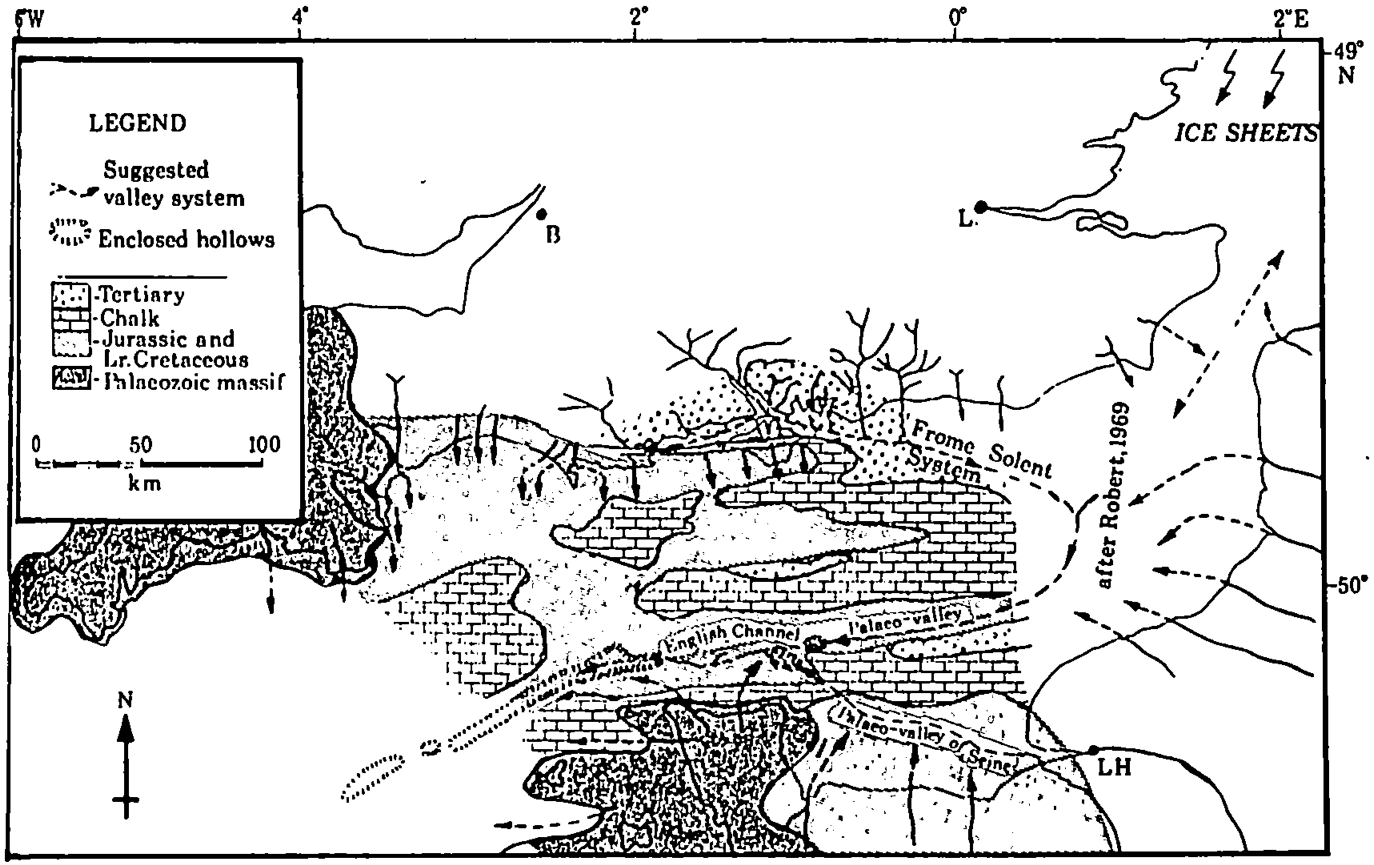


FIG 2.8 Suggested valley systems of the English Channel during the Tertiary and Quaternary (from Dingwall 1975)

extension of the Severn. Soundings show the rock floor of the former course of the Severn first reaches a depth of -100ft (30.5m), 5.5miles south of Penarth. Similarly a buried valley system in the Swansea Bay area shows a deepening to -130ft (39.6m) which Al-saadi and Brooks (1973) suggested to be overdeepened by ice along pre-glacial river courses.

Buried valleys therefore appear to be either cut by rivers as in Devon, Cornwall and Brittany or ice eroded as in the Welsh and East Anglian valleys. The English Channel palaeovalleys are linked more to the latter in their form, although their origin still remains problematical.

2.6.2 Drowned Shorelines

Evidence of lower sea levels also exists in the form of relict shorelines which have been drowned. Offshore work by Donovan and Stride (1975) has suggested the presence of three drowned coastlines around Devon and Cornwall. These have been revealed by contouring the soundings given on Admiralty Charts. A slope continues from the base of the modern cliffs from LWMST to depths of -7 to -20m. These are not recognised near sandy beaches or seaward of the major rivers presumably because of burial. A gentle slope then continues seaward to a depth of -27 to -37m; this is widest in Bigbury Bay, off Plymouth Sound and Whitsand, St. Austell and Falmouth Bays. In deeper water, three groups of cliffs are recognised (depths of base are given); upper cliff at -38 to -49m, middle cliff at -49 to -58m and the lower cliff at -58 to -69m. Seaward of this the floor is remarkably planar with gradients of 1:200 just beyond the cliffs to 1:1000 in mid channel.

Clarke (1970) considered the upper cliff to be pre-Flandrian since it is masked by deposits of Flandrian age. Donovan and Stride (1975) suggested they are not Late Quaternary as sea level data and theoretical considerations (Shackleton and Opdyke 1973) show steep rises and falls without stillstands in the -40 to -70m range, not long enough for bench and cliff formation. They consider it more likely that they were cut at times of low sea level which they also consider responsible for cutting the floor of the English Channel; probably in the last ten million years of the Miocene.

In the Start Bay area, Kelland (1975), mapped a variety of geological features which are shown in figure 2.9. A break of slope at an average depth of -42m was found, approximately parallel to the modern coastline, between 0.5 - 7km offshore. This compares to Donovan and Strides' upper cliff and to that described by Cooper (1948) near Plymouth. It is steepest in the vicinity of the River Dart where it outcrops at the sea bed to form a continuation of the present day cliffs. A number of buried channels extend between the -42m sub-contour and the present shoreline.

Wood (1974) also identified a submerged platform of marine abrasion around the South West. Palaeozoic rocks extend as a gently sloping platform, 16km seawards off the coast of south-west Wales, 18km off Ireland and for 15km off north-west Cornwall. Wood also considers the platform too wide to have been cut during a Pleistocene low sea level stage; he suggested that it is older than the St. Erth beds, considered to be of Pliocene age by some authors, and younger than the Lenham beds of Miocene age in south-east England. Similarly the river valleys crossing the shelf are thought to be older than Quaternary.

Shorelines which have been drowned have also been detected off northern France. Soundings off the south coast of Brittany revealed a shoreline -35 to -40m below the present shoreline with well preserved features (Pinot 1966). The foreshore is at -37m implying a sea level drop of at least this magnitude. In the Bay of Audierne a beach conglomerate resting on solid rock includes pebbles and shells which have been investigated by divers and radiocarbon dated to 15000 years BP (Saint-Requier and Guilcher 1969). Other similar features have been recognised at -52m (Pinot 1966, Guilcher 1967). During investigations on the French continental shelf in the English Channel and the Bay of Biscay, Verger (1970) described shorelines at -200m, -106m, -55m, -37m and -20m which he related to stages of the Flandrian transgression.

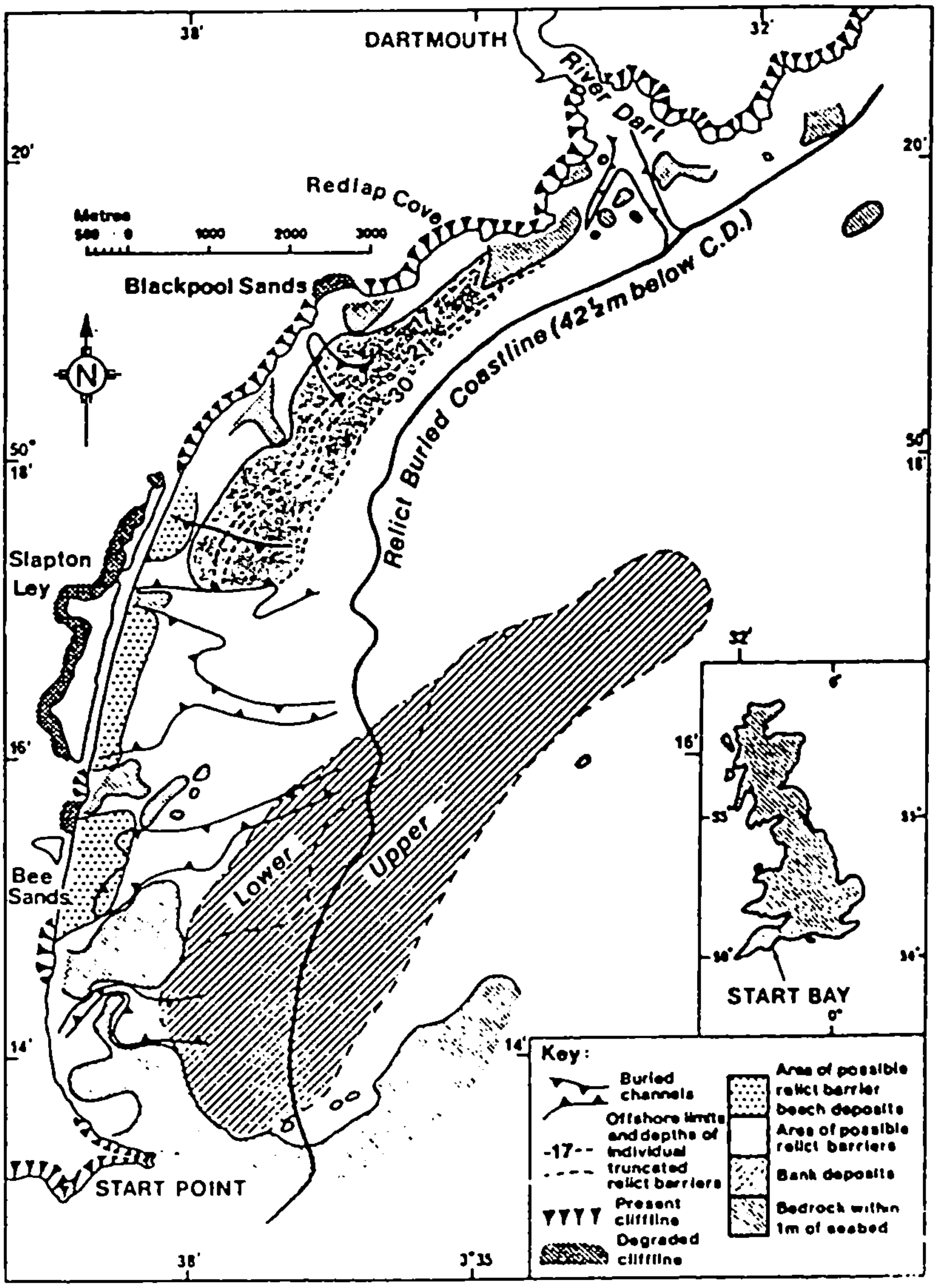


FIG 2.9 The drowned coastline and other major features in Start Bay (from Kelland 1975)

Other less significant ridges have been identified off the English coast and attributed to Late Quaternary sea levels. Stride (1962) found north-west trending ridges between the south coast of Ireland and the latitude of the Scilly Isles which he suggested were formed in the Late Pleistocene. The Flandrian rise in sea level is thought to have cut shorelines in uncompacted material and tidal current action may have cut isolated trenches along the strike of Jurassic Clays and soft sandstones off the Dorset coast. Near Weymouth trenches are 15miles (24km) long, greater than one mile (1.6km) wide and 150ft (46m) deeper than the surrounding ground (Donovan and Stride 1961).

Thus there are a number of differing views concerning the age of the drowned shorelines; these range from suggestions of Tertiary age to Late Quaternary. Sissons (1979) suggests the -42 to -43m platform around south-west England may be the same erosional phase that created the Main Lateglacial Shoreline in Scotland in the Loch Lomond Stadial. However, it is only by looking at the nature of the deposits adhering to these platforms that an indication of age will be obtained.

2.6.3 Deposits Associated With Low Sea Levels

It is expected that with oscillations in sea level, most of the sediments filling the buried channels and adjacent offshore areas would have been scoured out in the last regression of the sea and refilled by Flandrian deposits or earlier reworked Pleistocene deposits. These may consist of marine, estuarine or fluvial deposits depending on the extent and influence of these conditions at different times. It is likely that much of the sediment in the upper horizons is a result of Late Flandrian fluvial activity.

There have been few studies attempting to examine the nature of deposits filling these valleys, those that have will be discussed below. Cores obtained by early workers show layers of silts, intertidal muds and sometimes a lag of basal gravel in the buried channels. Typical sections as revealed in the nineteenth century railway borehole logs of the South Devon estuaries show silt layers overlying stiff clays with granitic boulders. At Kingswear Jetty on the River Dart, for example, 51ft (15.5m) of silt overlying 4ft (1.2m) of stiff red clay and stones was described and at the base of the rock channel of the River Tavy a stiff yellow clay with granitic boulders (Codrington 1898). Similar sections occur in the Millbay area of Plymouth. The earlier workers likened the 'stiff clay with boulders' to a glacial till but the ambiguity of the description does not lend any clues to whether it is or it is not.

Durrance (1971) described sediments from a flat bottomed channel to 10m depth at the head of the Teign estuary. Gravel deposits to 2.7m thick overlie the Devonian slate and dolerite bedrock, succeeded by 5-7m of silt and fine sand and 0.6-1.3m of clay and modern soil. A thin peat horizon was found in the silt. Similar deposits were described from the buried channel of the Exe at Exeter where a series of boreholes showed the channel to be filled with 3-4m of silty-clay overlying 4-6m gravels. The channel depth was found to be at -10m OD which Durrance (1975) considered similar to the Teign.

Clarke (1974) described a valley section from a small estuary at Porth Mear Cove, North Cornwall, of head, terrace gravel and a lacustrine clay. The estuary was impounded by a storm beach creating a lake. A peat band within the clay was radiocarbon dated to 3024±126BP.

More recently, Scourse (1985b) described a suite of intertidal sediments from the Amble valley, a tributary of the River Camel, in North Cornwall. The site is about 10 km inland from the mouth of the River Camel and has previously been called the 'Trewornan Lake Flat'. Scourse (1985b) described 4.6m of sediment retrieved using a wing auger; this showed 1m of grey silty clay over 1.5m of blue grey clay overlying 2m of grey silt. Pollen extraction from two thin bands of sedge peat at the base of the blue grey clay suggest a temperate climate of Late Flandrian age. Similar deposits of stiff grey clay with peat bands were seen in builder's excavations to 3.5m depth and in a sewer trench to 14.4m depth (Clarke in Scourse 1985b). Scourse considered this tributary of the Camel to be an anomaly as it has an extensively developed floodplain whereas the other tributaries are typical rias with steep bedrock slopes.

Clarke (1970) in an extensive study of the sediments of the west part of Great West Bay (Start Bay) showed most of the sediments to be of intertidal origin with a marine shelly fauna being introduced in the Flandrian transgression. Also in Start Bay, Hails (1975) analysed approximately 50 vibrocore and 200 bottom samples and found three discrete lithological units of barrier, bay and bank deposits. Barrier deposits consist of shingle or beach gravel including flint and quartz pebbles making up 85% of the total; bay deposits of medium fine sand, shells, clay and silt and buried channel deposits of gravel set in a coarse-fine sand matrix of mainly flint and quartz. Hails noted that the nearest barrier deposits have been reworked on several occasions and transported shoreward in the latter part of the Holocene. Denudation chronologists would suggest that the Tertiary rivers carried the flints to the sea with the erosion of the Cretaceous chalk cover, thus providing a local source of flint.

Core samples of the sea bed between Brittany and Cornwall show a few inches of gravel overlain by sand facies (Stride 1963). The western part of the English Channel has coarse gravels showing evidence of gelifraction (Boillot 1964) and the bottom of the Iroise, a body of water off west Brittany, is covered down to more than 100m with poorly worn pebbles which Guilcher considered remnant solifluction deposits. Hault *et al.* (1975) described deposits of the Seine from cores and seismic data as follows: i) Flandrian sediments representing brackish and marine formations, ii) freshwater post-glacial deposits and iii) basal gravels and pebbles on bedrock.

These studies show there has been no extensive work on the deposits filling the buried rock channels of south-west England although more is known about the sediments covering the offshore areas.

2.7 <u>The Flandrian Transgression</u>

After about 14ka, the glacial lowering of sea level was reversed with the melting of the world's ice caps. The main discussion points have centred on the rate of the sea level rise, whether the rise was smooth or oscillating, the time at which sea level reached near present levels and whether at any time, sea level was higher than today. These will be discussed here to identify the possible implications for the Erme valley.

2.7.1 The Nature of the Sea Level Rise

Evidence for the Flandrian sea level rise has been cited by many, (Fairbridge 1961, Shepard 1963, Jelgersma 1966, 1971) and in the British Isles the general rise in the last 10,000 years has been calculated at numerous points around the coastline (e.g. Kidson and Heyworth 1973, Devoy 1977a,b, Tooley 1978, 1985b, 1985c, Shennan 1980, Greensmith and Tucker 1973). Their evidence is usually on the basis of radiocarbon dating of peat layers intercalated with marine and estuarine sediments found below present sea level.

Up until 6000 years ago the rate of sea level rise is believed to have been very rapid. Some estimates of sea level for the first 2000 years of the Flandrian are given in table 2.1.

YEARS BP	DEPTH BELOW OD	AUTHOR
9600	43-47m	Fairbridge (1958) Curray (1961)
9300	40m	Jelgersma (1961)
9000	34m	Jelgersma (1961)
8600	28m	Jelgersma (1961)
8300	22m	Jelgersma (1961) Carr and Baker (1968)
8000	17m	Jelgersma (1961)

TABLE 2.1 ESTIMATES OF SEA LEVEL IN THE EARLY FLANDRIAN

Godwin *et al.* (1958) suggested a rate of sea level rise of c. 1m rise per century and Jelgersma (1966) 60cm / century for the 2000 years after 8300 BP. Speed was especially great at c. 8ka due to the final collapse of the Laurentide ice sheet. In Lancashire, Tooley (1978) suggested that a rate of perhaps 7m in 200 years was not unreasonable. Highest rates of sea level rise occur where low angle shelves exist and Evans (1979) suggested that sea transgressed 15km/ 1000 years in the Bristol Channel.

After 6000 years ago it is generally accepted that the rate was reduced. Shepard (1963) suggested that sea level has continued to rise to the present day, although the rate has diminished with time, whereas others have suggested that sea level reached near present day levels between 3-5000 years ago. For example, Godwin *et al.* (1958) suggested that sea rose steadily until c. 3600 BP and has since been fairly constant, and Jelgersma (1966) produced a model of sea level rising steadily, reaching its present level between 5 and 3.6ka BP

Fairbridge (1958), Mörner (1971) and others, consider that the Late Holocene sea level has oscillated to slightly above and below present OD. Fairbridge argued that sea level was between 1-4m higher than today at least six times between 6000BP and the Middle Ages; at 5700, 4900, 3700, 2400, 2200 and 1000 years BP. Mörner (1969) believed many curves do not show this due to lack of information although he considered the amplitude of the oscillations to be much smaller than Fairbridge's (1961) data. Mörner (1969) considered sea level has reached a maximum of 0.4m higher than today. He noted (1971) that Holocene climatic and glacier variations show correlations with eustatic transgressions and regressions and Binns (1972) found evidence of a number of shorelines related to a fall in sea level in the cold neoglacial phase c. 2500-2400 years BP.

Thus there has been some debate as to whether sea levels have been higher than today in the Holocene. Jelgersma's (1966) data have, however, failed to show this, as has Flemming's (1969) detailed archaeological research in relatively stable parts of the Mediterranean. He found that there has been no eustatic change in the last 2000 years, to within an accuracy of ±0.5m. Similarly Kidson (1981) disproved Fairbridge's claim of higher sea levels.

In Western Europe, the post glacial high sea level is called the Dunkirkian. In Brittany, at Penmarc'h at Beg an Dorchenn (Guilcher 1948), a pebble beach caps truncated sand dunes and shells associated with the pebbles have been dated to 1100BP. Kidson (1981) suggested however, that at 2-3m above present sea level, this could be an exceptional storm beach rather than representative of a higher sea level than today. Work on deformation of the earth's crust, for example by Walcott (1972), Chappell (1974), Clark et.al (1978), Clark and Bloom (1979), demonstrated that even those post glacial strandlines higher than present sea level may be explained by isostasy, especially hydro-isostasy rather than eustatic change.

The present tide gauge records show that following the current post-neoglacial (Little Ice Age) amelioration in climate, there has been a rise in sea level. Historical records for London, show high tide and surge levels related to Newlyn OD are becoming progressively higher with an increase of 1.3m, between 1791 and 1953. It is however, difficult to isolate the separate effects of subsidence, eustatic rise, embanking, changes in water temperature affecting tides by viscosity of water and changes in climatic conditions (Bowen 1972, Horner 1972) that will have contributed to sea level rise relative to the land.

In the south-west, Rossiter (1972) in an analysis of the 1916-1980 Newlyn records of secular variation (measured changes in sea level), suggested that sea level is currently rising at a rate of 2.2mm/year. This compares well with a value of 2.1mm/year for Brest on the opposite side of the channel. In relative terms, Scotland is rising relative to south-east England by at least 1.5mm/year, irrespective of eustatic variations.

Thomas (1985) suggested that around the Isles of Scilly sea level is rising at a rate of 9"/century or 2.4mm/year. He considered this figure was slightly different from Newlyn because of isostatic differential; Scilly is 60km west of Newlyn. Thomas noted that the sea level fall at Malin Head (northern tip of Ireland) is exactly the same as the rise at Scilly at 2.4mm/year (Carter 1982).

2.7.2 Important Sites in Flandrian Studies

In Britain, many sites have been studied in pursuit of a picture of the rising sea levels. In Scotland, for example, complex sequences of marine and freshwater sediments in the Firth/Clyde lowlands have been described. North-west England could be described as the type site for identifying Flandrian sea level changes; Tooley (1982) identified twelve transgressive and regressive overlaps dated from 85 radio-carbon dates. At no single site are they all represented, and they are not synonymous with the transgression sequences Lytham I-IX (Tooley 1974, 1978, Huddart *et al.* 1977) which used mixed criteria to estimate limits, and should not therefore now be used.

Greensmith and Tucker (1973) recognised six transgressive and five regressive sequences defined on the basis of retreats and advances of salt marsh fronts in deposits on the Essex coastal plain. They believe the controlling factor to be eustatic despite subsidence in the North Sea basin. Similar features exist on the Dutch coast (Jelgersma 1961), in the Fens of East Anglia (Shennan 1982a,b) and the Somerset Levels (Kidson and Heyworth 1978). Data obtained in locations near to the study area will be considered here.

i) The Somerset levels

In the Somerset Levels, rivers were still graded to lower than -30m around 4ka; infilling of valleys led to seawards movement of the shoreline (Jardine 1981). The seaward ends of these valleys are filled with blue-green clay to approximate sea level; the clay which is probably of brackish origin, was succeeded by freshwater marsh and sphagnum bogs. These were probably deposited during fluctuating sea levels in the Bronze Age between 3-2.5ka. An increase in wetness meant wooden trackways had to be constructed, which were inundated in Romano-British times at around 2ka, with further deposition of marine clay. To what extent this inundation was due to a sea level rise, occasional high tides or storm surges is a matter of controversy (Kidson 1977). Further movement due to artificial drainage and building of embankments has occurred in the last 2ka (Jardine 1981).

ii) The Bristol Channel

Kidson and Heyworth (1978) produced a sea level curve for the Bristol Channel area using pollen, macroscopic plants, forams, diatoms, peats and trees *in situ*. Before 5000 BP, sea level showed a very rapid rise whilst from 4000 BP sedimentation was in equilibrium with the rate of sea level rise, and peat formation occurred. A fluctuating coastline was suggested between 5.5-4Ka. If the curve is extrapolated, at 10,000 yrs ago, sea level appears to be -50m below mean high water level (MHW). Kidson and Heyworth suggested there may have been a pause in sea level rise ending at 10000 BP with the formation of a submerged cliff line at -45m OD. No significant difference was found between sea level change in the South West and Cardigan Bay.

iii) Devon

Hawkins (1969) dated the submerged peats off Torquay and concluded that sea level was -150ft (46m) below HWST at 10,000BP, implying that the Bristol Channel would have been largely dry. Submerged forests have been seen along the South Devon coast at Blackpool Sands (seen in 1802 and 1850), North and South Sands at Salcombe, Bigbury and Thurlestone Sands (Pengelly 1866). The latter was described by Pengelly as being 15' wide extending seawards 94', broken by 30' of sand and continuing for another 50'; oak trunks up to 18" were found in the submerged forest. Blue clay containing hazelnuts was found at the LWST line at Blackpool Sands by Pengelly (1869).

Foraminifera from Holocene sediments in Start Bay were studied by Lees (1975) and showed that c. 8000 yrs ago an area of lagoons, salt marshes and river channels occurred. Peat dated at 8108±60 yrs BP showed sea level to be 20m lower than today. Morey (1983) considered that the development of the Start Bay coastline corresponds with models suggested by Halsey (1979) and Oertel (1979) where estuaries were kept clear by scour during the Early Holocene transgression but around 3000 years BP, gravel became less mobile and accumulated as barriers allowing lagoons to develop.

Rogers (1946) described a kitchen midden site with Mesolithic flints immediately below a submerged forest at Westward Ho! in North Devon.

iv) The Isles of Scilly

Thomas (1985) calculated the position of sea level on Scilly at various times using the archaeological Minimum Occupational Layer (M.O.L.) concept. This theory involves the placing of settlements at the lowest possible levels; thus with rising seas they subsequently became drowned. Thomas concluded that separation of the land mass into distinct separate islands was completed in early historic times. This partly coincided with a linguistic change from Cornish to English and thus place-names may confirm the former coastlines. Thomas suggested that the isles attained their present form in Tudor times.

v) Northern France

On the Atlantic coast of France, several Neolithic buildings, dolmens and standing stones are more or less submerged at high tide. On the Isle of Er Lannig in southern Brittany, there is a double circle of stones, the upper is partly above and partly below HWM, the lower is completely submerged, even at low tide (Declosmadadeuc 1882, Le Rouzic 1930 in Guilcher 1969). The upper was suggested to be Neolithic and the lower was reinvestigated by Decatoire 1964-5, who found that mean sea level at 4.5-5ka was 10m less than today. These figures do not correlate with the evaluations of Jelgersma, Shepard and Curray, which assumed sea level to be -4 to -5m at 5ka and -10m at 7ka. Guilcher considered that no subsidence was likely to have occurred there and thus there is a discrepancy between the figures of the two sets of workers.

2.7.3 Inaccuracies in the Collection and Interpretation of Data

These differing views concerning the nature of the Flandrian sea level rise have arisen largely as a result of lack of understanding about the conditions in which the deposits were formed, and errors in their collection. There are a number of sources of potential errors; these include differential consolidation and compaction of peat layers (cf. Veenstra 1970), inaccurate measurements of altitude of deposits and benchmarks, the assumption that tidal range had remained constant as sea level changed in constructing sea level curves (Tooley 1985a), choice of sea level indicators (Shennan 1982a), different isostatic upwarpings or subsiding elements and errors in radiocarbon dating (Heyworth and Kidson 1982). In addition, many studies have failed to define 'present sea level' or have used datums which make comparisons with other work difficult (Kidson and Heyworth 1979).

Van der Plassche (1977) defined the indicative meaning of a coastal sample as the relationship of the local environment in which it accumulated to a contemporaneous reference tide level. In Brittany Gerrard *et al.* (1984) noted the difficulties of comparing data from one bay to the next because of the indented nature of the coastline, and warned that any model of reconstruction of past regional sea level will need to accommodate wide local variations.

Even where marine/brackish inorganic and freshwater organic deposits alternate, and a full range of biostratigraphic techniques are used there is still a problem of defining the point of sea level rise and the relation to sediment accumulation. Kidson and Heyworth (1973,1976) argued that with the decreasing rate of sea level rise in the Holocene, sea level would variously fall below or exceed the rate of sedimentation; thus alternation of marine and terrestrial sediments could be emplaced without a fall or rise in sea level. Streif (1978) favours phases of low sea level rise as the most favourable conditions for the development of intercalating peat layers.

One of the major problems in assessing whether sea levels were ever higher than today in the Holocene is because

> "most of the evidence is based on the misconception of the operation of marine processes. Evidence could well be interpreted in the context of a change in energy levels, for example, the growth of sedimentary structures or infilling of lagoons or estuaries" (Kidson 1981).

In some cases where evidence is cited for higher shorelines than today, insufficient allowance is made for the considerable height range over which the present sea operates and for changes of energy levels, for example, resulting from spit growth over time. Kidson (1981) suggested only biological evidence where fossil material with a clear relationship to former sea levels can be accepted at face value. Erosional forms and transported material cannot be used without strong supporting evidence.

With the realization that climatic and sea level changes in the last 10000 years have not been uniform over the earth, a great deal has been written about the terminology applied in the study of sediments (e.g. Jardine 1981, Shennan 1980, 1982a, 1983a, Tooley 1982, 1985a, Jennings and Smyth 1985). As the sea level literature is full of references to the terms 'transgression' and 'regression', Shennan (1980, 1982a) and Tooley (1982) suggested that these were unsuitable as formal chronostratigraphic terms and should only be used as process and lithostratigraphic descriptions. The term 'contact' was introduced where there is a change from minerogenic to biogenic material, or vice versa, within a single borehole, and 'overlap' where a change can be traced laterally between one or more boreholes. Hence points of changing sediment types in a borehole are described as 'transgressive contact', 'transgressive overlap', 'regressive contact' and 'regressive overlap'.

Thus there has been much debate over the nature of Flandrian sea level changes, largely because of the difficulties in measuring and interpreting evidence for sea level changes and the difficulty in applying sea level curves for sites other than for which they were derived. It is now apparent that the concept of global sea level changes can no longer be supported. This is shown by the project IGCP 61 (1975-82) which aimed to establish a graph of trend of mean sea level in the past 15000 years. Conclusions from this project suggested that local conditions were of great importance and thus IGCP 200 (1983-87) was set up to identify and quantify the processes of sea level change by considering local tectonic, climatic, tidal and oceanographical fluctuations. (Tooley 1985a). This was expressed by Pirazzoli (1985) who gives examples of sea level curves for different zones of the sea surface. Evidence arising from the project IGCP 200 indicates that sea levels in the northern hemisphere reached near present levels in the past few thousand years, whilst in the southern hemisphere by around 6000 years BP. Overall the rise occurred in phases rather than a smooth or exponential rise (Devoy 1986).

2.8 Fluvial Activity during the Late Flandrian

Many of the upper units filling the buried valleys in Devon are undoubtedly fluvial in origin, and although there have been limited studies of the more estuarine deposits (for example Scourse 1985b, Ranwell 1974, Richards 1979) there is little or no investigation of the fluvial sediments. Some researchers have considered the geomorphological aspects of the rivers instead (Kidson 1962, Brunsden 1963). In many situations one would expect to find sediments of both fluvial and estuarine origin.

In Devon, the few studies of mention are the works of Green (1949) on the River Dart and Kidson (1962) on the Exe who identified major stages in valley development along these rivers. They dated these stages by looking at their long profiles which were eroded to progressively lower sea levels. Cant (1973) suggested a considerable time would elapse before the effects of such base level changes are transmitted to the upper reaches, and in studying the upper Exe basin, he considered the actual changes to valley morphology would be slight.

Hooke (1977) examined river channel pattern changes in Devon by looking at old maps such as the Tithe maps and OS county series. If lateral movement was occurring then questions could be asked about changes in discharge, sediment load etc. She found that in East Devon, most of the streams had altered their course but in West Devon only on short isolated reaches. She attributed this difference to the fact that streams on the resistant rocks of Dartmoor are relatively stable, except where erosion of superficial material has occurred. In East Devon, it seems that the rivers are becoming more sinuous, although it is difficult to assess how much is due to agricultural practice, field drainage and urban activity.

Human activity on Dartmoor may have contributed to the fluvial sediments. It is well documented that forest clearance first began in the Neolithic and in other parts of Britain, recent studies of floodplain sediments suggest they are often associated with human modification of catchment areas. Some recent examples are provided in table 2.2, where the pattern of floodplain sedimentation has been altered by forest clearance, change of agricultural techniques or mining.

AUTHOR		SITE	AGE
Limbrey	1978 1983	Lowland Britain	Neolithic
Shotton	1978	Severn-Avon	Late Bronze Age, after 2.7ka
Robinson	1978	Upper Thames	Iron and Roman Age
Hazledon & Jarvis	1979	Windrush Valley Oxfordshire	After 2.6ka
Brown & Barber	1985	Ripple Brook	Late Bronze Age & Early Iron Age
Burrin	1985	R.Ouse, Weald	Iron Age, Roman Age and 15th century mining
Macklin et al.	1985	Lox Yeo Valley	17th-19th century mining
Saunders et al.	1989	Ilston River, Gower	Post Medieval coal mining

TABLE 2.2 EXAMPLES OF HUMAN INFLUENCES ON FLUVIAL PROCESSES

Some discussion has also centred around the incorporation of loess into floodplain units. Catt (1978) suggested a former more extensive cover of loess sediments over southern England has been removed by natural erosional processes resulting from a wetter climate and erosion induced by agriculture. The thickness of loess covering western Dartmoor is relatively thin in comparison to those deposits recognised in the south-east of England, however some loess may have been incorporated into the valley sediments of the rivers draining the moor.

The extent to which these aspects of floodplain alteration have influenced the Erme valley will be considered in detail in this study.

2.9 Conclusions

This chapter has considered some of the aspects affecting development of river valleys in Devon and south-west England. Quaternary climatic fluctuations have produced oscillations in sea level. This has affected rivers in that they graded to sea levels higher or lower than today and is evidenced in the identification of buried rock channels at depths of up to c. -50m below MHWST. As south-west England is believed to have escaped any significant glaciation during the last cold stage of the Pleistocene (the Devensian) one can expect to find a mixed suite of deposits filling these channels. Sediments may originate from periglacial processes, the postglacial rise in sea level and fluvial activity. Solifluction deposits flank much of the landscape; they are best seen in coastal exposures and have been described as incorporating loess in many areas. In lowland England, recent work has suggested that many floodplain deposits have formed as a result of anthropogenic modification of catchments.

Previous studies have not attempted to investigate in detail the sedimentological sequences filling these channels. The exception was the exploration during early nineteenth century engineering works that extracted sediment from great depths within the channels. By considering deposits from the buried channel of the Erme, it is hoped to provide more evidence on the nature and origin of these channels and establish an initial model for development of rivers and their valleys in south-west England during the Quaternary.

CHAPTER 3 THE STUDY AREA

3.1 Introduction - The River Erme Valley

In this chapter the Erme catchment area will be described in terms of the geology, geomorphology, vegetation, soils, climate and current river discharge. The River Erme has its source high on Dartmoor, close to the source of its neighbouring rivers, the Yealm and the Avon. Like these, it is drowned in its lower reaches and as described in chapter 2 has a buried channel.

The River Erme drains southern Dartmoor. The upper course is characterised by impeded drainage and associated upland bog, followed downstream by a meandering valley tract and then through salt marsh to tidal flats at the coast. The river is 24km long and the catchment covers an area of 105 square km making it one of the smaller rivers of Devon. It is shown in relation to the other rivers in Devon in figure 3.1 and a general location map is provided in figure 3.2. The catchment area, drainage and height of the river above sea level are shown in figure 3.3.

The river begins on the high moor (442m OD) at Erme Head and descends over 13km and through two gorges to Ivybridge (at an altitude of 76m OD). The first gorge occurs 6km north of Ivybridge near Harford Moor at Higher Piles. This shelters the ancient woodland of Piles Copse (c.300m OD), believed to be a remnant of the forest which once covered Dartmoor. The second gorge ends at Ivybridge. The Erme continues over a 6km stretch through Ermington to Sequer's Bridge (at 23m OD). Ludbrook, a significant tributary joins the river at Ermington and just below Sequer's Bridge the river is tidal. The river continues through a floodplain used for grazing and an area of reclaimed marsh; these often become flooded during high spring tides. At the salt marsh stretch another tributary, Ayleston Brook, enters the estuary before it turns to tidal mud and sand flats at Mothecombe.

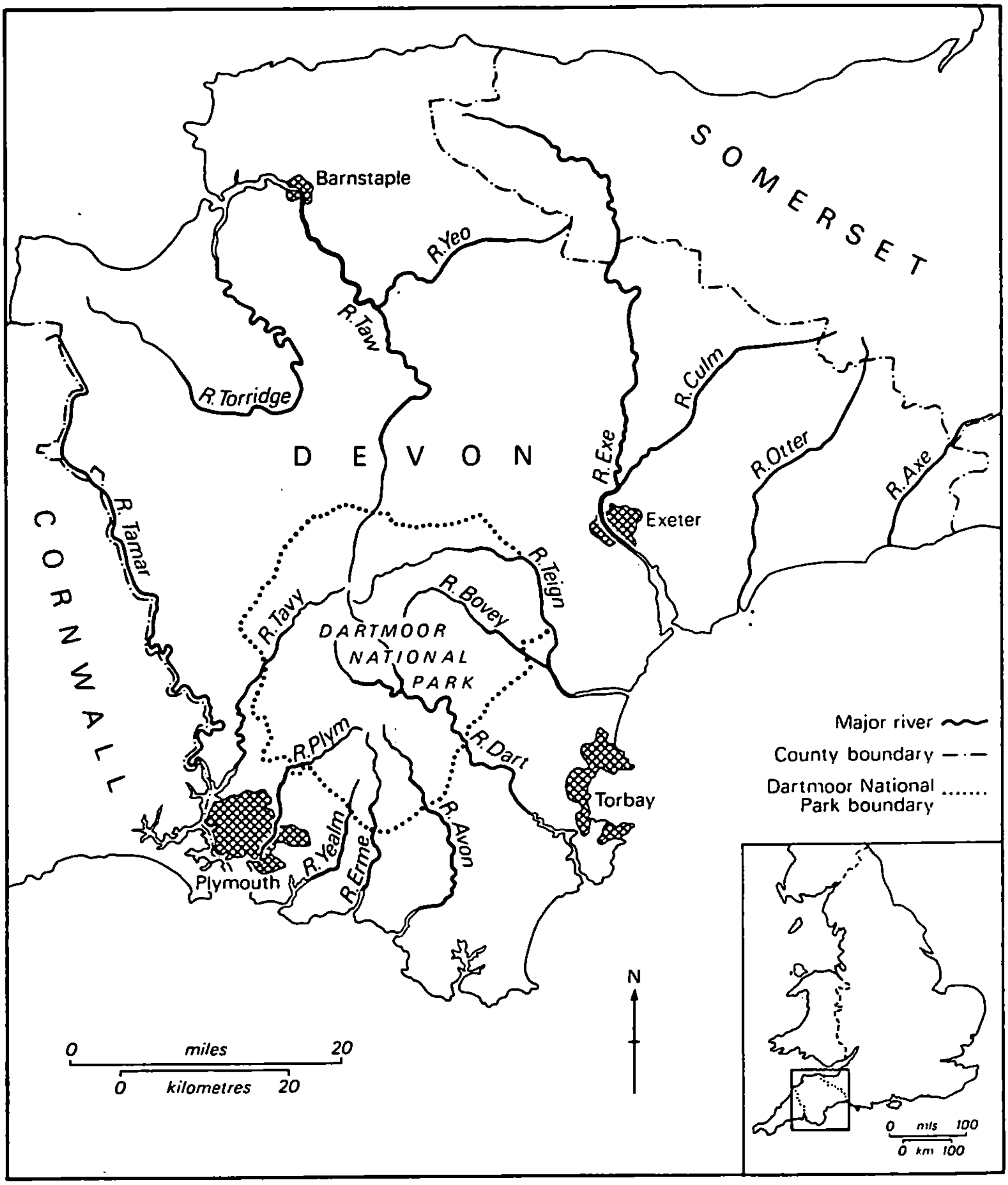


Fig 3.1 The Rivers of Devon

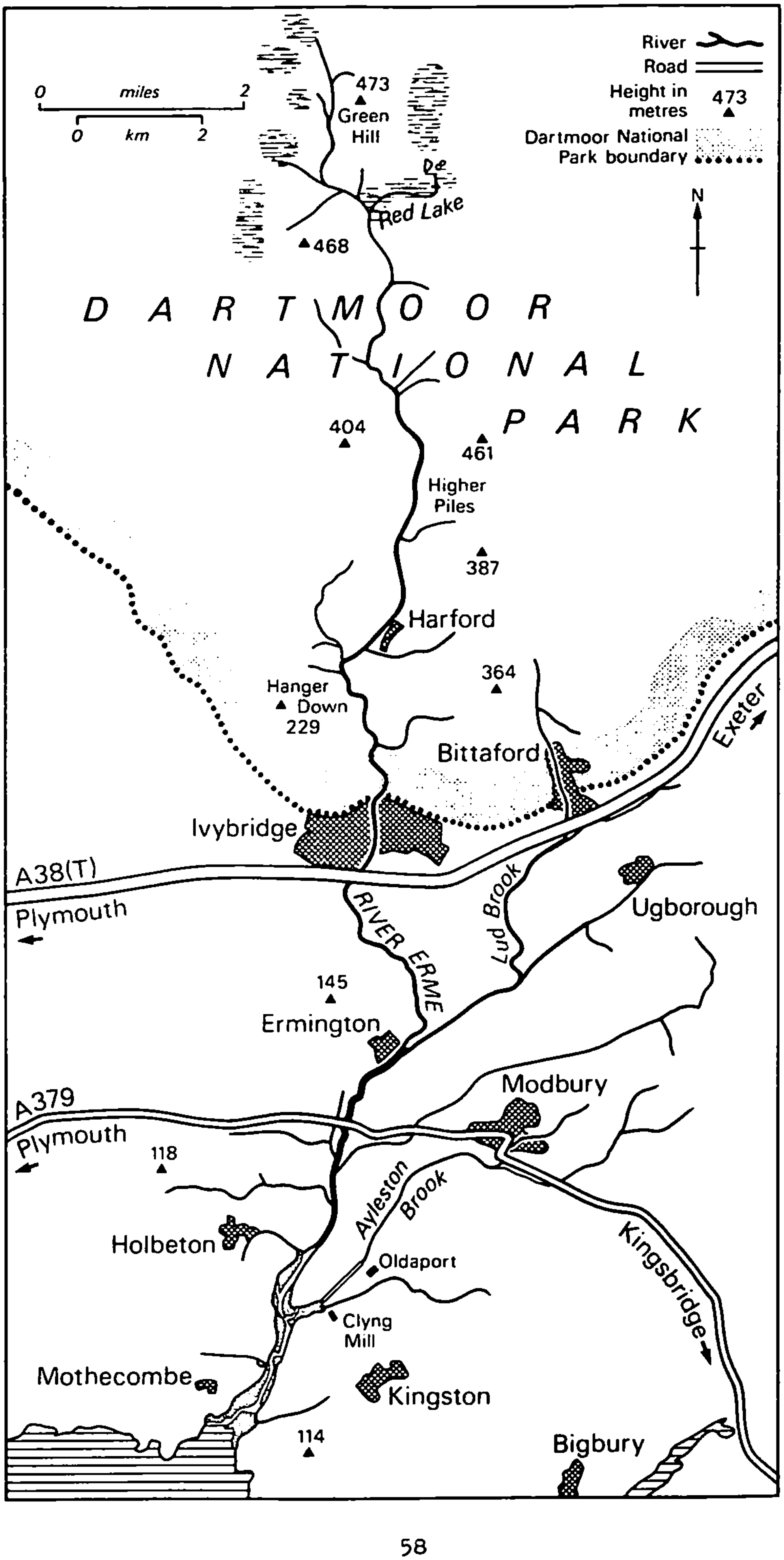


Fig 3.2 General location map

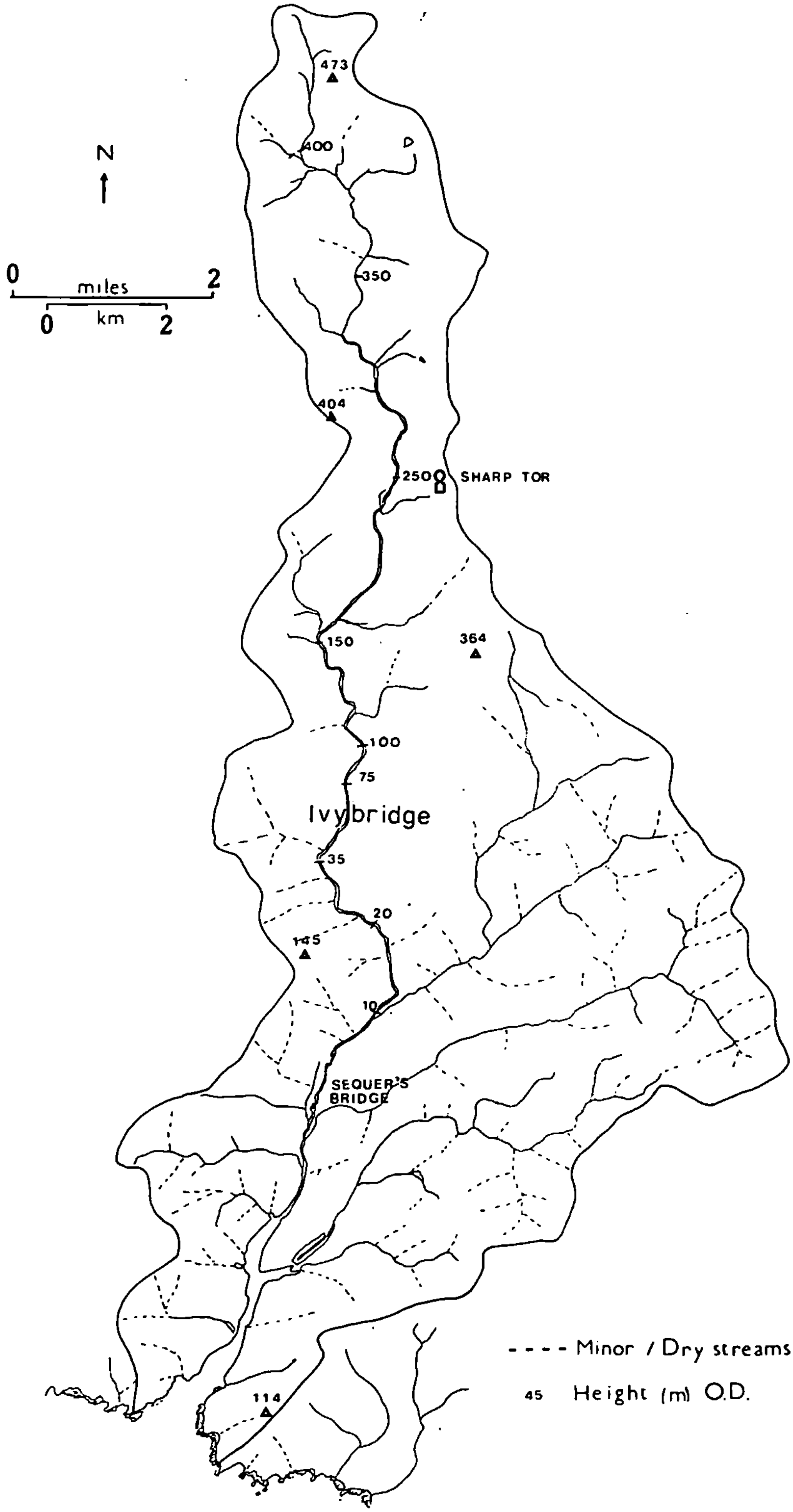


Fig 3.3 The Catchment of the Erme

3.2 Solid Geology

The solid geology of the valley is relatively simple with the Erme flowing off the granite at and above Ivybridge, over the metamorphic aureole and then over progressively older rocks of Devonian age (Staddon Grits, Meadfoot Group, Dartmouth Slates) to the sea. A geological map is shown in figure 3.4. The succession of different geological types along the course of the Erme can be considered as a number of marker horizons. The changing facies of the slates and the igneous intrusions of volcanic tuffs and diabase along the Erme valley are shown in table 3.1.

The granite around Ivybridge is a coarse blue crystalline granite incorporating minerals from the surrounding lithologies. Carboniferous shales and limestones which occur just north-east of Ivybridge and at south Brent between the granite and Devonian beds, were metamorphosed to form calc-flinta. Calc-flinta was formed when limestone was replaced by lime silicates, producing hard, fine grained rocks. Felsite was quarried at the Rutt granite quarry half a mile north of Filham (just south of Ivybridge).

The Dartmouth Slates are of Lower Devonian age and form the base of the succession. They are composed of river, lake and delta deposits and include coarse conglomerates, coarse and fine sands, shales and quartz veins (Perkins 1974). They are dominantly argillaceous and vary in colour from purple, green to grey. Dolerite intrusions break up the Lower Devonian outcrops which are seen in the lane between Oldaport and Kingston. Near Oldaport pink felsite and white quartz are seen at Torr Rock. Volcanic tuffs mark the beginning of vulcanicity which continued through the Devonian into Carboniferous times. The Dartmouth Slates are overlain conformably by the Meadfoot Beds, a succession of finely alternating siltstones and sandstones with rare but persistent limestones of marine origin. Volcanic activity is seen in the form of coarse agglomerates and tuffs and form a ridge south of the Ermington-Avonwick road, where they are known locally as dunstones and make valuable farm land (Perkins 1974). The Staddon Grits appear to follow in

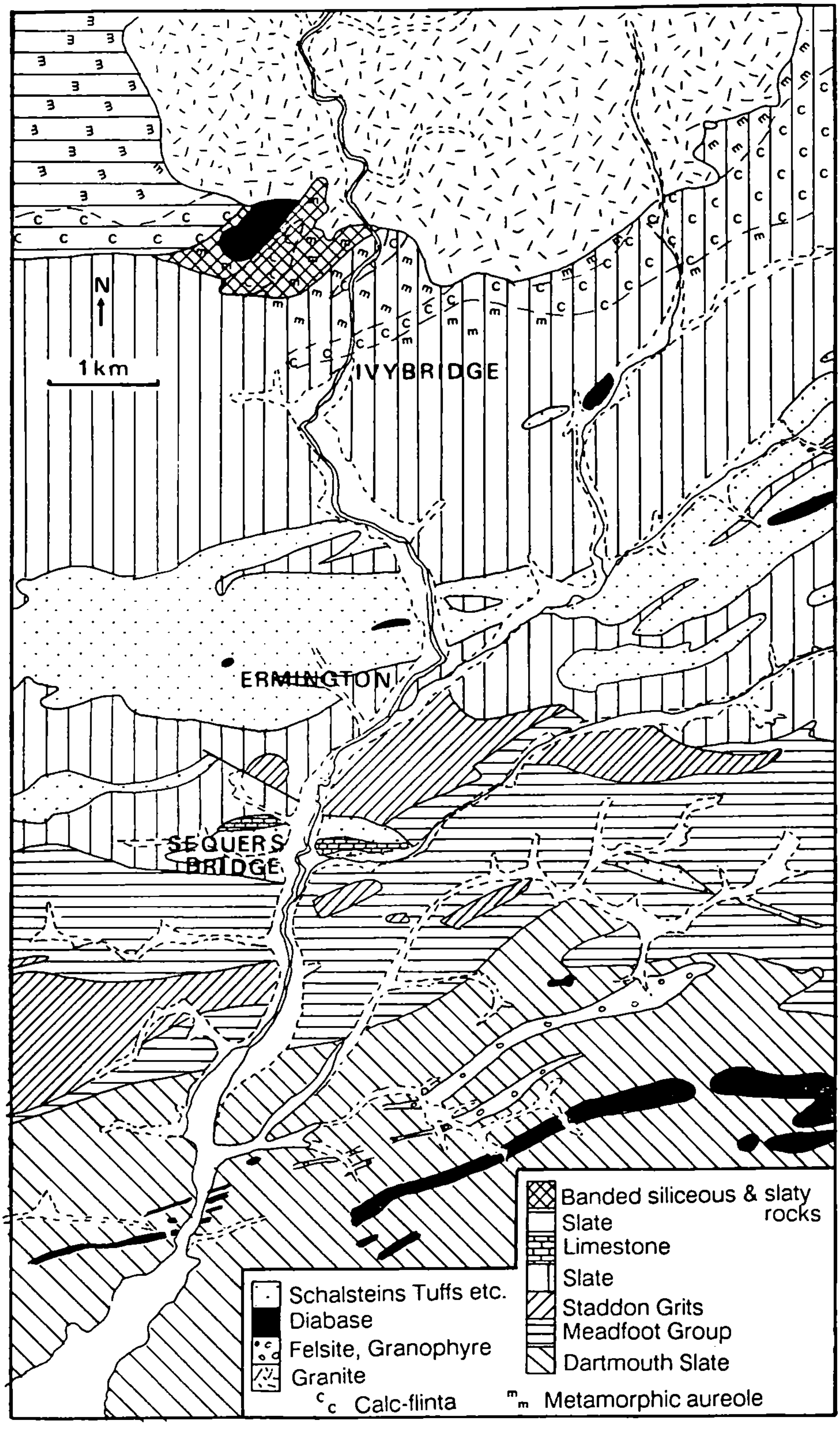


Figure 3.4 Geological outcrops in the Erme valley

LOCATION	GEOLOGICAL OUTCROP	AGE
Dartmoor	Granite	IGNEOUS
Ivybridge and the gorge	Metamorphic aureole and Calc-flinta	METAMORPHIC
	Banded siliceous and slaty rocks	CULM MEASURES CARBONIFEROUS
South of Ivybridge	Slate	UPPER DEVONIAN
North of Ermington	Schalsteins Tuffs (Igneous)	IGNEOUS
Ermington	Slate	MIDDLE
Sequers Bridge	Limestone	DEVONIAN
	Schalsteins Tuffs	IGNEOUS
South of Ermington	Staddon Grits (grits and slates)	
Sequers Bridge - Efford House	Meadfoot Group (slates with grit)	LOWER
Holbeton	Staddon Grits	DEVONIAN
Efford House - Mothecombe	Dartmouth Slates	
Torr Down and Pamflete	Diabase	IGNEOUS

TABLE 3.1 CHANGING GEOLOGY ALONG THE COURSE OF THE ERME

normal succession above the Meadfoot Beds but are probably in part equivalent age. They consist of sandstones, intraformational conglomerates and thin limestones. In Middle Devonian times, thick limestones accumulated around Plymouth, Torquay and Chudleigh. The nearest outcrops to the Erme occur in a small area at Sequer's Bridge and can be seen with volcanic tuffs in a cutting on the main Plymouth-Kingsbridge road. They are seen as pink limestones at Eastern Torrs quarry and at Yealmpton where they form the Kitley Caves.

It is anticipated that the sediments filling the buried channel of the Erme will reflect the area's bedrock since, as discussed in Chapter 2, South Devon is believed to be beyond former glacial limits.

3.3 Geomorphological Relationships

It is generally believed that South Devon escaped glaciation during the Quaternary but experienced severe periglacial activity. In this study area there is no evidence that the southern Dartmoor area has been glaciated or that the Erme has an over deepened valley cut by glacial ice. Worth (1898), however, considered that many of the river valleys are indicative of glacial action, including the Erme. He considered the cross valley profile of the Erme at Ermington and likened the steep sides to a glacial valley modified by fluvial processes. The steep sides and flat valley floors of other rock channels in the region, as detailed by Codrington (1898) from engineering works, convinced Worth(1898) that the area has been extensively glaciated. These views, however, are not generally supported. Cross sections across the Erme valley at Ivybridge, Ermington and towards Mothecombe are shown in figure 3.5. The vertical scales have been exaggerated to show the depth of the channel and general relief, but they do not indicate a glacial origin for the channel. A maximum depth for the Erme was found at Owen's Point at the mouth of the river, at -27m OD (McFarlane (1955) and this is entirely in keeping with a low Quaternary sea level.

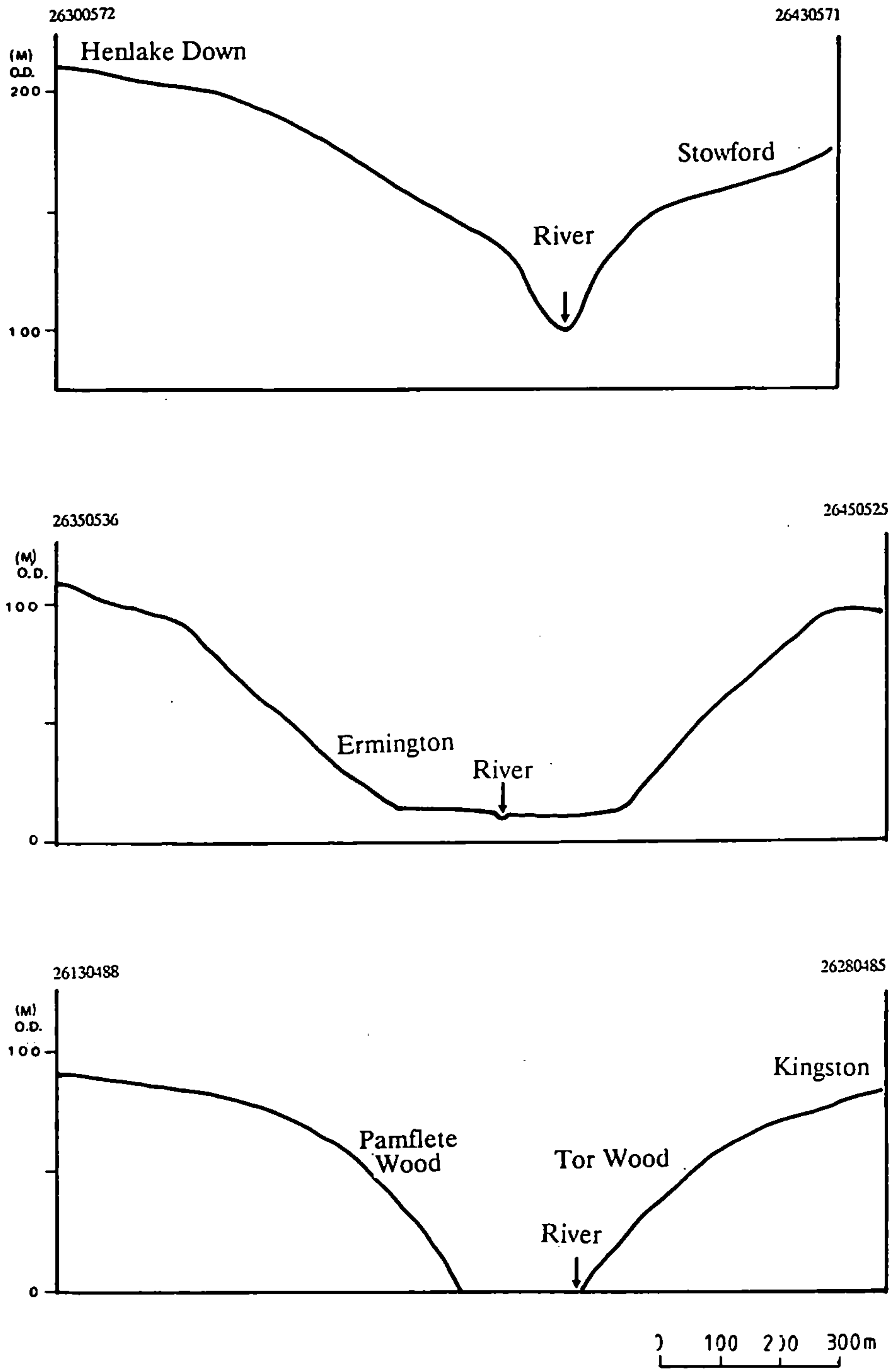


Figure 3.5 Cross sections across the River Erme valley

The hills and interfluves of the area are typical of South Devon in that they have rounded summits, strongly convex hillslopes, steep slopes and limited concave elements. The steepest slopes occur on Dartmoor at Ivybridge and near Piles Copse where deep gorges have been cut into the granite. In the more estuarine reaches, the slopes are steeply wooded. Orme explained the absence of wide floodplains by rivers attempting to grade to lower base levels thus involving considerable down cutting and little time for valley widening and also to the presence of resistant rocks. Brunsden (1968) compared the steep wooded rivers draining Dartmoor with the Rivers Exe and Teign which are wider and shallower since they have been cut into permo-triassic rocks.

As Orme (1964) described, the major river valleys in the South Hams generally disregard the structure and cut across the dominant grain of relief, but their tributaries are controlled by the east-west trending geological structures. This is partly seen in the Erme valley, for example, part of Lud Brook, that begins near Ugborough, flows along the boundary of the Middle Devonian slates and the schalsteins and tuffs. Between Ermington and Sequer's Bridge the main channel is controlled by the boundary between the Middle Devonian slates and Lower Devonian Staddon Grits. The longest tributaries have developed on the eastern side of the main channel, these are Lud Brook, Sheepham Brook and Ayleston Brook. Other tributaries are less than 3km in length.

The multiple suites of planation surfaces mapped by Orme in the area were not investigated during the field study. However, of mention is the 730-820 foot (225-250m) surface between Lee Moor and Ivybridge believed to be a Late Tertiary surface and the 690-700 foot (c. 215m) surface at Ivybridge. Orme believed that the Erme and the Yealm probably united south of Hanger Down to flow south-west to an extended Tamar estuary as there is an anomalous bend in the Erme's course south of Ivybridge. Gilbertson and Sims (1974) however likened this feature more to diversion of the Erme along the western margin of an alluvial cone spreading from the Ivybridge gorge, forming river cliffs (bluffs) at Westover Wood and Filham Moor.

Terrace deposits appear to be present around Ermington and Ivybridge but the lack of exposures in the area makes detailed study difficult. However during construction of the A38 cuttings revealed large (up to 2m diameter) boulders of granite, slate and calc-flinta in a sandy matrix spreading out from the foot of the gorge at Ivybridge as described by Gilbertson and Sims (1974). This led Gilbertson and Sims (1974) to suggest the presence of an alluvial fan formed by periglacial processes. Figures 3.6-3.9 show the fan and sections through it, revealing head and loam deposits overlying fluvial sands and boulder beds. In the Filham Moor area south of Ivybridge, the oldest deposits are jumbled boulders and gritty sands which pass laterally into imbricate boulder beds (figure 3.7a). These are overlain by sandy loams and platy head, and channels cut into the platy sandy loams are infilled with coarse sand, resting on the boulder units (figure 3.7b).

The jumbled boulder deposits of granite, slate and calc-flinta appear to fan out of from the Erme gorge. This led Gilbertson and Sims to suggest deposition under a periglacial environment maybe as earth flows. The imbricate boulder beds however showed evidence of fluvial reworking (figure 3.9), implying powerful river conditions and the authors suggested that aggradation of the alluvial fan led to diversion of the Erme along the western margin which may have caused the river to form the large cliff feature at Westover Wood which has a face 50m high and over 1km long.

Similar massive granitic boulder deposits were described in the bottom of the gorge of the River Teign between Sandy Park and Clifford Bridge by Somervail (1901a,b).

Further downstream, at Ivybridge and Ermington, there is evidence of usage of granite beyond the moorland border in housing and field walls. The blocks are water worn and appear to have been obtained from the river bed rather than transported from the moor (Perkins 1972). These blocks may have also been obtained from terrace deposits found when building the village of Ermington

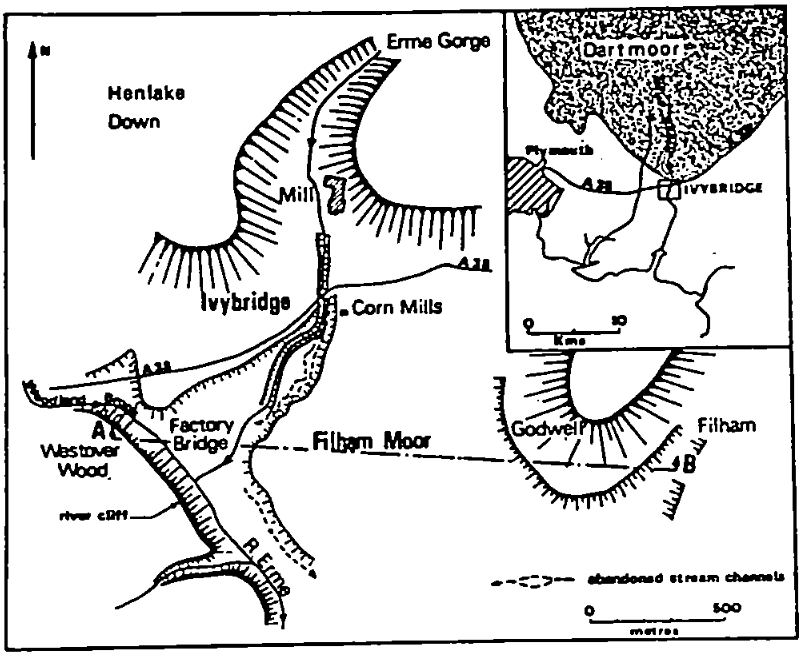


FIG 3.6 Location of features in the Ivybridge Area (from Gilbertson and Sims 1974)

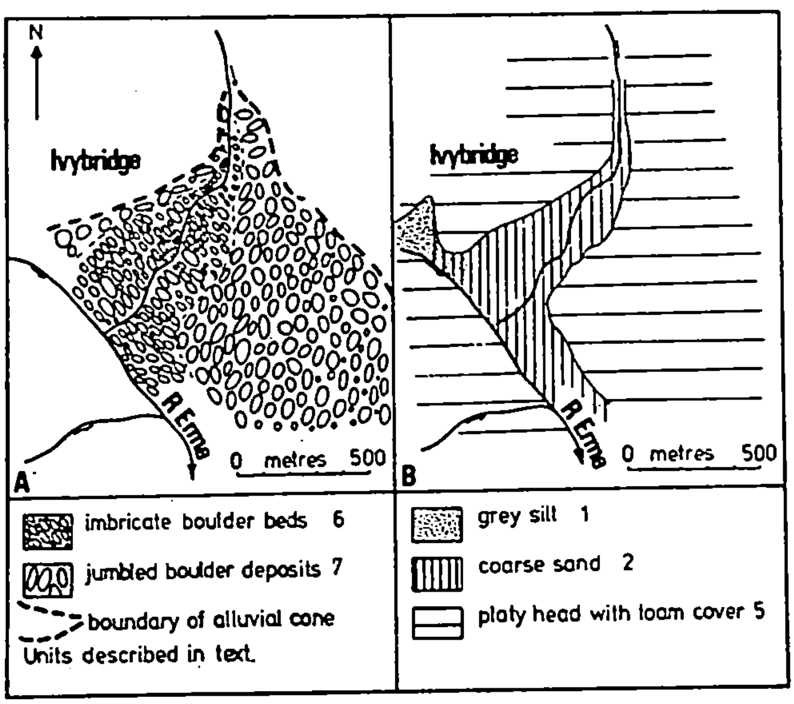


FIG 3.7 Pleistocene deposits around Ivybridge: A Alluvial cone; B The distribution of heads and Flandrian fluvial deposits (from Gilbertson and Sims 1974)

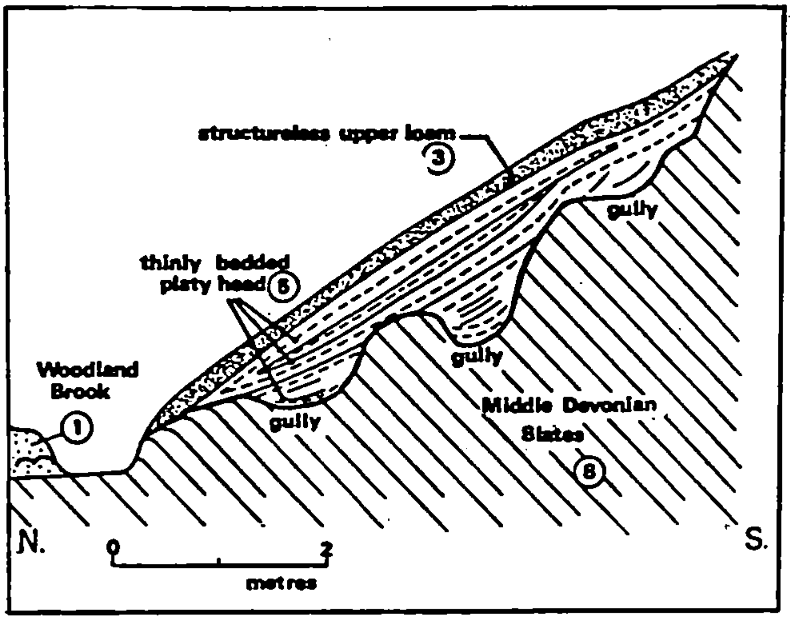


FIG 3.8 Head and loam deposits at Westover Wood, Ivybridge (from Gilbertson and Sims 1974)

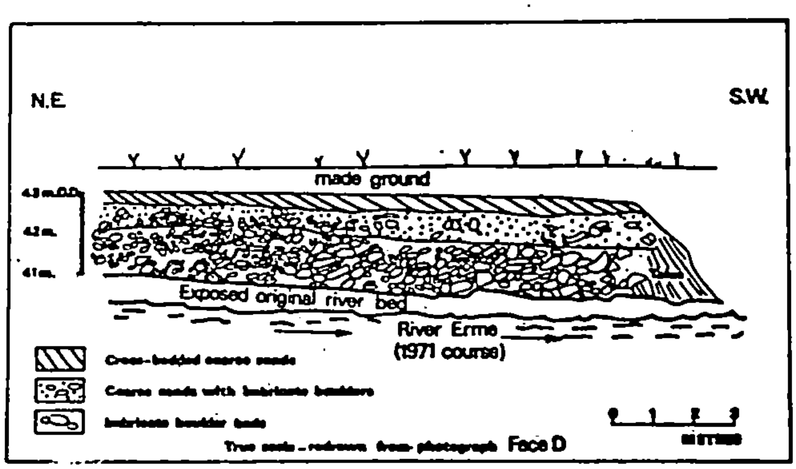


FIG 3.9 Section of imbricate boulder beds at Factory Bridge, Ivybridge (from Gilbertson and Sims 1974)

into the hillside. This suggests the river once had a higher discharge than today (if the granitic boulders were river transported to Ermington).

Evidence of periglacial activity is widespread and can be seen in the extensive mantles of solifluction deposits on the plateau and valley slopes below Ivybridge and on the clitter-strewn slopes of the granite moorlands, where the Dartmoor tors are also a characteristic feature related by Palmer and Nielson (1962) to phases of periglacial processes. Sharp Tor occurs in the Erme catchment area on the sides of the valley at Harford Moor (figure 3.3). Guilcher (1950) described altiplanation terraces formed under periglacial conditions rather than marine planation surfaces, and snow shaped notches as further evidence for periglaciation of the area. Catt and Staines (1982) mapped loess deposits on Dartmoor where in places, they are greater than 0.3m thick.

Although extensive head deposits occur at the mouth of the Erme at Mothecombe, there are also shallower deposits occurring over the rest of the valley. Some of these are noted on the Ivybridge Geology Sheet (No. 349) and coincide with the area mapped as an alluvial fan by Gilbertson and Sims (1974). The effect of the local bedrock in determining the nature of the head can be obtained by comparisons at different sections within the valley. Gilbertson (1973) noted the various types of heads used to construct hedgebanks in the Ivybridge area. On Devonian slopes bordering the granite, he found an upper loam overlying a platy head with occasional boulders of harder slates, calc-flinta and granite as illustrated in figure 3.8. On the metamorphic siliceous rocks and dolerites of Henlake Down, on the edge of Dartmoor, a coarse sandier head with angular rock fragments and more cobbles than on the Devonian rock was described. Further south Gilbertson found that hedgebanks on the floodplain of the Erme in the Filham Moor area were composed of floodplain sediments containing up to 3m diameter boulders in a gritty sand matrix. Between the floodplain and the Middle Devonian slates of Godwell Hill, the head is composed of sand and silt with occasional 2m diameter cobbles and boulders which overlie jumbled boulder deposits.

Further head deposits are seen at the coast at Mothecombe and a typical section of the head at the mouth of the Erme is shown in plate 3.1. The head shows variable characteristics from shattered bedrock to large boulders overlain by angular head and which in places grades to a finer laminated head. It is not clear whether any aeolian derived sediment has been included in the head, as described by Mottershead (1971) for other parts of the South Devon coast, or whether the finer layers are a weathering product. The head is often 3m or more thick, and forms the classic sequence seen in the South West of head overlying a raised wave cut platform as detailed in chapter 2. The sediments filling the Erme channel will include some of these head deposits reworked as fluvial sediments. No raised beach deposits can be seen overlying the raised wave cut platform in the vicinity of the Erme.

3.4 The Age of the Erme Valley and it s Deposits

Complex theories of superimposed Tertiary drainage patterns, and associated upland erosion surfaces are difficult to assess in relation to the formation of the River Erme. Many older studies suggested at least a Tertiary age for the drainage system on Dartmoor. Simpson (1964) considered that the drainage pattern is best understood as superimposed from an Upper Cretaceous cover. This hypothesis invoked an original drainage pattern on an easterly sloping Cretaceous surface, seen in the west-east flow of the Rivers Exe and Teign. A Mid-Tertiary uplift imposed a southerly tilt leading to the establishment of the Rivers Tamar, Plym, Avon, and Erme, whose development was interrupted in the Late Tertiary by a transgression of the 690ft sea, leaving Dartmoor as an island. When the sea regressed, most rivers reoccupied their old valleys, except the Dart which started to flow south-east rather than east. (Brunsden 1968).

Alternatively the Erme valley may have been cut during the Quaternary. Worth (1898) suggested that these channels owe their form to glacial origins and any glacial deposits will have been almost entirely removed and replaced by alluvial deposits; these views are generally not supported today. Durrance

PLATE 3.1

A section of the head overlying the Dartmouth Slates at the mouth of the River Erme

(1975) suggested that the Teign, comparable in size to the River Erme, was formed in a recent cold stage of the Pleistocene, such as the Devensian and that the Exe was created during an earlier stage of the Pleistocene (Durrance 1969). The presence of a buried channel and the incised nature of the drainage below Ivybridge suggests that the Erme was not cut in the Devensian although an earlier Quaternary date cannot be dismissed.

It is likely that some of the deposits filling the buried channel are older than the current interglacial if the valley was cut before the Devensian. However their recognition will depend on dateable interglacial deposits. Undoubtedly the channel and lower parts of the valley will be filled with a large proportion of Flandrian sediments.

Gilbertson and Sims (1974) attributed the boulder deposits and the overlying platy loams making up the alluvial fan at Ivybridge, to two separate periglacial episodes, and suggested dates of perhaps Wolstonian and Devensian age. This cannot be substantiated from the evidence provided, as can neither their suggestion that the Erme valley and the gorge are of pre-Upper Pleistocene age respectively.

The head deposits are all considered to be of Devensian age and the underlying raised wave cut platform is conventionally thought to date from the last interglacial.

3.5 Climate and Current River Discharge

The present day rainfall on Dartmoor varies from 2500mm (c. 100") on the highest parts of the northern moor to 1300mm (c. 50") at the eastern margin. On the lower surrounding land, rainfall is between 850-1000mm (c. 35-40") per annum. Severe storms causing flooding are rare but there are a few cases of extreme flooding as in 1929 when a famous flood affected the Yealm, Meavy and Teign (Gill 1970). It is very probable that the Erme was similarly affected.

Streamflow data from a gauging station on the River Erme (station SX65f051) near Ermington have been plotted as a flow duration curve (figure 3.10) using the method described by Gregory and Walling (1973). The mean daily flow, for a ten year period between 1974-1983, was used to display the frequency with which magnitudes of flow are equalled or exceeded. To prevent details of the lowest flows being obscured, the discharge values in cubic metres/second have been plotted on a log scale. The curve gives a useful indication of the variability of flow but has the disadvantage that any seasonality of flow is not displayed. The curve shows the highest discharge recorded to be 30 cumecs, 99% of the time to be less than 10 cumecs and 50% of the time less than 1.1 cumecs. Steep curves throughout indicate 'flashy' whereas a more gentle curve indicates groundwater or surface storage.

Selected storm hydrographs, derived from the 10 years of data of mean daily flow, are shown in figure 3.11 to indicate the general flow characteristics of the river in response to high rainfall. These indicate that the river generally rises and falls within 24 hours.

Browne (1978) constructed streamflow recession curves for a number of streamflow gauges in Devon including the River Erme. The stations at Chudleigh on the Teign and on the Erme had lower recession values than the other Dartmoor rivers which Browne attributed to the northern Teign draining hard metamorphosed impermeable culm rocks and the large area of blanket bog at the head of the Erme indicating poor drainage.

3.6 Present Sea Level and Tides

The present tidal limit of the Erme is as far upstream as the weir just south of Sequer's Bridge. During high tides, the land in this area is often flooded, but is situated above the level of the present salt marsh. Salt marsh covers an extensive area in the middle part of the estuary. Ranwell (1972) stated that generally salt marsh develops in estuaries in i) the upper estuary where there is an absence of wave action ii) in mid-estuary where the greatest amount of

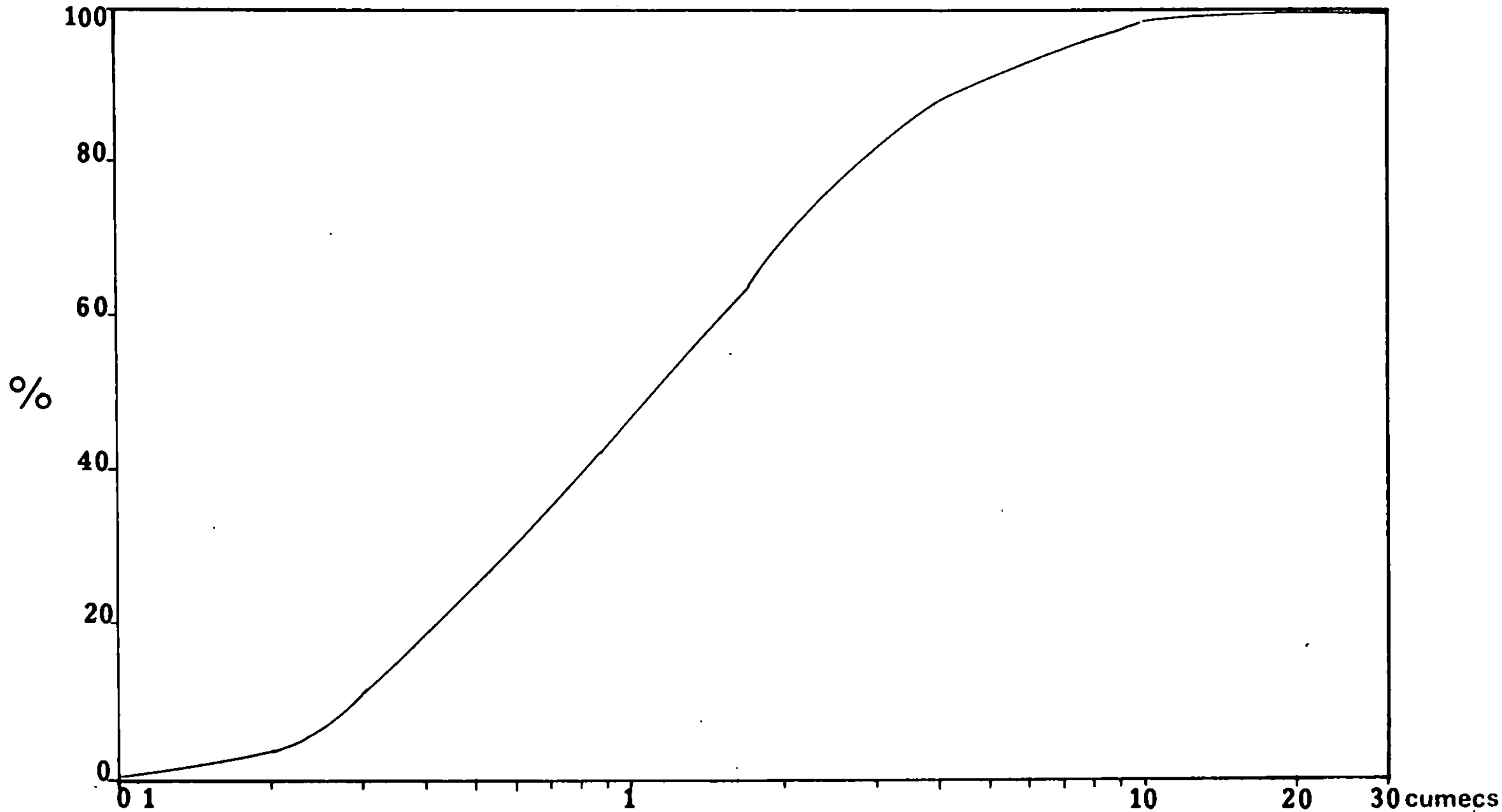


FIG 3.10 FLOW DURATION CURVE – using Mean Daily Flow at Ermington 1974 – 1983

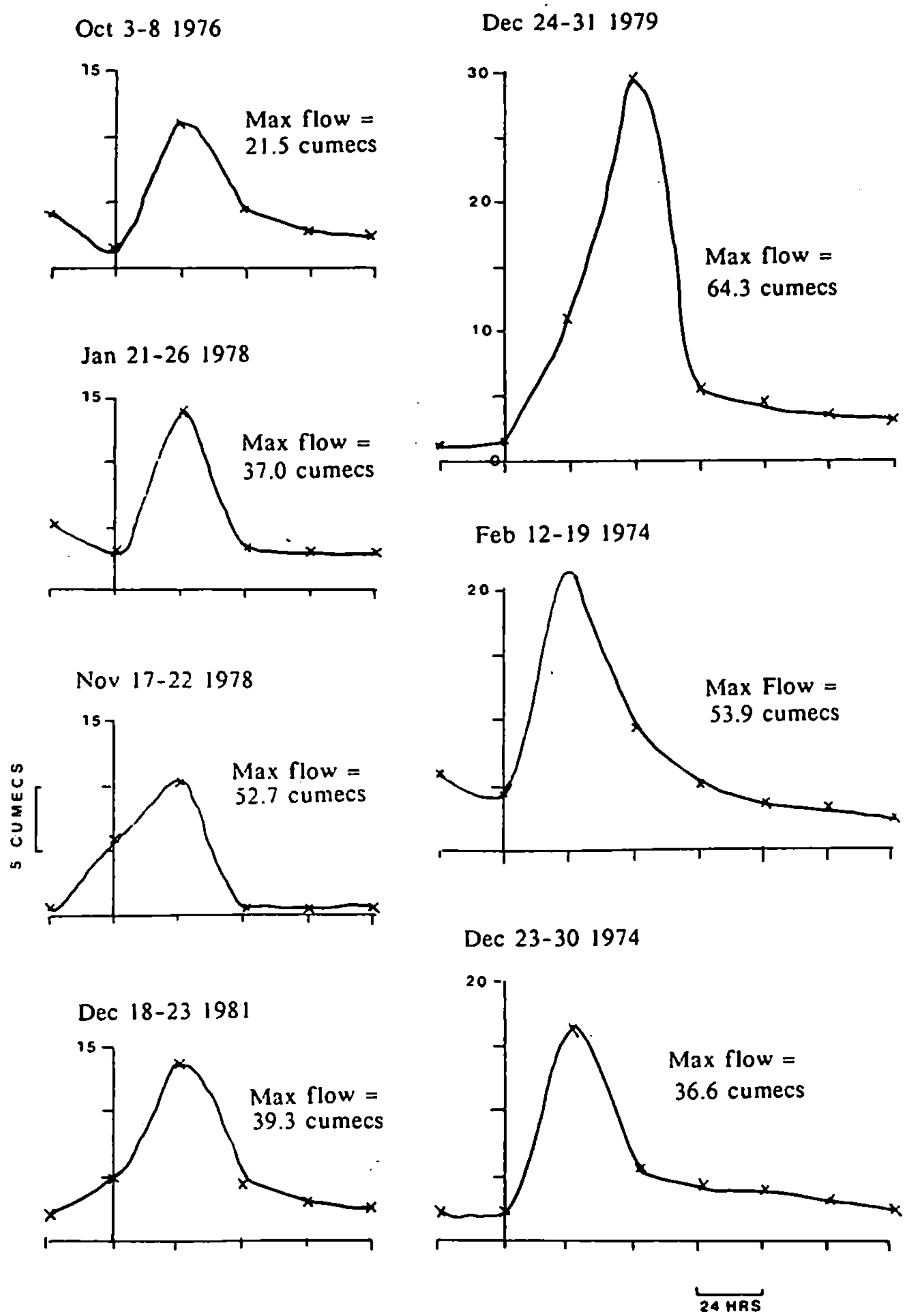


Figure 3.11 Selected hydrographs derived from records of mean daily flow at Ermington

silt deposition occurs and iii) at the mouth if protected by a coastal barrier. Salt marsh may be found between Mean High Water Neap Tides and the extreme high water of Spring Tides.

It is believed that the South West is fairly stable in terms of crustal movements and current estimates of sea level rise are 2.2mm/year at Newlyn (Rossiter 1972) and 2.4mm/year on Scilly (Thomas 1985). This figure will be assumed for the Erme mouth.

3.7 Vegetation and Soil Development During the Flandrian

Today the Erme valley and adjacent interfluves and plateaux below Ivybridge are used for agricultural purposes. On Dartmoor all the forest has been cleared except for Piles Copse, a small sheltered woodland in a deep valley on the moor, and the moor is used mainly for grazing. Between Ivybridge and Ermington there is a variety of land usage, the agricultural practices being mainly livestock farming. The steeper hill slopes tend to be forested. Downstream of Sequer's Bridge the land forms part of a private estate and is used for livestock farming, with some forestry of the steeply sloping valley sides. The expected sediment yield to the river directly from agricultural practises is therefore likely to be low. However, since this study is more concerned with former sediment yields and deposition, the effect of prehistoric activities in the catchment area will be considered. Earlier land clearance in the upper Erme catchment will have had an effect on the discharge and sediment yield of the River Erme. To assess the potential influences that there have been on the river regime, it is necessary to consider the vegetation changes on Dartmoor since the end of the Devensian glacial stage.

In the Late Glacial, open tundra like vegetation was present, succeeded in pollen zone IV by juniper scrub and then birch. Until 7000 years ago and with a warming climate, nearby Bodmin Moor was covered in oak woodland with elm (Brown 1979) and Dartmoor is thought to have had a similar cover to 400-450m altitude (Simmons 1964). Signs of Palaeolithic and Mesolithic occupations are rare on Dartmoor. Staines (1979) considered that during the Mesolithic (7000-5000 years ago) there was probably low intensity activity on the moor with little widespread effect on vegetation. Pollen evidence indicates some light demanding trees such as rowan, bracken and grasses indicating some deforestation (Gill 1970). Blanket bog is thought to have been present above 460m OD at around 6000 years BP (Hammond 1979).

During the Neolithic (5300-4500 BP) bigger clearings occurred in a continental climate with slightly higher temperatures than today. This marked the beginning of some soil leaching and peat formation (Gill 1970). Staines (1979) considered possibly that Mesolithic and Neolithic activities had greater influences so that the subsequent clearance in the Bronze Age would be thought of as secondary vegetation. At the beginning of the Bronze Age around 4000 BP, it seems the land was cultivated to 455m. This is just at the end of the climatic optimum when temperatures were 2-3 degrees Centigrade greater than today (Beresford 1981). The habitat became increasingly open with the spread of pastoralism and agriculture. There was a steady clearance of the woodland with little tree regeneration and a subsequent spread of bracken. This continued throughout the Middle and Late Bronze Age (3500-2460 BP) with the formation of peaty gleyed soils from brown earths. From about 2900 BP onwards there was a climatic deterioration into the Sub-Atlantic with cooler temperatures and a more variable climate. The spread of hill peat, *Sphagnum* and *Eriophorum* reduced the grazing capacity. Around 2500 BP desertion of the higher altitudes to less than 300m had taken place (Staines 1979).

During the Iron Age (2500BP onwards) even wetter conditions pushed activities to the edge of the moor, with little evidence of re-occupation over 300m in the Mid- or Late Iron Age, or even in the Roman Age. There may, however, have been some summer grazing.

Clearance continued into the Roman, Saxon and Medieval periods. From 400-1200 AD (1550-750 BP), another climatic optimum with temperatures 1-2 degrees Centigrade higher than today allowed cultivation to 395m between 800-1000 AD (1150-950 BP). In 1204, legal permission was given for forest clearance on Dartmoor (Roberts 1983). Between 1200-1400 AD (750-550 BP) mixed weather of floods and droughts, mild and severe winters meant retreat to valleys and any settlements left were abandoned in the thirteenth and fourteenth centuries (Beresford 1981). Total clearance of the moor was probably complete in Medieval times, possibly by Medieval tinners (Taylor 1975).

There is evidence for agricultural activity in the upper Erme catchment. Harris (1975) suggested the 'ancient' woodland of Piles Copse may be younger than is commonly believed. Pollen evidence from the site seems to show that deliberate replanting occurred both before and after deforestation in Roman times. It was then cut again and the present woodland possibly originates from the end of the eighteenth century. Roberts (1983) considered that the smelting of tin ore led to cutting and deliberate planting of Piles Copse at several points throughout the last few centuries. Pollen evidence indicates the presence of Oak at the base of the soil profile examined.

At Redlake clay works analysis of pollen across a peat-soil boundary was dated to pollen zone VIIa (Taylor 1975). An increase in heather and grass with a decrease in hazel and bracken was identified. A soil examined at Piles Hill at 300m showed a very thick iron (Bs) horizon with evidence of woodland clearance. The presence of charcoal fragments at depth in the subsoil are of alder rather than oak and therefore suggest perhaps secondary woodland after the burning of early oak forest. Taylor suggests that the warming of the climate in the Iron Age may have led to an increase in woodland.

The soils in the study area have developed from weathered parent material and head. On Dartmoor they are derived from granite and granitic heads and on the Devonian outcrops from slate, slate head or river sediments. Thus they tend to be more podzolic or peaty on the moor with a transition to a brown earth soil group in the lower valley. The following soil descriptions are taken from the Soil Survey Map of England and Wales, Harrod *et al.* (1976), Hogan (1977) and Kent and Sims (1991).

The Crowdy 2 Soil Series, an oligomorphous peat, occurs over much of the central moor at the head of the Erme. The Princetown Series, a stagnohumic gley, occurs just north of Ivybridge, and is characterized by peat overlying a sandy loam. Towards the edge of the moor, the Moor Gate and Moretonhamstead Series both belong to the brown podzolic soil group and are characterized by gravel, sand and silt loams.

On the edge of the moor, at the granitic boundary, the Manod Series occurs; this soil is a brown podzol derived from slate and slate head forming a clay loam. The Yeolland Park Series covers an area to the south-east of Ivybridge and is classed as a cambic gley, of clay loam. Over the surrounding interfluves as far as the south coast, the Ivybridge Soil Series is present. It forms a fine loamy soil classed as a gleyic brown earth. The Teign Soil Series is a coarse loamy sandy soil, grouped as a Ranker-like alluvial soil, formed from granitic derived alluvium it occurs in the valley bottoms.

Thus, on Dartmoor peaty soils are generally present including blanket bog, gleyed soils and podzols developed upon granite or growan. On Devonian rocks, the soils are free draining, fine textured brown earths. In low lying valley areas gleyed brown earths are present (Brunsden 1968).

3.8 Archaeological Data

There is some evidence of occupation by prehistoric groups in the Erme valley. Abundant stone rows and circles are believed to date from the Bronze Age. The longest stone row is 4km long which starts above Harford Moor and continues past Redlake to Green Hill at 474m OD. This was probably constructed between 2000-2500 BC by the Beaker Folk arriving towards the end of the Bronze Age (Gill 1970). A prehistoric trackway extends between the Erme and the Plym which used to have standing stones. Fox (1964) visualised the stone rows occupying open swathes in oak forest rather than 'marching' across open moor.

In the lower valley evidence of earlier occupation is almost totally lacking. The only location known is at Mothecombe where a vertical face of soil, 1.2-1.5m above high tide exposed an occupation layer and has been described by Fox (1961) (figure 3.12). The main feature was a hollow 1.5-1.6m wide and 0.8m deep, lined with yellow clay, filled with charcoal, dark soil and burnt daub and covered with stony debris. Fox suggested this to be the remains of a temporary occupation by traders. The pottery was identified as imported amphorae of post-Roman Age similar to that found at Bantham (Fox 1955). It was dated to the 5th or 6th century A.D. corresponding to the so-called Dark Ages. Sand dunes burying the occupation layer must have formed since the 5th or 6th centuries. The dunes at Mothecombe can be compared with those in Perran Bay, North Cornwall, which show two phases of dune accretion, the first during prehistoric time and a resurgence of growth in the twelfth century (French 1983). A palaeosol buried by dunes at Praa Sands, on the southern Cornish coast has been dated to 1290±70 BP (Keeley unpublished - in French 1983). Thus there has been an active phase of sand dune formation during the last 1000 years around parts of the Devon and Cornwall. At present the Mothecombe dunes are being eroded.

Other archaeological data has been obtained from the Erme valley at Oldaport where a fort and harbour are said to have existed possibly in Roman times (Farley and Little 1968) and indicates siltation of the lower Erme estuary in recent centuries. Greeves (1981) studied the evidence for Medieval tin mining and earlier tin streaming on Dartmoor. He identified a large number of sites in the upper Erme valley, above Ivybridge. Both these will be discussed in a later chapter concerned with historical evidence, in an attempt to reconstruct channel changes of the River Erme and the extent of silting of the estuary in historical times.

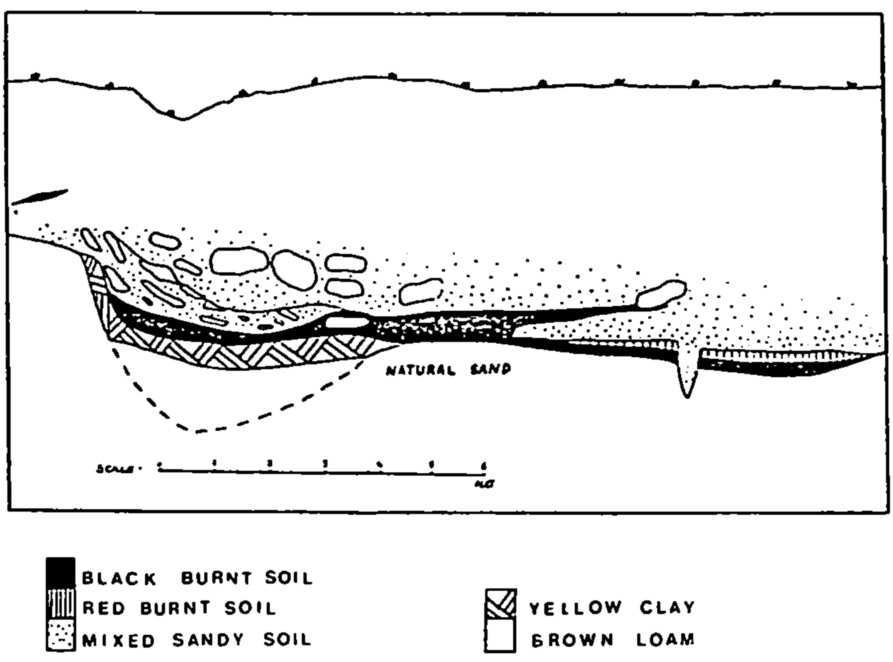


FIG 3.12 Section of the occupation site at Mothecombe (from Fox 1961)

3.9 The Area to be Studied

This study concentrates on the sediment filling the channel of the lower Erme below Sequer's Bridge. Apart from the data from the early nineteenth century engineering works, there is little information concerning the sediments filling the buried channels of the rivers in south-west England. A drilling programme has been undertaken in the lower valley below Sequer's Bridge. This area was chosen because a reasonable depth of sediment could be expected to be retrieved and because of the variety of environments that the area covers.

CHAPTER 4 LITHOLOGY OF THE VALLEY SEDIMENTS: FIELD METHODS AND LABORATORY ANALYSIS

In this chapter the field and laboratory methods used to collect and analyse sediments from the floodplain and buried channel of the River Erme are described.

4.1 Field Methods

Two separate drilling programmes were undertaken; the first was unsuccessful in obtaining sediments for analysis because of difficulties with equipment. Instead the borings were used to try and ascertain depths to bedrock across parts of the current floodplain. A second drilling programme was successful in collecting sediment from the buried channel of the Erme, thus providing the data for most of the study.

4.1.1 Drilling into Floodplain Deposits

Initial work in the early part of this study in the Erme valley concentrated on trying to ascertain the depth to bedrock in the channel of the Erme. Using an Atlas Copco power driven drill a series of attachable rods were driven into the valley sediments in an attempt to determine the depth of sediment infill. Bedrock was assumed to be reached when the rods could penetrate the sediments no further and considerable resistance was met. Two transects were made across the floodplain near to Sequer's Bridge (see figure 4.1) and at the mouth of the Erme one site in the centre of the valley was drilled (see figure 4.2). The most important aspect of this study relates to the depths representing a minimum channel thickness at the sampled points. These minimum depths are listed in table 4.1. At the mouth of the Erme (drilling point C in figure 4.2), opposite the lime kiln the depth reached by drilling was 14m, representing a minimum depth for the channel at this point.

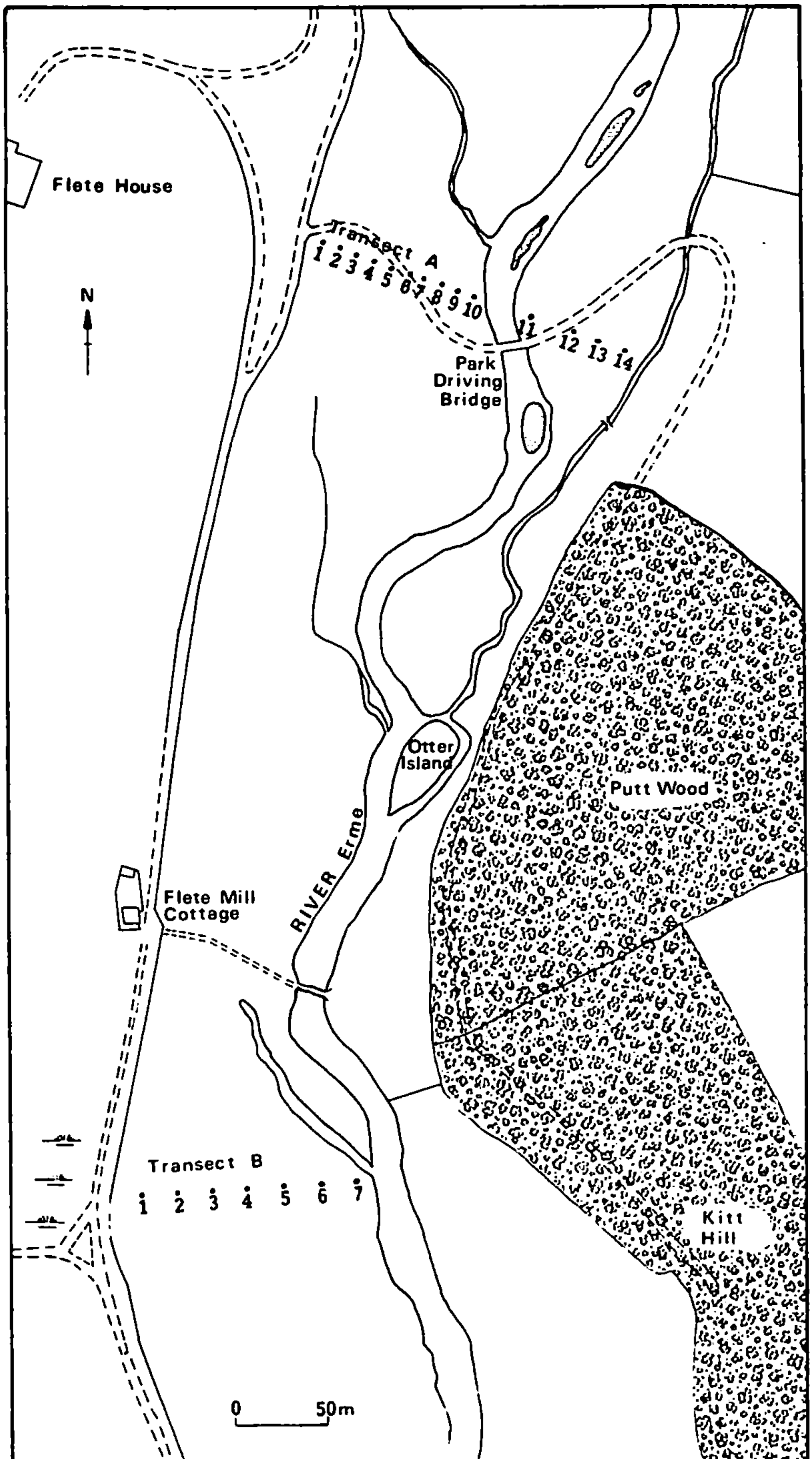


FIG 4.1 Initial transects across the floodplain

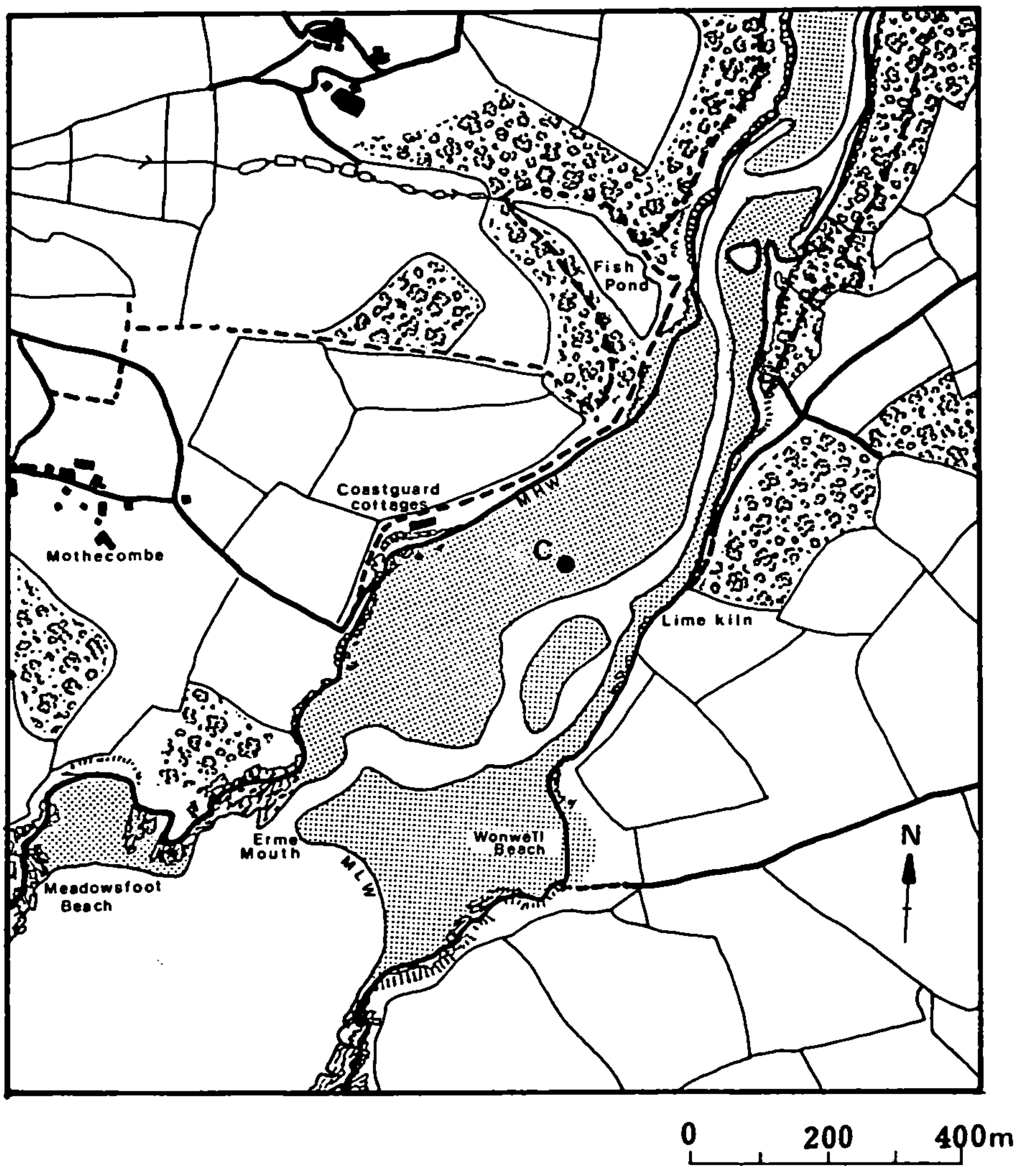


FIG 4.2 Drilling point C at the mouth of the River Erme

HOLE	DEPTH (M) TRANSECT A	DEPTH (M) TRANSECT B
1	4.0	4.9
2	6.5	6.4
3	6.7	7.6
4	7.7	8.1
5	8.2	8.5
6	8.1	7.5
7	5.9	7.1
8	5.5	
9	6.3	
10	5.7	
11	8.0	
12	8.2	
13	7.2	
14	6.5	

TABLE 4.1 MINIMUM DEPTHS ALONG TRANSECTS A AND B

The second drilling programme was instigated to collect sediment from the floodplain. The Atlas Copco drill was prevented from collecting cores because of the resistant granitic sands and waterlogging of the sediment. Instead a Craelius 'Minuteman' was used. Drilling was carried out in three separate episodes lasting a week each; these were in January 1985, April 1985 and August 1985. Although the sediments were collected by augering, they will be referred to as cores or augered cores, and their sites of drilling as boreholes.

4.1.2 Location of Drilling Sites

The sites that have been investigated in the Erme valley are shown in figures 4.3-4.8. Figure 4.3 shows locations of all the boreholes and figures 4.4-4.8 show the locations in more detail. Figure 4.4 shows sites in the main valley just below Sequer's Bridge and figure 4.5 sites around and downstream of the Park Driving Bridge. Figure 4.6 shows the tributary valley of Sheepham Brook that enters the main valley from Goutsford bridge, figure 4.7 locations on the reclaimed land and figure 4.8 boreholes on the salt marsh near Efford House.

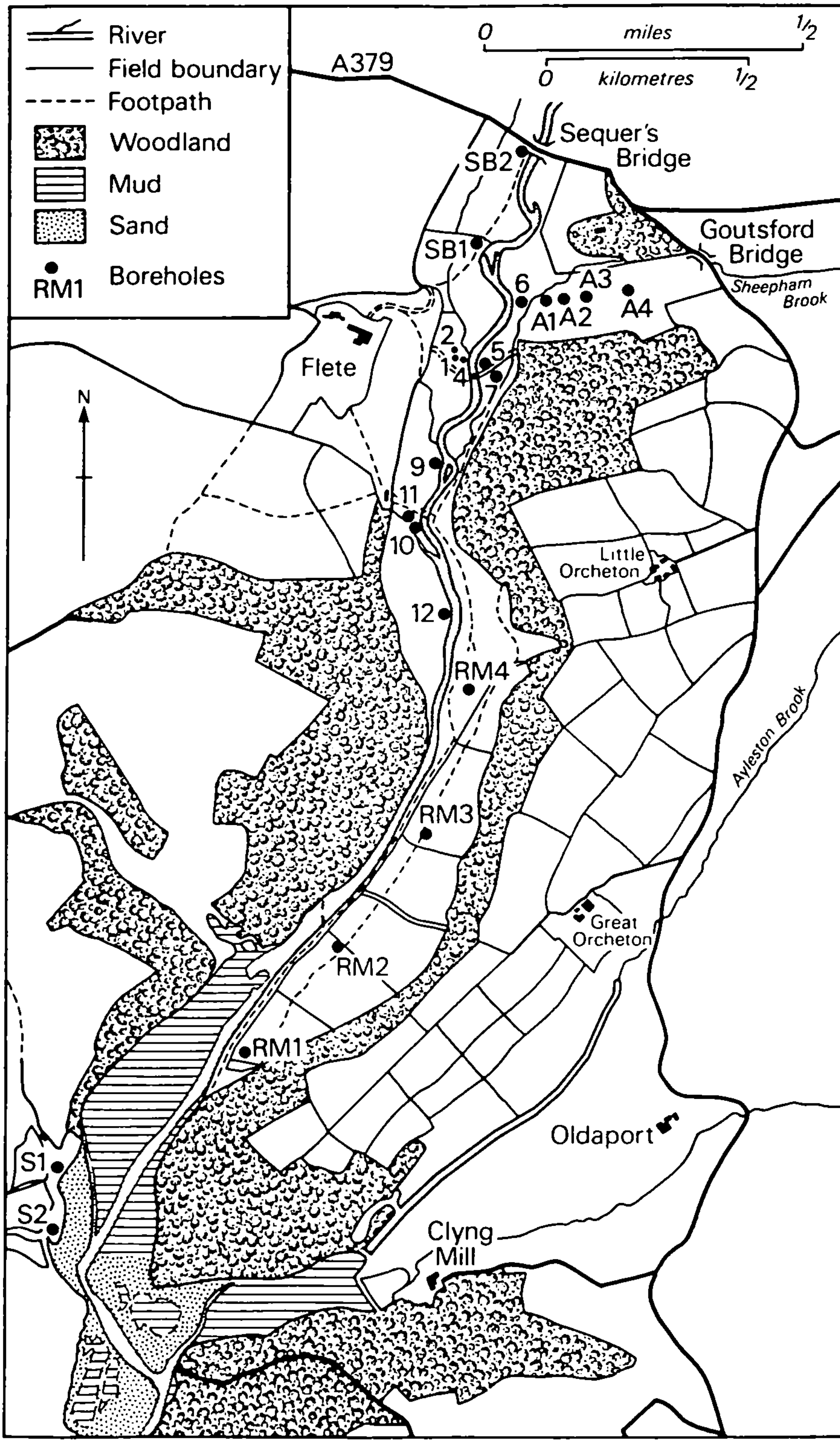


FIG 4.3 Location of all drilling sites

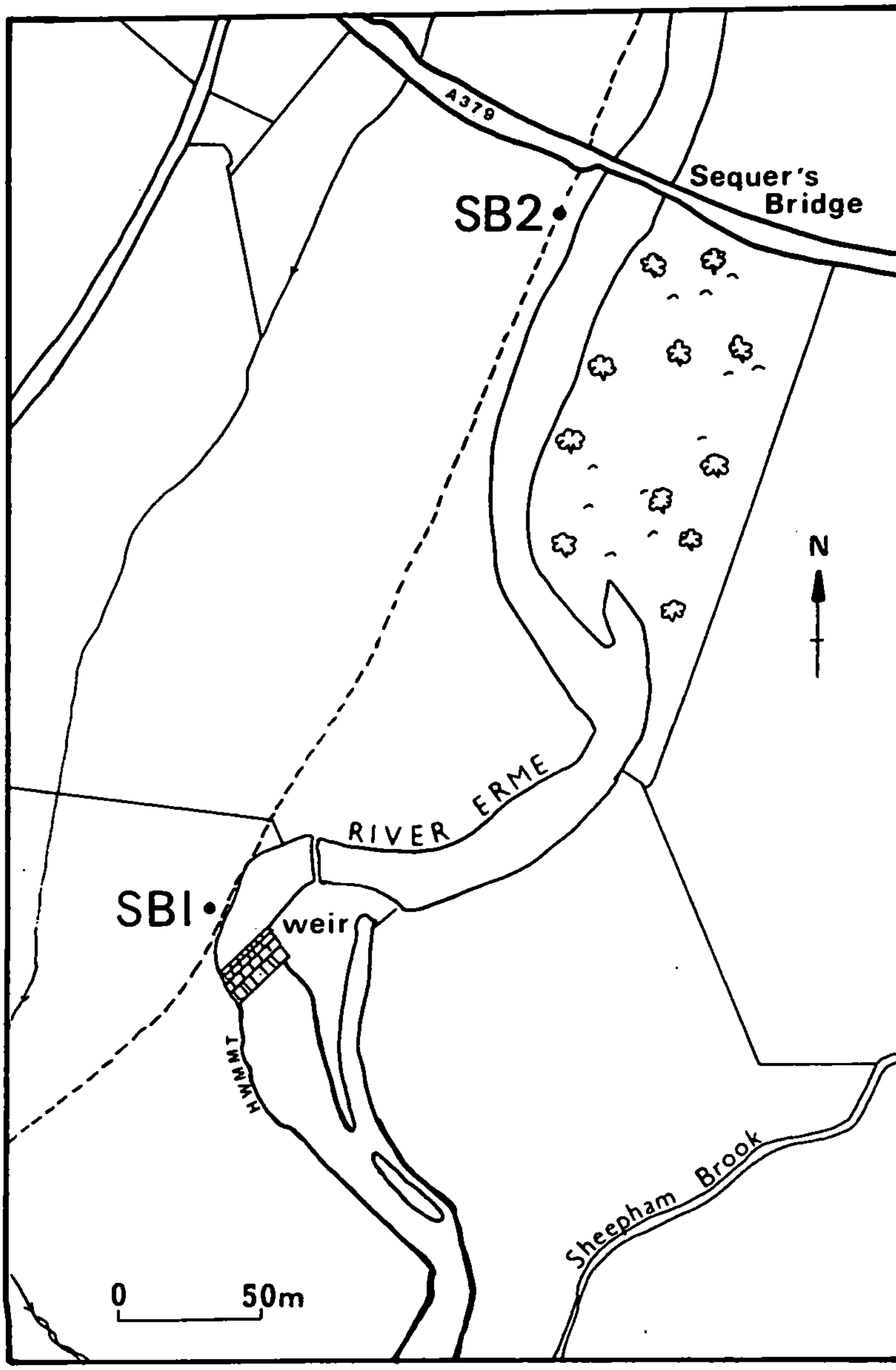


FIG 4.4 Location of coring sites at Sequer's Bridge

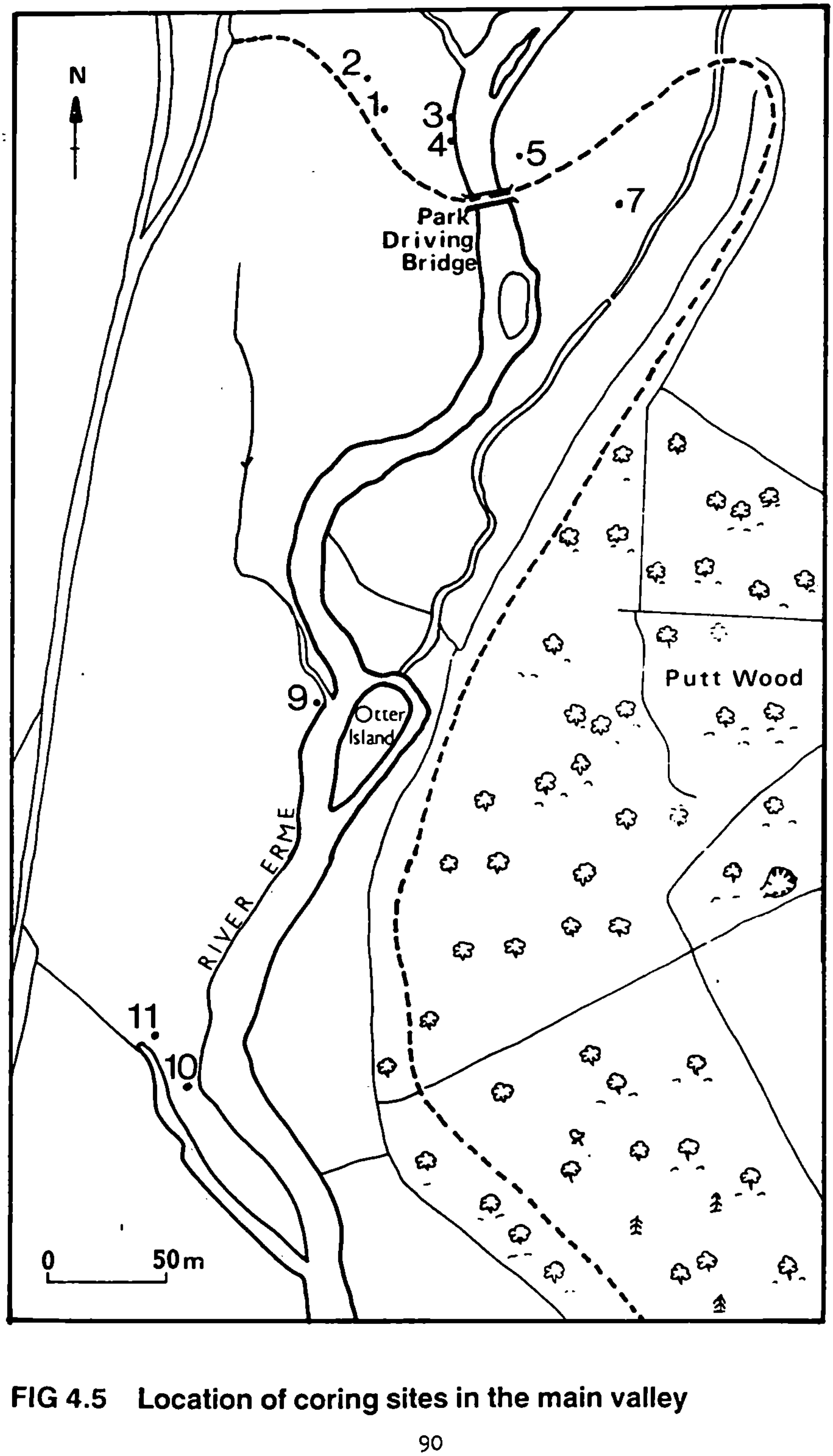


FIG 4.5 Location of coring sites in the main valley

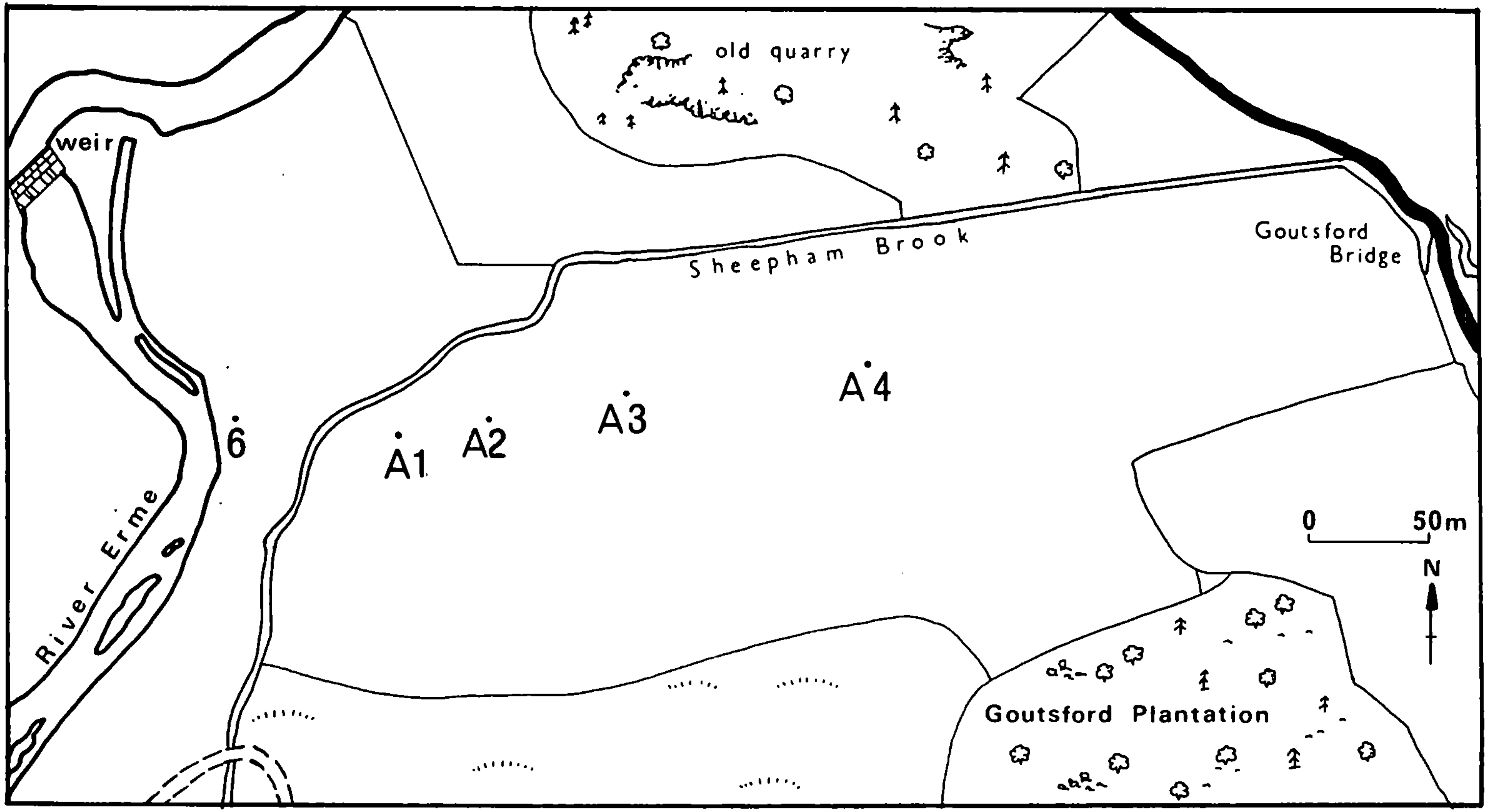


FIG 4.6 Location of coring sites in the tributary valley

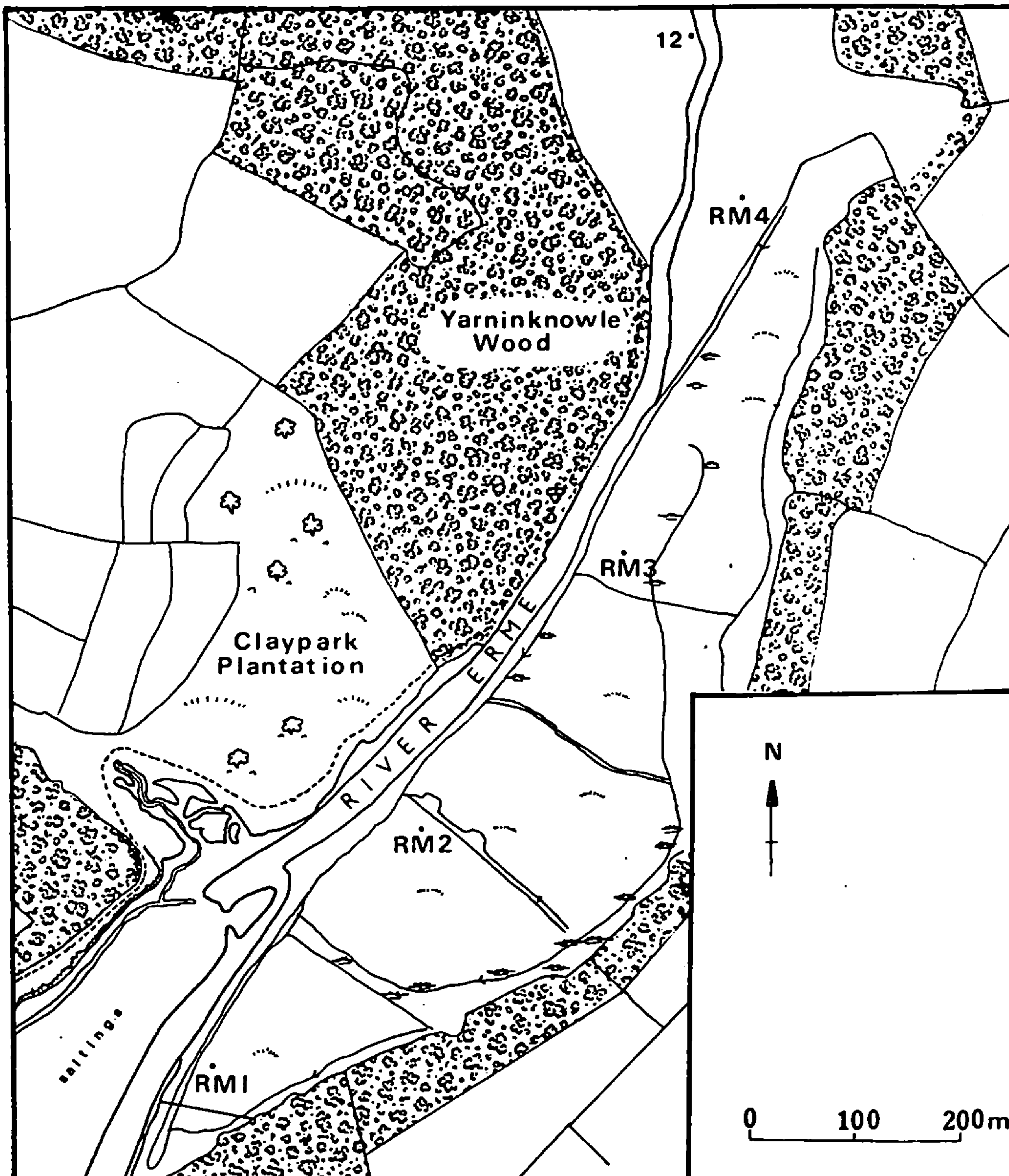


FIG 4.7 Location of coring sites on the reclaimed land

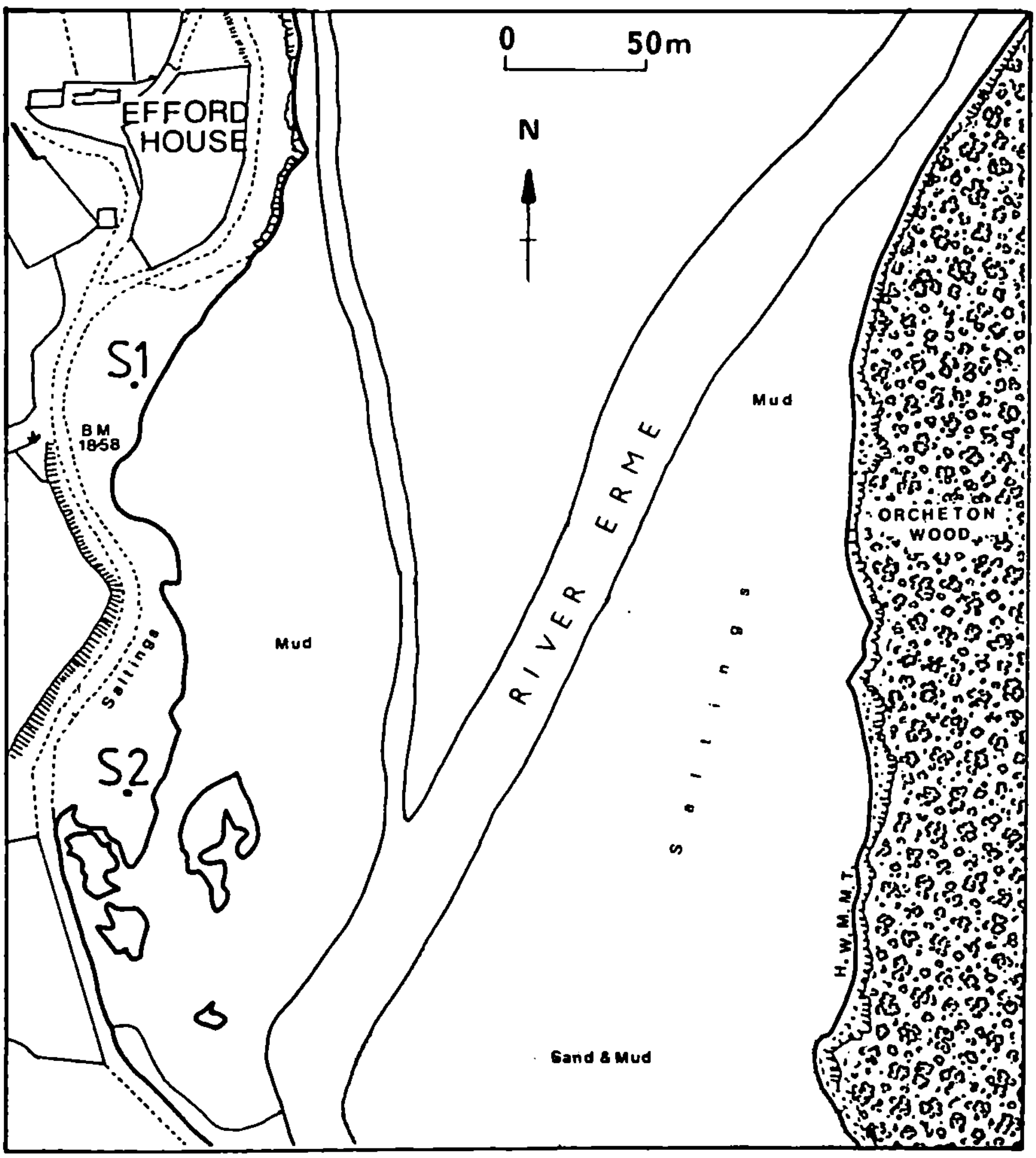


FIG 4.8 Location of coring sites on the salt marsh

The boreholes have been named according to their location; those in the main valley are prefixed by 'BH', those in the tributary valley by 'A', at Sequer's Bridge by 'SB', from the reclaimed land by 'RM' and from the salt marsh by 'S'. These prefixes were originally used in the field sampling and have remained in use throughout the study to avoid confusion of samples. The Atlas Copco drill and drilling sites in the main valley and on the salt marsh are shown in plates 4.1 and 4.2.

The boreholes in the main valley run approximately down the centre of the valley (SB1, SB2, BH1, BH2, BH9, BH11, BH12,) and across valley at the Park Driving Bridge (BH1, BH2, BH4, BH5, BH7). This was the only location where the valley was wide enough and accessible enough for a cross-valley transect to made. Further downstream, boreholes were drilled in the drained salt marsh (RM1-4) and the existing salt marsh area (S1 and S2). It was hoped that these boreholes would give a general indication of the range of sediments occurring in the main valley. After sediment was collected from BH6, further samples were obtained from the Sheepham Brook valley (A1-4), the main tributary valley where drilling was possible. Throughout the study area the locations of the cores were determined largely by the accessibility of various fields, the length of the valley section, the range of environments to be covered and the time available.

All cores will be discussed in a standard order throughout the text. This order is SB2, SB1, BH6, A1, A2, A3, A4, BH1, BH4 BH7, BH9, BH11, BH12, RM4, RM3, RM2, RM1, S1 and S2. This is generally from north to south, although the cores in the tributary valley (A1-A4) are discussed between BH6 and BH1.

4.1.3 Collection of Samples

Borehole samples were obtained from an auger powered by a Craelius 'Minuteman' drill. Auger flights of 3' (0.915m) long were used and whilst there was no difficulty in drilling the auger flights into the ground, problems arose in extracting the auger string plus sediment. This limited the depth to which

PLATE 4.1

Drilling in the main valley at location BH12.

Drilling at site BH5 next to the Park Driving Bridge
next to the River Erme.

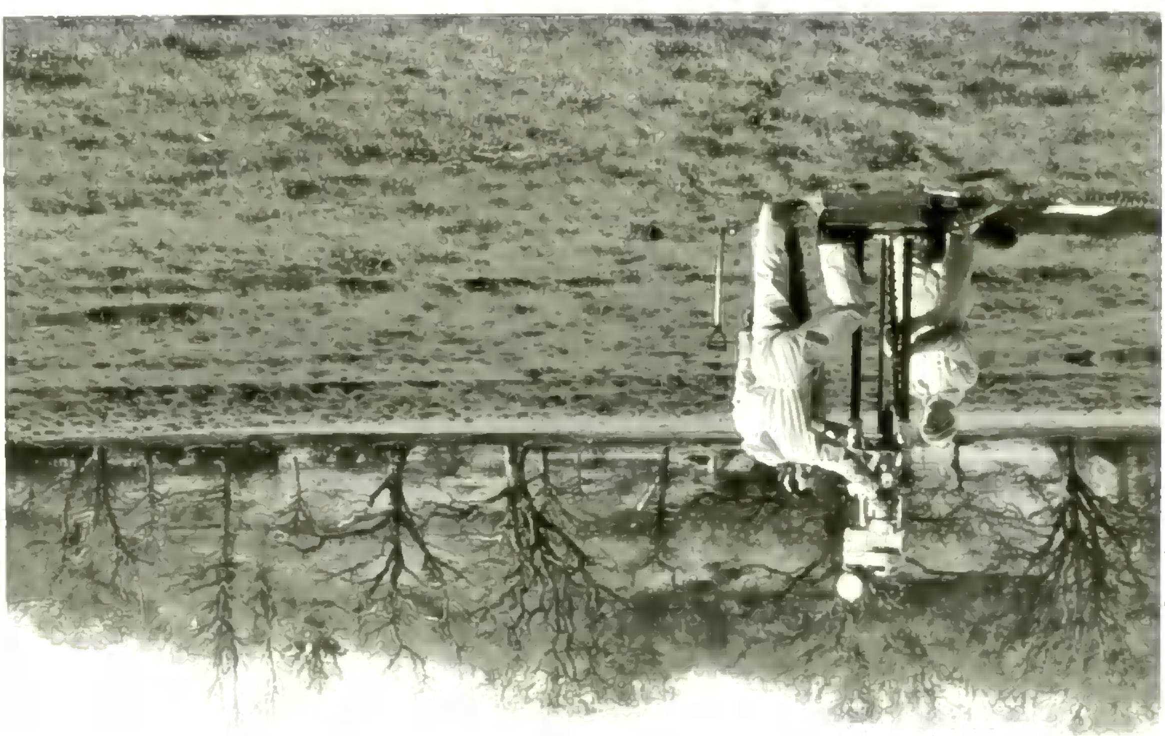


PLATE 4.2

Extraction of the auger flights from a drilling site on the salt marsh.

coring was feasible, a maximum of 7m or less in many locations. Augers had to be lifted from the ground after every two flights, which lead to the holes caving in before the next flights were added and thus some contamination of the sides of the sediment occurred. This was later removed in the lab during initial examination of the sediment.

Recovery of sediment was successful in the case of fine sand, silt and clay but where sandy/gravel horizons were encountered, the sample was sometimes lost. Samples were taken from the auger flights in the field (as shown in plate 4.3) at 20cm intervals (BH 1-12) and at 10cm intervals (A1-A4, S1,S2, SB1,SB2, RM1-4) and examined in the laboratory. The extent of recovery of sediment from these boreholes is shown in figure 4.9. No sediment was retained from drilling at locations BH3, BH5, BH8 and BH10 because of difficulties in extracting the augers from the borehole and waterlogging of the deposits.

4.1.4 Surveying to Ordnance Datum

The boreholes have been surveyed relative to the Ordnance Survey benchmark (7.003m OD) at Sequer's Bridge (benchmark no. G5027 at Grid Ref. 63205187) and a benchmark in Holbeton village (Grid Ref. 61765017) at 28.64m OD. Both refer to Ordnance Datum Newlyn. Although other benchmarks are marked on the OS 1:2500 maps of the area they were impossible to find. Temporary benchmarks were therefore established in the field area. Surveying was necessary to relate the top of each borehole to Ordnance Datum and plot their positions on 1:2500 maps of the area. The heights of the top of each borehole and depth of sediment collected are shown in table 4.2. It can be seen that the tributary valley is lower than the main floodplain and the sites at RM1-3 are lower than the current salt marsh.

PLATE 4.3

Collection of sediment from the auger cores.

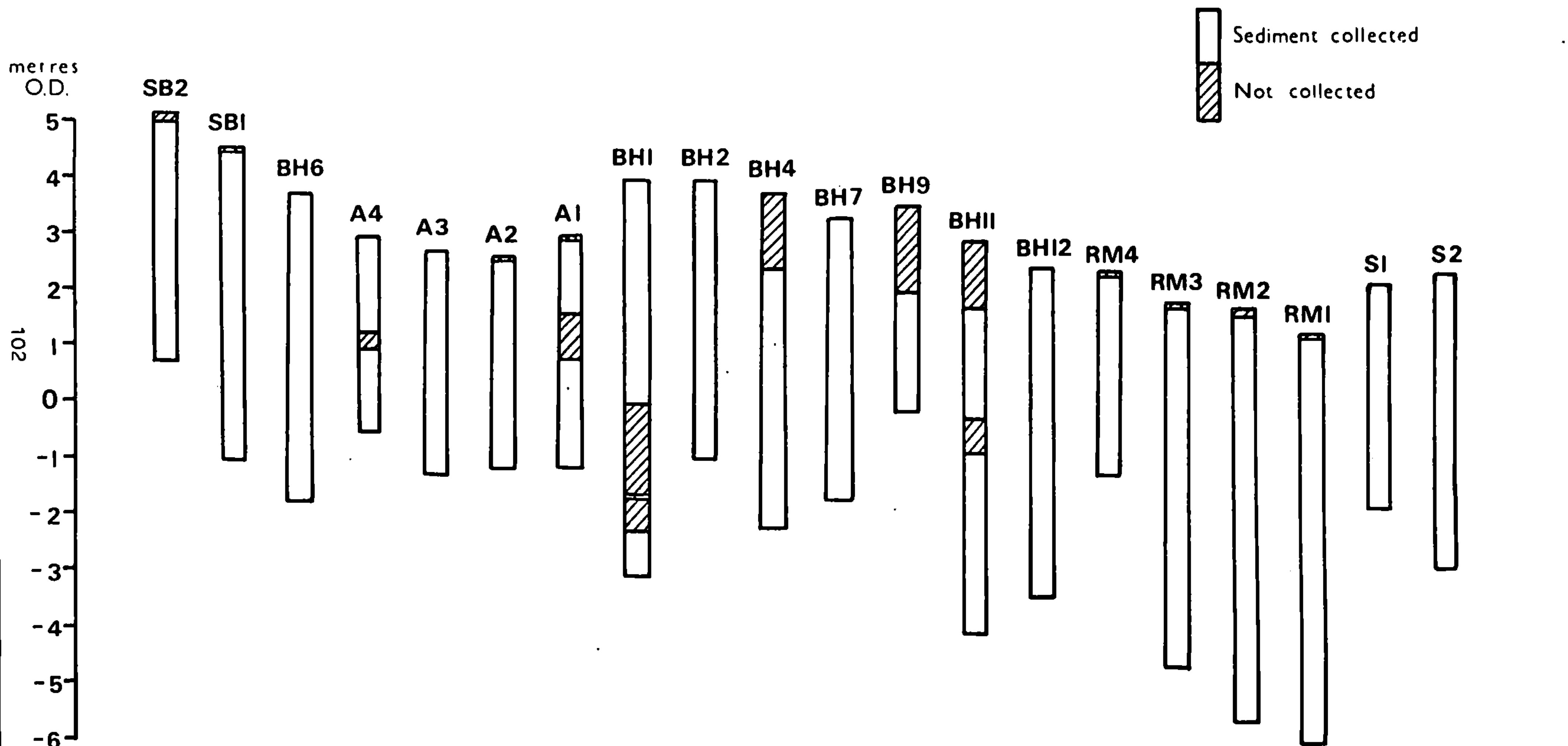


FIG 4.9 Extent of recovery of sediment from cores.

BOREHOLE	TOP OF CORE (m OD)	DEPTH OF SEDIMENT RECOVERED (m)	SEDIMENT RECOVERED (m OD)
SB2	5.06	0.1-4.4	4.96-+0.66
SB1	4.53	0.1-5.6	4.43--1.07
BH1	3.97	0.0-7.1	3.97--3.13
BH2	3.95	0.0-5.0	3.95--1.05
BH4	3.74	1.4-6.0	2.34--2.26
BH6	3.67	0.0-5.45	3.66--1.79
BH7	3.24	0.0-5.0	3.24--1.76
BH9	3.46	1.5-4.3	1.96--0.84
BH11	2.82	1.2-7.0	1.62--4.18
BH12	2.34	0.0-5.8	2.38--3.42
A1	2.94	0.1-4.15	2.84--1.21
A2	2.59	0.1-3.8	2.49--1.21
A3	2.71	0.0-4.0	2.71--1.29
A4	2.91	0.0-3.5	2.91--0.59
RM4	2.33	0.1-3.6	2.23--1.27
RM3	1.76	0.1-6.5	1.66--4.74
RM2	1.60	0.1-7.3	1.50--5.70
RM1	1.20	0.1-7.3	1.10--6.10
S1	2.19	0.0-4.1	2.19--1.91
S2	2.23	0.0-5.2	2.23--2.96

TABLE 4.2 SEDIMENT RECOVERED FROM AUGERED CORES

4.2 Laboratory Methods

The analysis techniques used are described in the next few sections. The sediment was initially logged to provide a general description of the different horizons found. Particle size analysis, some mineralogical and S.E.M. study was also undertaken.

4.2.1 Logging of Sediment

The position of boundaries between differing sediment types was undertaken in the laboratory. As far as was possible the sediment was examined to remove contamination and a general description was produced for each core. Criteria used in the description are particle size, nature of clasts (composition, size, roundness), presence of organic horizons, bits of wood, seeds etc., presence/type of molluscan shells, and colour using Munsell colour charts.

4.2.2 Particle Size Analysis of Samples

Borehole sediments chosen for particle size analysis were from BH1,BH4, BH6, BH7, BH9, BH11, BH12, A3 and SB2. These are mainly from the upper part of the study area. They were chosen because they cover a range of sediment types, whereas those further seawards tended to be more uniform and estuarine in nature. Sediment size analysis was undertaken in order to get an accurate indication of the grain size making up the deposits and aid correlation between cores.

4.2.2.1 Sieving

Samples for size analysis from each core were chosen according to changing lithology in order that the smaller horizons were not overlooked; if a regularly spaced sampling pattern had been used then this may have happened. Where a sediment appeared uniform samples were taken at regular intervals. These intervals depended on the length of the uniform sequence, but were about every 40cm. About 100g of sediment was used for size analysis. The samples were first oven dried and weighed and then broken down using a pestle and mortar and dry sieved in accordance with the British Standard method for test sieving (BS1796). British Standard sieves (BS410) were used, with a size range of -4 to +4 Phi (16-0.063mm). The stacked sieves were placed on a mechanical sieve shaker for 10-15 minutes. The different fractions retained by the sieves were weighed. It was found necessary to also wet sieve the samples due to the problems of binding caused by the high proportions of silt and clay sized material. The silt and clay sized material that was obtained from dry sieving was retained for later use in pipette analysis.

The material to be wet sieved was weighed and left in water for at least 24 hours before wet sieving. The same sieve sizes were used and samples were wet sieved until the water running through the sieves was clear (usually 20-25 minutes). The sieves and the sieved fractions were then dried and re-weighed. Amounts of the total silt and clay content in the sample were calculated by the weight loss in wet sieving.

4.2.2.2 Pipette Analysis

The silt and clay (< 0.063mm) fraction was analysed using the Andreasen pipette method as outlined in the British Standards guide BS1377. This method calculates the amount of sediment that settles through 10cm depth in liquid at a given temperature; it is thus dependent on Stoke's Law.

Organic material was removed by treating the samples with 50ml of Hydrogen Peroxide. The sample was weighed and mixed in a mechanical stirrer with distilled water and 50ml Calgon (a mixture of 50g Sodium Hexametaphosphate, 5.7g Sodium Carbonate and 1000ml distilled water) for 15 minutes. Samples were transferred to a 500ml tube in the pipette apparatus, and allowed to reach a temperature of 23 degrees Centigrade in a water bath.

At 23 degrees Centigrade, the times taken for sediment to settle through 10cm are:

size fraction	time
50μm	37 secs
20μm	4mins 28secs
9.8μm	18mins 37secs
2μm	7hrs 26mins

Samples were taken at these times and collected in pre-weighed glass jars. These were oven dried and re-weighed.

4.2.3 Mineral Composition of Sediments

Sediment from cores BH1, BH6, BH7 and A3 was chosen for an analysis of their mineral content. These cores were chosen as they extend across the valley and to test whether clasts from BH1, BH6 and BH7 in the main valley and from A3 in the tributary valley have similar origins. It might be expected that A3 would have a higher amount of slate derived sediment since Sheepham Brook drains mainly Devonian rocks.

Clasts were counted for size fractions -4Phi, -3Phi, -2Phi, -1Phi and 0 Phi. Two main groupings were used, a granitic class and a slate class to reflect the two main rock types that the river flows through. Divisions of the former were quartz, feldspar, mica, hornblende. A granitic class was used for clasts which were too large or were a combination of differing minerals, thus preventing assignment to any one of the above groups. The slate group was divided into slate, metamorphosed slate and vein quartz and any other minerals were individually specified. Up to 500 clasts have been sampled for each size fraction, depending on the total obtained from the wet sieved fraction. This was considered to be a statistically significant number and large enough to include any foreign clasts that might be present.

4.2.4 Scanning Electron Microscope (S.E.M) Analysis Of Sediment

4.2.4.1 The Method

S.E.M. is used to study surface textures occurring on quartz grains as these are believed to show characteristics indicative of different depositional environments. A preliminary investigation of sediment from two boreholes in the Erme valley was undertaken in order to assess the varying environments through which the sediment may have travelled. As some of the material occurring in the cores was predominantly fine sand and silt the possibility existed that there had been some incorporation of loess from head deposits on nearby Dartmoor and the surrounding interfluves. S.E.M. analysis of the quartz would also help assess the effect of fluvial erosion on the grains.

The underlying principle of the S.E.M. technique is that the assemblage of different microtextures occurring on a quartz grain is attributable to its environmental history (Krinsley and Doornkamp 1973). Both mechanical and chemical weathering processes produce surface textures on the grains and a number of different groups of features have been recognised. Initial work by Biederman (1962), Porter (1962) and Krinsley and Takahashi (1962) established a set of features attributed to aeolian, beach and glacial environments. This work was enhanced by Krinsley and Donahue (1968) where a more comprehensive classification of surface textures, distinguishing littoral, aeolian, glacial and diagenetic environments is provided.

Quartz grains tend to be used more than other rock types as quartz is relatively resistant to chemical and mechanical breakdown. It has been noted that different mineral types will have a different set of surface textures for the same environment and that any analysis of the surface textures of quartz will depend on a knowledge of quartz crystallography. Some studies have identified a number of different environmental cycles through which quartz grains have passed by a succession of surface textures occurring on a grain.

It is also possible that many grains will have the same end product but are the result of a number of differing environments, i.e. they are equifinal.

Detailed analyses of quartz grains have often been carried out on a presence and absence basis of surface textures, which had been devised by Margolis and Kellner (1969) using the presence / absence of 30 different textures. However Bull (1978) stated that:

> "Attention must be drawn not only to the number of grains required but also to the combination of features which are themselves diagnostic".

Hence some have developed this into a more rigorous statistical analysis by various grouping methods and cluster analysis in order that some general grain surface characteristics could be ascribed to different groups of sediment.

4.2.4.2 Selection of Material for Analysis

Samples for S.E.M. analysis were chosen from two boreholes in the Erme valley: SB2, near Sequers Bridge (figure 4.4) and A3 (figure 4.6) from the tributary valley. Both these cores contained fine-grained sands and silt in their upper horizons, and hence may include sediment of aeolian origin. Samples were initially obtained from four horizons in each core; in SB2 from depths of 0.1-0.2, (fine sand) 1.3-1.4 (sand), 2.9-3 (sand), 4.3-4.4 (sandy-gravel), and in A3 from 0.7-0.8 (silt-sand), 1.2-1.3 (sandy-gravel), 2.8-2.9 (sand), 3.6-3.7 (silty-clay). These samples reflect the main sediment layers from these cores and a preliminary analysis should identify any sediment of aeolian origin.

Bull (1978) noted that there was a lack of any uniform acceptance of the number of grains needed for analysis. Studies have used from 10 grains per sample (e.g. Fitzpatrick and Summerson 1971), to 30 grains (e.g. Campbell 1984), to 200 (Vincent 1976). However, Bull (1978) also suggested that 20 grains were probably sufficient and between 15-20 as a standardization to compare with other research work. For an initial analysis nine quartz grains from each horizon were chosen as this is a convenient number to fit on to an S.E.M. stub. In addition Bull (1978) suggested that medium sized grains displayed the best surface textures to indicate depositional environments.

Krinsley and Takahashi (1962) used grains between 0.5-2 microns, whilst Whalley and Krinsley (1974) used grains between 0.25-1.0 microns. The grains for this study of the Erme sediments ranged from 0.5-2 microns. Quartz grains were selected under a low powered microscope from material that had been wet sieved and mounted on stubs with double sided adhesive tape. The grains and stubs were coated with a thin layer of gold in a standard vacuum evaporator. They were examined at magnifications from 35 to 5000x, although most frequently between 100 and 1000x. Photographs were taken during routine examination to aid in identification of the surface textures present.

4.3 Results

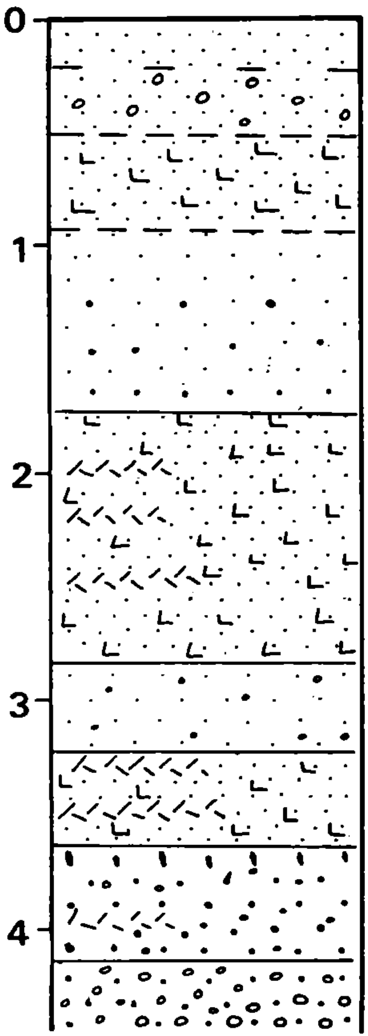
In this section, the results of the physical analyses of the sediments will be presented.

4.3.1 Description of the Cores

Descriptions of the sediments from each of the boreholes are shown in figures 4.10-4.28. The solid lines indicate distinct changes in sediment type and the dashed lines, gradual boundaries. The main layers identified in each core are described below.

SB2

SB2 (figure 4.10, map 4.4) is the furthest upstream and most northerly of all the cores. The top 1m is mainly of sand with some silt and has occasional large rounded pebbles of granite in the top 40cm. This coarsens to sand between 1.1 and 1.7m with no gravel sized material. Between 1.7 and 3.5m a uniform material of silty sand occurs with occasional bark and twigs. This overlies a sand unit at 3.5-4.1m, and between 4.1-4.3m, sandy gravels with rounded pebbles of slate and granite. The fine nature of most of the sediment in this core makes it comparable to the fine-grained sediments in the cores from the tributary valley and some of the horizons of the other main valley cores.



FINE SAND
10YR4/3 brown

FINE SAND with up to 2cm rounded granitic pebbles
10YR4/3 brown

SAND with some silt
10YR4/3 brown

MEDIUM SAND becoming coarser to 1.7m
10YR4/3 brown, 10YR4/2 dark greyish brown

FINE SAND with some **SILT** and bark fragments between 1.9-2m, 2.1-2.2m, 2.4-2.5m
2.5Y4/2 dark greyish brown, 10YR4/2 dark greyish brown

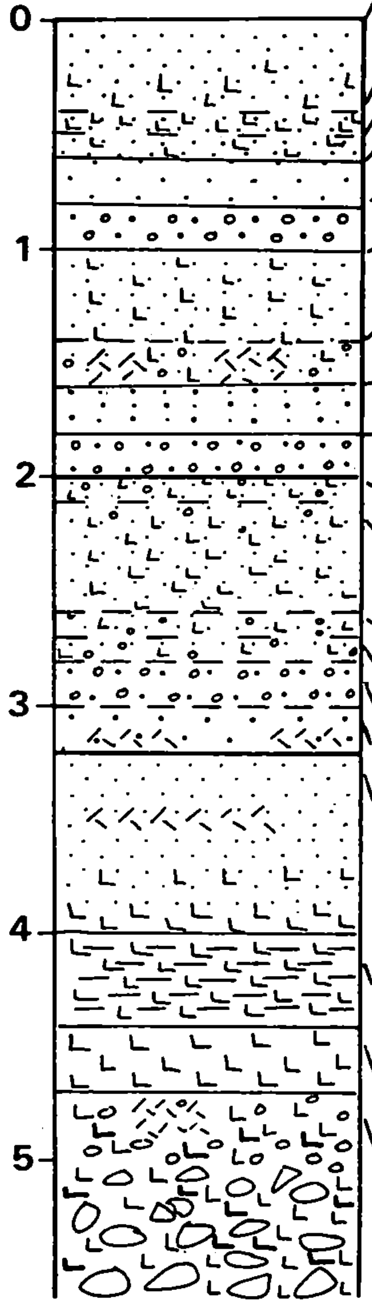
FINE SAND with 2mm sized rounded gravels
2.5Y4/2 dark greyish brown

FINE SAND and some silt with bark fragments between 3.2-3.3m and 3.4-3.5m
2.5Y4/2 dark greyish brown

COARSE SAND some 2mm gravel and occasional bits of organic material
2.5Y4/2 dark greyish brown

SANDY GRAVEL rounded granite and slate
2.5Y4/4 dark greyish brown

FIG 4.10 SEDIMENT DESCRIPTION - SB2



FINE SAND with increasing silt with depth
10YR4/3 brown

SILTY SAND
10YR4/4 dark yellowish brown

SILT and MEDIUM SAND
10YR4/3 brown

SAND
10YR4/3 brown

COARSE SAND with 1cm rounded granitic gravel
10YR4/3 brown

FINE SAND and SILT
10YR4/3 brown in 2.5Y4/2 dark greyish brown

FINE SAND and SILT with some gravel and organic material
2.5Y4/2 dark greyish brown

COARSE SAND bands in FINE SAND - SILT
2.5Y4/2 dark greyish brown

SANDY GRAVEL with rounded granitic clasts to 1cm
2.5Y4/4 olive brown

SILT - FINE SAND with rounded gravel to 6mm
2.5Y4/4 olive brown

SILT - FINE SAND a little gravel
2.5Y4/4 olive brown, 2.5Y4/2 dark greyish brown

SILT - FINE SAND some 4mm sized gravel
2.5Y4/2 dark greyish brown

SILT-SAND rounded 1cm granitic clasts
10Y4/1 dark grey

SANDY GRAVEL with up to 6mm clasts
2.5Y4/2 dark greyish brown

COARSE SAND and 6mm gravel and some bark fragments
2.5Y4/2 dark greyish brown

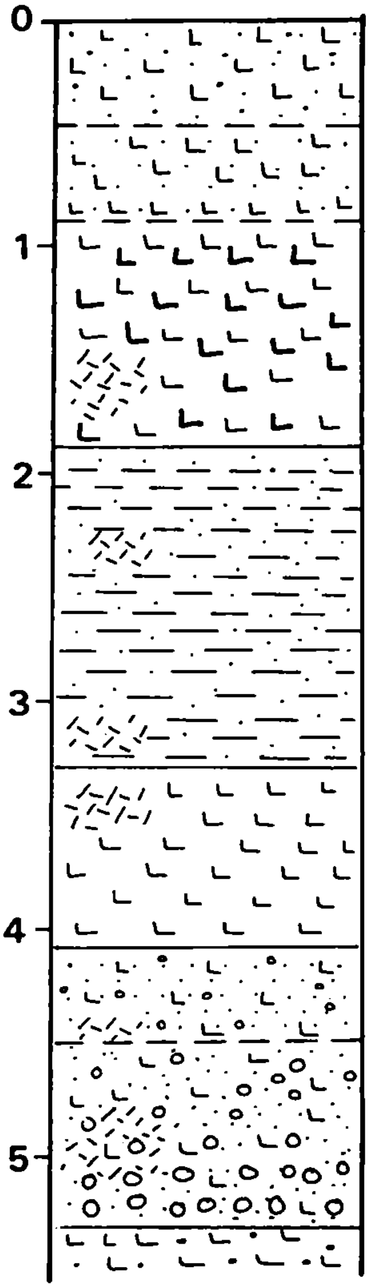
FINE SAND increasing silt content with depth, organic material between 3.4-3.5m depth
2.5Y4/2 dark greyish brown, 10YR3/1 very dark grey, 10YR3/2 very dark greyish brown, 10YR3/3 dark brown, 10YR2/2 very dark brown

ORGANIC SILTS fibrous
2.5Y3/2, very dark greyish brown, 10YR3/1 very dark grey, 10YR4/2 dark greyish brown, 10YR3/3 dark brown

SILT
2.5Y4/2 dark greyish brown, 10YR3/1 very dark grey

TOUGH SILT some clay, banded, with weathered slate and rounded granite to 4cm and some twigs
5Y5/3 olive, 5Y6/3 pale olive, 5Y6/1 light grey, 2.5Y7/6 yellow, 5Y5/2 olive grey, 2.5Y4/2 dark greyish brown

FIG 4.11 SEDIMENT DESCRIPTION - SB1



SILT - FINE SAND with some 2mm granitic and slate gravel
10YR4/4 dark yellowish brown

SILT - FINE SAND becoming finer to SILT
10YR4/3 brown

SILT with some clay, organic material between 1.45-1.65m
10YR4/3 brown, 10YR4/2 dark greyish brown, 10YR3/2 very dark greyish brown

ORGANIC SANDS of peaty nature with bark, wood and twigs, fibrous
10YR2/1 black, 10YR2/2 very dark brown, 10YR3/1 very dark grey, 5Y2.5/2 black

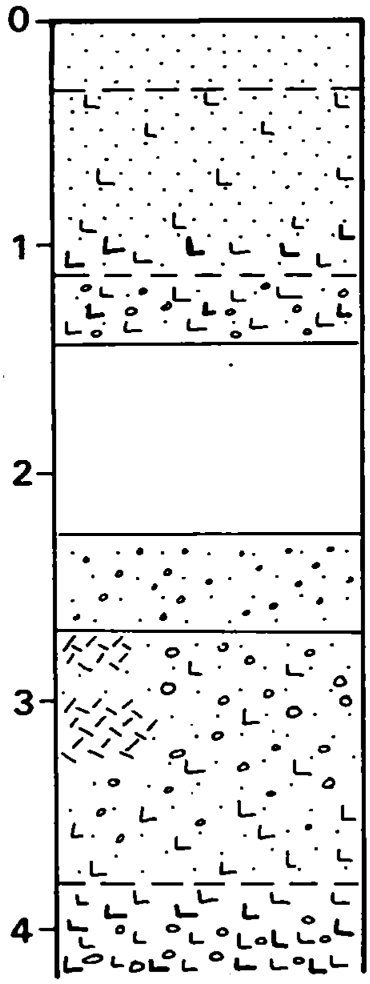
SILT with 2mm granitic, quartz and slate gravel, some organic material between 3.25-3.45m
5Y2.5/2 black, 5Y3/1 very dark grey

SILT - SAND with 1cm slate and granite, bark and twigs between 4.25-4.45m
5Y3/1 very dark grey

SILT - SAND becoming sandier; 3cm sized granitic and slate gravels increasing in percentage of the total to 5.25m. Some organic material - bark, twigs between 4.75-5.05m
5Y2.5/1 black, 5Y2.5/2 black

SILT with 4mm sized granite and slate
5YR2.5/2 black

FIG 4.12 SEDIMENT DESCRIPTION - BH6



FINE SAND
7.5YR5/6 strong brown

FINE SAND / SILT becoming finer with some clay
7.5YR5/6 strong brown

SILT some clay, with 2mm-1cm rounded slate and granitic gravel
10YR4/4 dark yellowish brown, 10YR4/3 brown

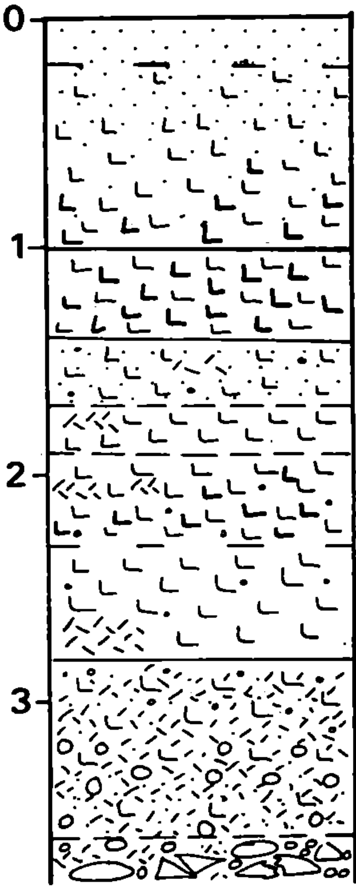
NOT COLLECTED

SAND with some 5mm rounded slate and granite
2.5Y3/2 very dark greyish brown

SAND and SILT layers with up to 2cm slate, granitic and quartz pebbles, bark, twigs and wood fragments, banded
5Y2.5/2 black, 2.5Y3/2 very dark greyish brown, 2.5Y4/2 dark greyish brown, 5Y3/2 dark olive grey

SILT / CLAY with 1cm rounded slate and granitic clasts, some organic layers
2.5Y3/2 dark greyish brown, 5Y6/1 light grey, 2.5Y4/2 dark greyish brown

FIG 4.13 SEDIMENT DESCRIPTION - A1



FINE SAND
7.5YR4/6 Strong Brown

FINE SAND increasing silt and clay
7.5YR5/6 strong brown, 7.5YR6/4 light brown, 7.5YR4/6 strong brown, 7.5YR5/4 brown

SILTY CLAY dark organic layers
10YR4/3 dark brown, 10YR3/2 very dark brown, 2.5YN2/0 black, 10YR4/3 brown

SANDY SILT 1mm slate and quartz, 2 small wood fragments, organic layers
2.5YN3/0 very dark grey, 2.5YN2/0 black

SILT 1mm slate and quartz, a few twigs
2.5YN3/0 black, 2.5YN2/0 black, 10YR4/2 dark greyish brown

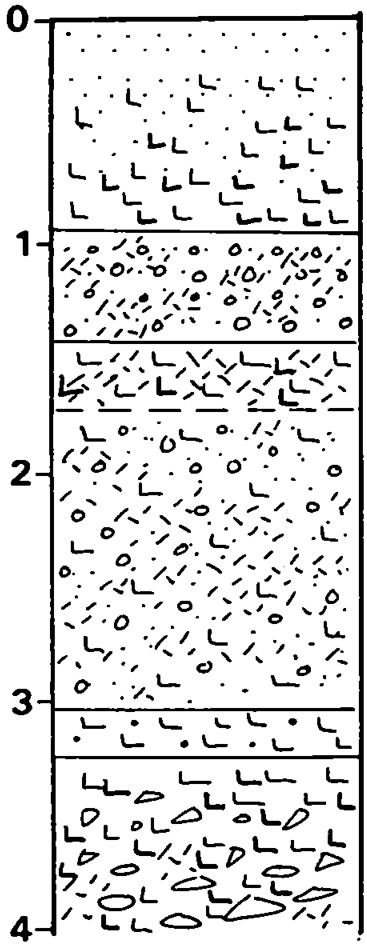
SILTY CLAY 1mm sized clasts and small pieces of wood, banded red and black layers
7.5YR6/6 reddish yellow, 2.5YN3/0 black, 10YR4/2 very dark brown, 2.5YN2/0 black

SILT some organic material
2.5YN2/0 black, 10YR4/3 brown

SILT becoming coarser to **SAND** at 3.4m, 1mm-3cm slate and quartz gravel, and lots of twigs and wood fragments
2.5YN2/0 black, 10YR4/2 very dark brown, 7.5YR6/6 reddish yellow

SAND with 5cm sub-rounded and shattered slate and quartz, some organic material
7.5YR6/6 reddish yellow in 10YR4/2 dark greyish brown

FIG 4.14 SEDIMENT DESCRIPTION - A2



FINE SAND and SILT increasing in silt until **CLAYEY SILT** at 0.9m
10YR4/3 brown, 7.5YR5/4 brown, 7.5YR5/6 strong brown

SAND with 2cm rounded slate and quartz, rich in wood fragments
10YR4/3 brown, 10YR4/4 dark yellowish brown

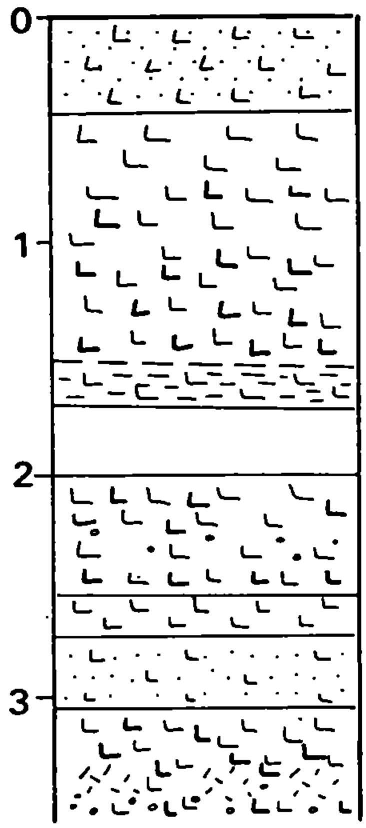
SILT some clay and organic material
10YR4/4 dark yellowish brown, 2.5Y3/2 very dark greyish brown, 10YR4/3 brown

FINE SAND and SILT BANDS with 1mm-1cm sized angular gravels, some bits of wood and seeds of *Scirpus* sp. or *Blymus* sp.
10YR4/2 dark greyish brown, 2.5Y4/2 dark greyish brown, 2.5YN2/0 black

SILT organic material, fibrous, 1-2mm gravel
2.5Y4/2 dark greyish brown, 2.5Yn2/0 black

SILT CLAY, 2cm angular slate, especially from 3.8m depth, yellow, grey and brown layers, some seeds.
2.5YN2/0 black, 10YR4/2 dark greyish brown, 2.5Y7/4 pale yellow, 5Y6/1 light grey, 10YR6/2 light olive grey, 5Y6/3 pale olive, 10YR5/3 brown

FIG 4.15 SEDIMENT DESCRIPTION - A3



FINE SILT / SAND
7.5YR5/4 brown

SILT increasing CLAY to SILTY CLAY at 1.5m, banded
7.5YR5/6 strong brown, 10YR5/4 yellowish brown, 10YR4/2 dark greyish brown, 10YR3/2 very dark greyish brown

ORGANIC SILTS
10YR2/1 black

NOT COLLECTED

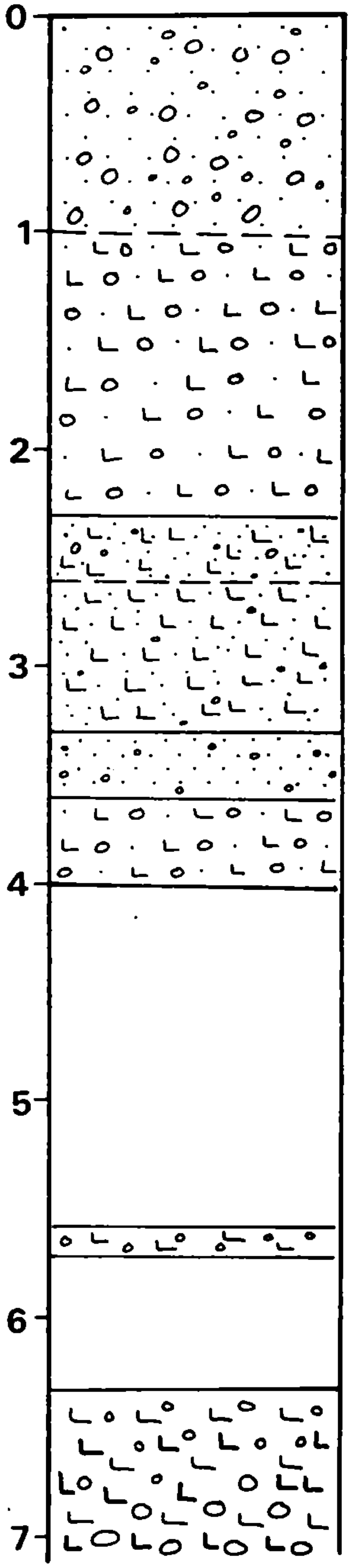
SILTY CLAY with 1-2mm sized slate at 2.2m depth, organic layers
7.5YR6/4 light brown, 7.5YR5/4 brown, 10YR3/2 very dark greyish brown, 10YR2/1 black, 7.5YR6/6 reddish yellow

SILT organic layers
10YR4/3 brown, 10YR2/1 black, 10YR3/2 very dark greyish brown

SILT SAND
10YR2/1 black, 10YR3/2 very dark greyish brown, 2.5Y4/2 very dark greyish brown

SILTY CLAY 2-3mm slate in basal 10cm, some organic material
2.5Y4/2 dark greyish brown, 10YR3/2 very dark greyish brown

FIG 4.16 SEDIMENT DESCRIPTION - A4



SAND with 1-3cm rounded pebbles of quartz, granite and slate
10YR4/3 brown

SILTY SAND 3cm rounded granitic and slate pebbles
2.5Y3/2 very dark greyish brown, 2.5Y2.5/1 black

SILT FINE SAND 2mm gravel, occasional 2cm clasts
5Y2.5/2 black, 5Y3/1 very dark grey

SILTY SAND 1-3mm slate and granitic clasts
2.5Y3/1 very dark grey, 5Y2.5/2 black

FINE SAND 1cm slate and granitic clasts
10Y4/1 dark grey

SILTY SAND 2-3cm rounded slate and granite
10Y4/1 dark grey

NOT COLLECTED

SILT 1cm rounded granite and slate clasts
2.5Y3/2 very dark greyish brown

NOT COLLECTED

SILTY CLAY lots of 3cm rounded pebbles
7.5YR6/4 light brown, 10YR6/4 light yellowish brown, 7.5YR7/4 pink, 7.5YR6/6 reddish yellow

FIG 4.17 SEDIMENT DESCRIPTION - BH1

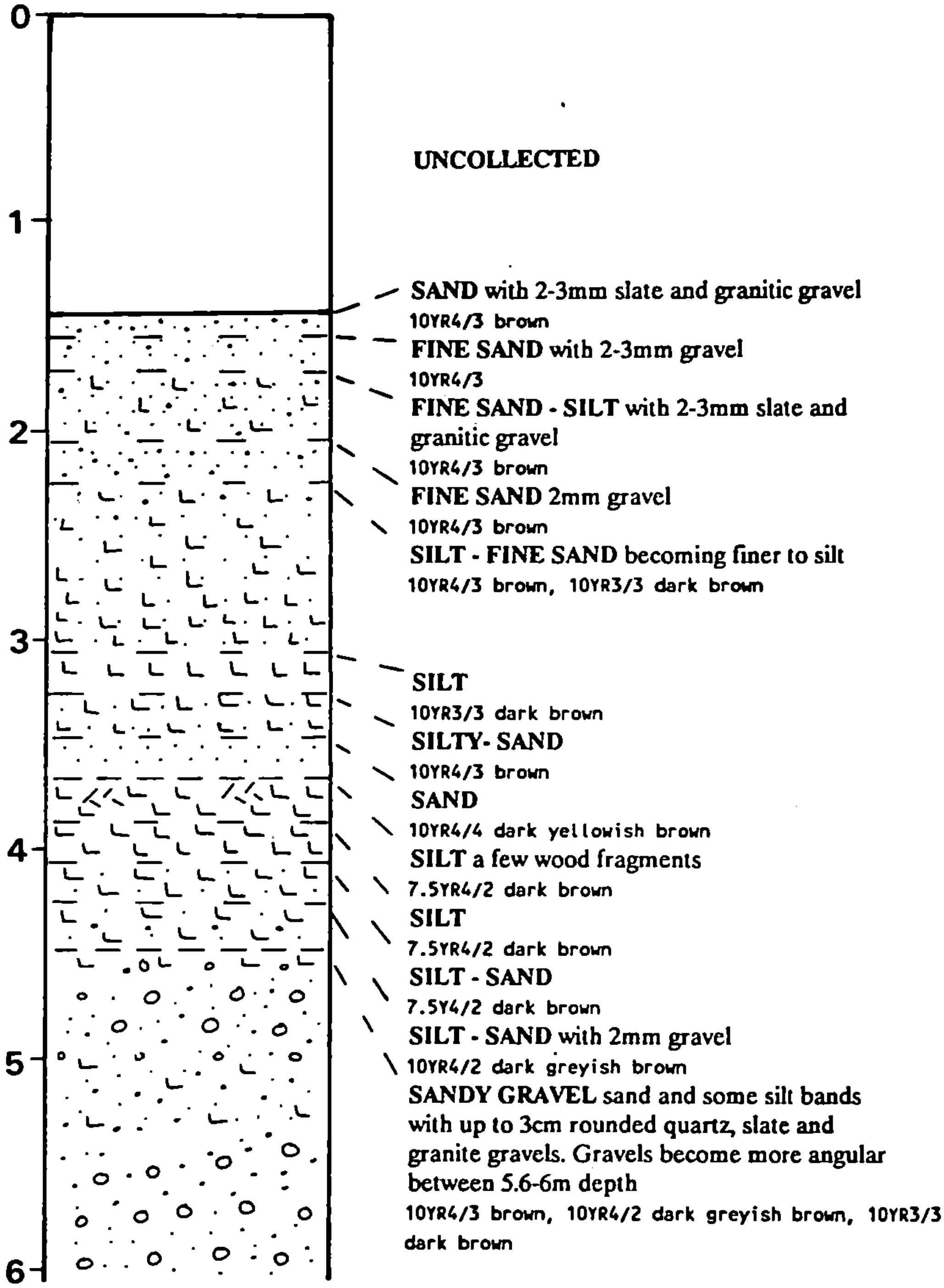
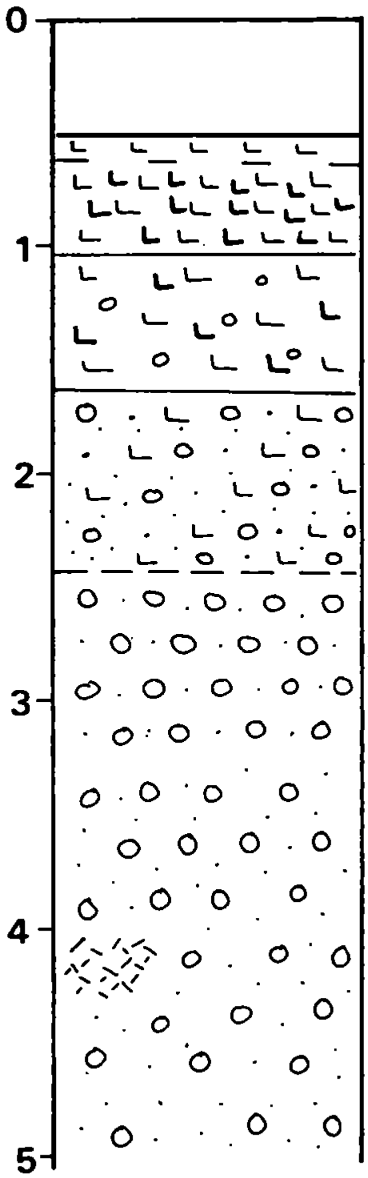


FIG 4.18 SEDIMENT DESCRIPTION - BH4



NOT COLLECTED

SILT
10YR4/4 dark yellowish brown

SILTY CLAY
10YR4/3 brown

SILT with some clay, 2mm-2cm rounded granite and slate clasts
10YR4/4 dark yellowish brown, 10YR4/2 dark greyish brown, 10YR4/3 brown

SILTY SAND up to 2.5cm sized granitic and slate gravels
10YR3/3 dark brown, 2.5Y3/2 very dark greyish brown, 5Y2.5/2 black

SAND 3cm rounded slate and granitic gravels, increasing percentage of gravel with depth, bark fragments between 4-4.2m
5Y2.5/2 black, 2.5Y3/2 very dark greyish brown, 2.5Y4/2 dark greyish brown, 5Y3/1 very dark grey, 10YR4/2 dark greyish brown, 10YR4/4 dark yellowish brown

FIG 4.19 SEDIMENT DESCRIPTION - BH7

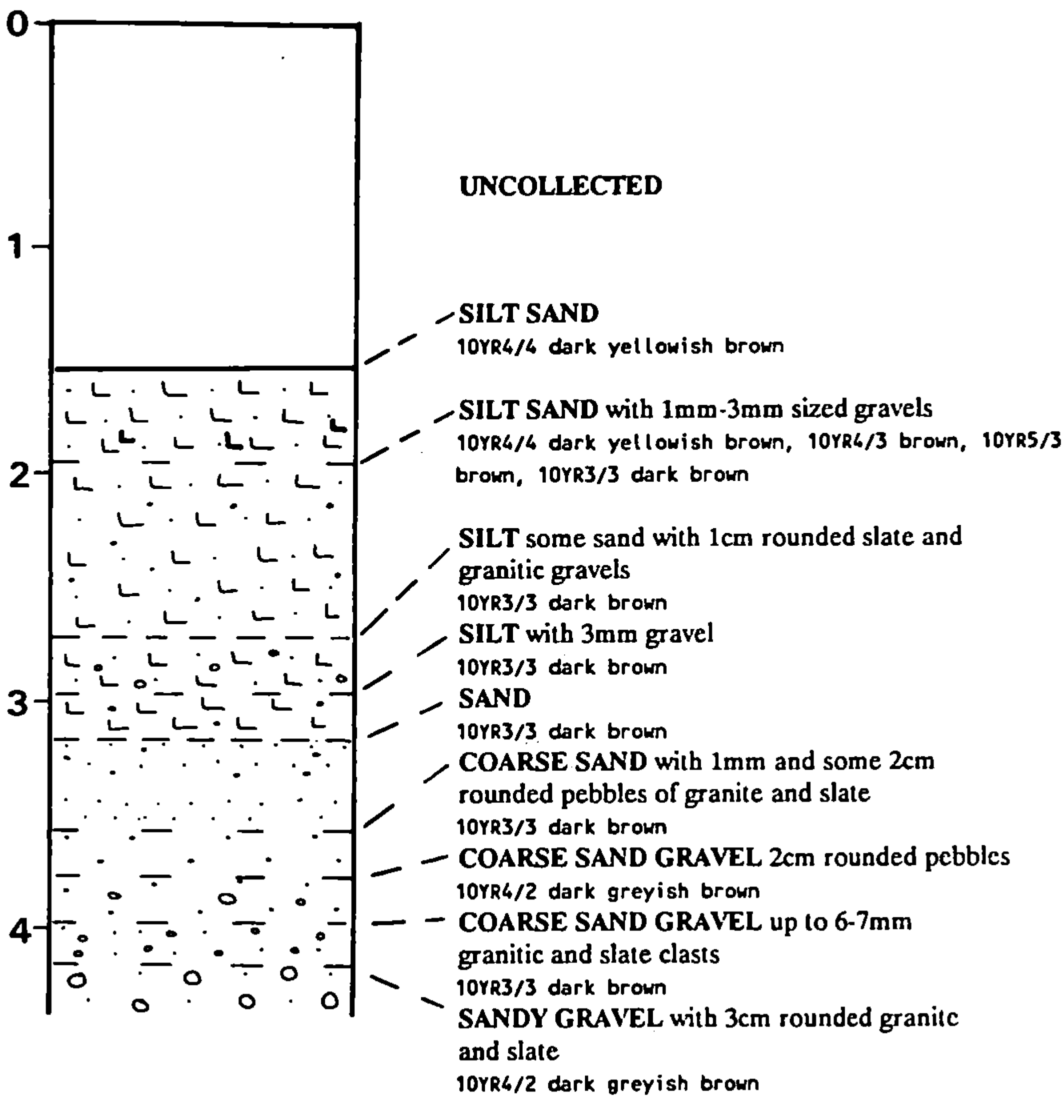
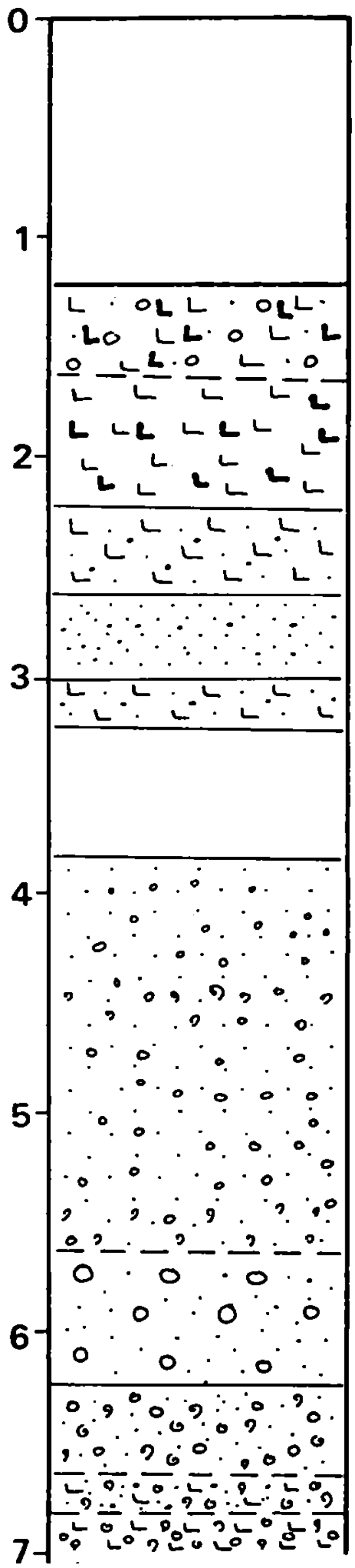


FIG 4.20 SEDIMENT DESCRIPTION - BH9



NOT COLLECTED

SILT / FINE SAND high clay 1-3cm slate and quartz clasts
10YR4/3 brown

SILTY - CLAY
10YR5/3 brown, 10YR3/3 dark brown

SANDY - SILT 2-3mm quartz and slate gravels
10YR4/2 dark greyish brown, 2.5Y3/2 very dark greyish brown

SAND 2mm slate and quartz gravels
2.5Y3/2 very dark greyish brown

SANDY SILT 2-3mm slate and quartz gravels
2.5Y3/2 very dark greyish brown

NOT COLLECTED

SAND with 1mm - 1cm rounded clasts of slate and granite, shell fragments at 4.5m and 5.5m depth
5Y3/2 dark olive grey, 5Y3/1 dark grey, 2.5Y3/2 very dark greyish brown

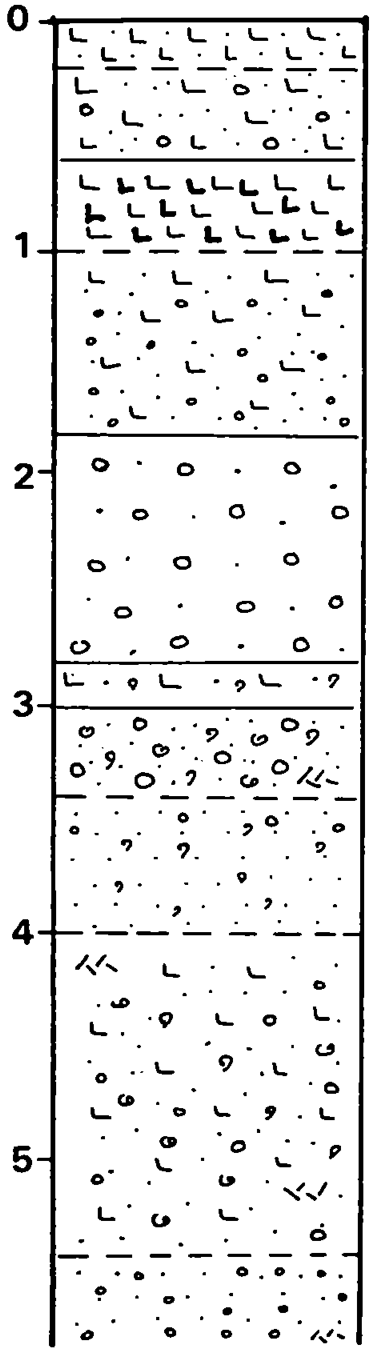
SANDY GRAVELS to 3cm of rounded slate and granite
5Y3/2 dark olive grey, 2.5Y2/0 black

SAND with 1.5cm slate and granite, shell fragments
5Y3/2 dark olive grey, 5Y3/1 very dark grey

SAND - SILT 1cm slate and granite with shells and shell fragments
5Y3/2 dark olive grey

SILT 1.5cm slate and granite clasts, shells and shell fragments
5Y3/2 dark olive grey

FIG 4.21 SEDIMENT DESCRIPTION - BH11



SILT / FINE SAND
10YR4/2 dark greyish brown

SILT / FINE SAND with 2cm rounded granitic and slate pebbles and 1 twig
10YR3/3 dark brown, 10YR5/4 yellowish brown

SILT and CLAY 1-2mm quartz and slate clasts
10YR4/3 brown, 10YR3/3 dark brown

SILT increasing in size to sand at 1.8m, up to 6mm sized clasts
2.5Y3/2 very dark greyish brown, 5Y2.5/2 black

COARSE SAND and GRAVEL 2cm rounded slate and granitic gravels
2.5Y4/2 dark greyish brown

SILTY SAND with some shells
5Y3/2 dark olive brown

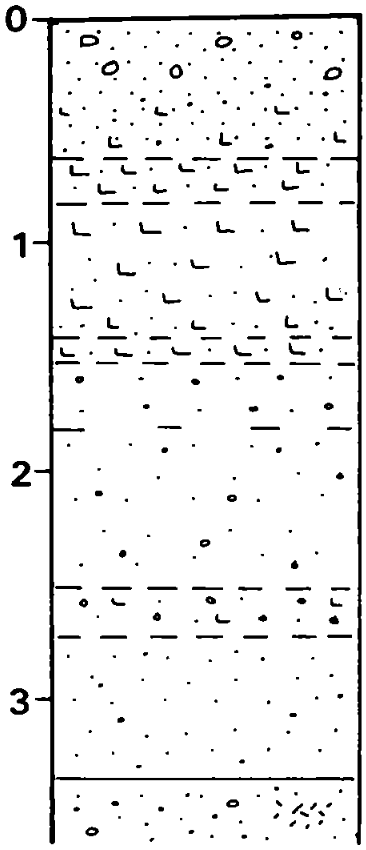
SANDY GRAVEL 2mm- 1cm granite and slate clasts. Whole shells and shell fragments and some bark
5Y3/2 dark olive grey, 5Y3/1 very dark grey

SAND occasionally some 1cm gravel, shell fragments
5Y3/2 dark olive grey

SILTY SAND rounded pebbles of granite and slate to 2cm, shell fragments, some bark
5Y3/2 dark olive grey, 5Y3/1 very dark grey, 5Y4/1 dark grey

SAND 1cm slate and granite pebbles and some bark fragments
5Y3/2 dark olive grey, 5Y3/1 very dark grey

FIG 4.22 SEDIMENT DESCRIPTION - BH12



SAND, silt increases and gravel decreases with depth
10YR3/3 dark brown

SILT, SAND and a little gravel
10YR3/3 dark brown, 10YR4/3 brown, 10YR5/3 brown

SILT - increase in fine sand to 1.4m depth, a little gravel
10YR5/3 brown, 10YR4/2 dark greyish brown, 2.5Y4/2 dark greyish brown

SILT / FINE SAND layers
5Y3/2 dark olive grey

SANDY GRAVEL - 2-3mm gravel
5Y3/2 dark olive grey

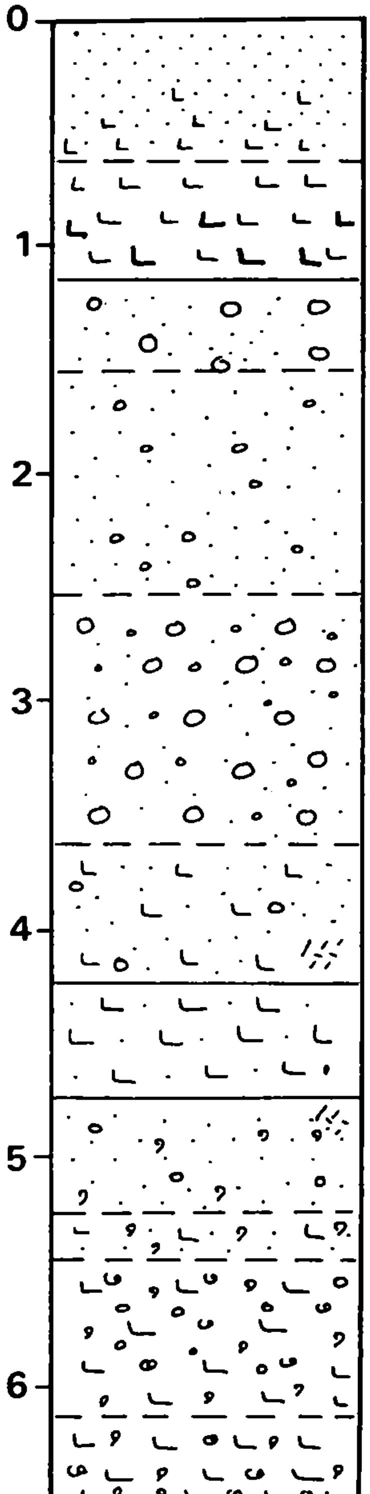
COARSE SAND becoming gravelly with depth
2.5Y4/2 dark greyish brown

SAND / SILT / GRAVEL bands
5Y3/2 dark olive grey, 5Y3/1 very dark grey

SAND some 2mm slate and quartz
5Y3/1 very dark grey, 5Y3/2 dark olive grey

COARSE SAND and **GRAVEL** 1cm slate and granitic gravels, some organic material - twigs and bark at 3.4-3.5m
5Y4/2 olive grey

FIG 4.23 SEDIMENT DESCRIPTION - RM4



FINE SAND, some silt, a little gravel
10YR4/4 dark yellowish brown, 10YR4/3 dark brown

SILT - increasing clay percent
10YR4/2 dark greyish brown, 5Y3/1 very dark grey, 5Y4/2 olive grey

SANDY GRAVEL - 2cm granitic clasts
2.5Y4/2 dark greyish brown

COARSE SAND - 1cm gravel
2.5Y4/2 dark greyish brown, 10YR4/2 dark greyish brown

COARSE SAND and GRAVELS 0.5-2cm rounded clasts
2.5Y4/2 dark greyish brown, 2.5Y4/3

SILT, SAND with gravel 1-2cm, some organic material
10YR4/1 dark grey, 2.5Y4/1 dark grey, 2.5Y4/2 dark greyish brown, 5Y3/1 very dark grey

FINE SAND / SILT, some 2mm gravels, black organic layers
2.5Y4/2 dark grey, 5Y3/2 dark olive grey, 5Y4/1 dark grey, 5Y3/1 very dark grey

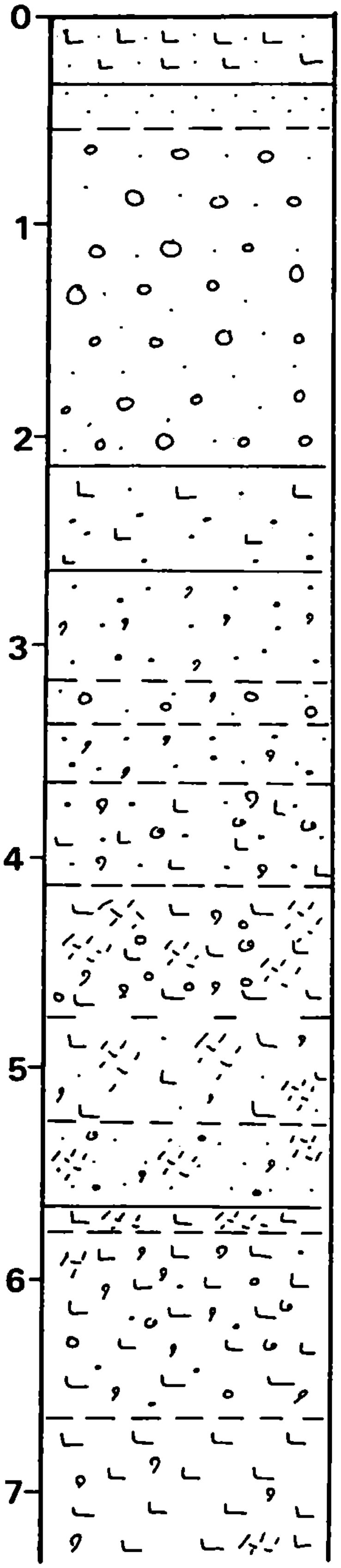
SAND with up to 1.5cm gravel, shell fragments and some organic material
5Y3/1 very dark grey

FINE SAND / SILT some 1cm slate gravels, shells
5Y4/1 dark grey

SILT with 1cm mixed gravels decreasing to 6.1m depth, shells
5Y4/2 olive grey, 5Y3/2 dark olive grey

SHELLY SILT
5Y4/2 olive grey

FIG 4.24 SEDIMENT DESCRIPTION - RM3



SILT / FINESAND
10YR4/3 brown

SAND with some granitic gravel
10YR4/4 dark yellowish brown

SANDY GRAVEL - rounded granite between 0.5-2cm
10YR5/5 yellowish brown, 10YR5/4 yellowish brown

SILT/ FINE SAND - with some 2mm gravel
10YR5/4 yellowish brown, 5Y4/1 dark grey

COARSE SAND 2mm-5mm gravels, some shell fragments
5Y4/1 dark grey

COARSE SAND and GRAVEL to 1cm,fining downwards, shells and shell fragments
2.5Y4/2 dark greyish brown

SAND
2.5Y4/2 dark greyish brown

SILT / SAND 3mm gravel, shells and shell fragments
5Y4/1 dark grey, 2.5Y4/2 dark greyish brown

SILT 3mm gravel, and occasionally some 1cm size gravel, organic material-bark, shells
5Y4/2 dark greyish brown

SILT/ FINE SAND organic material and shells
5Y4/2 dark greyish brown

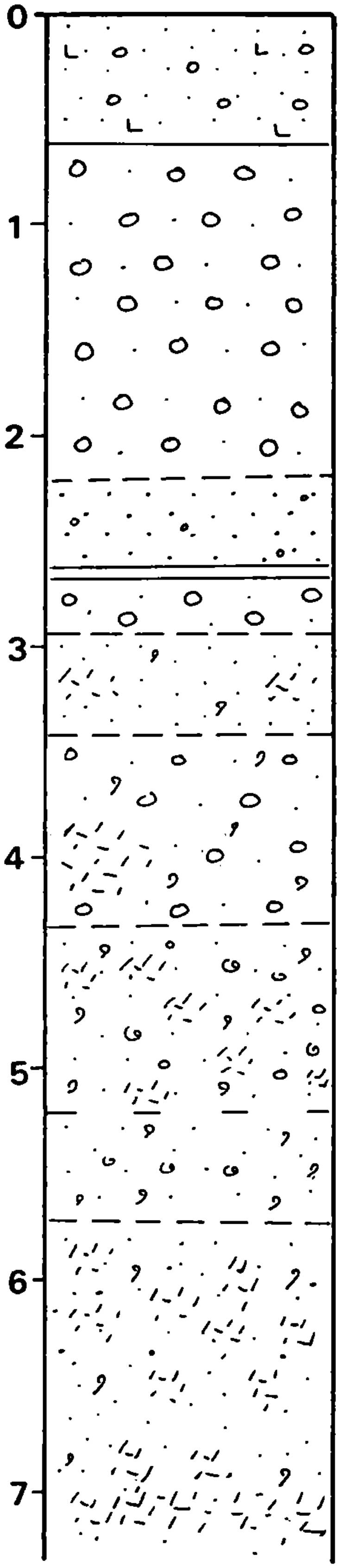
FINE SAND 5mm gravels, a few shells and organic material
5Y4/2 dark greyish brown

SILT organic material and shells
5Y4/2 dark greyish brown

SILT 2mm and some 2cm gravels, shells and some organic material between 5.8-5.9m
5Y4/2 dark greyish brown

SILT fining downwards, shells and a little organic material
5Y4/2 dark greyish brown

FIG 4.25 SEDIMENT DESCRIPTION - RM2



SAND with silt and rounded slate and granitic gravels to 2cm
10YR5/4 yellowish brown, 2.5Y4/2 dark greyish brown

SANDY GRAVEL - rounded granite and slate 0.5-2cm, decreasing in size with depth
2.5Y4/2 dark greyish brown, 2.5Y4/4 olive brown, 10YR5/4 yellowish brown

COARSE SAND a little gravel
2.5Y4/2 dark greyish brown

SANDY GRAVEL
2.5Y4/2 dark greyish brown

COARSE SAND - little gravel, with shells and organic matter from 3.1m
10YR3/1 very dark grey, 5Y4/1 dark grey, 2.5Y4/2 very dark grey

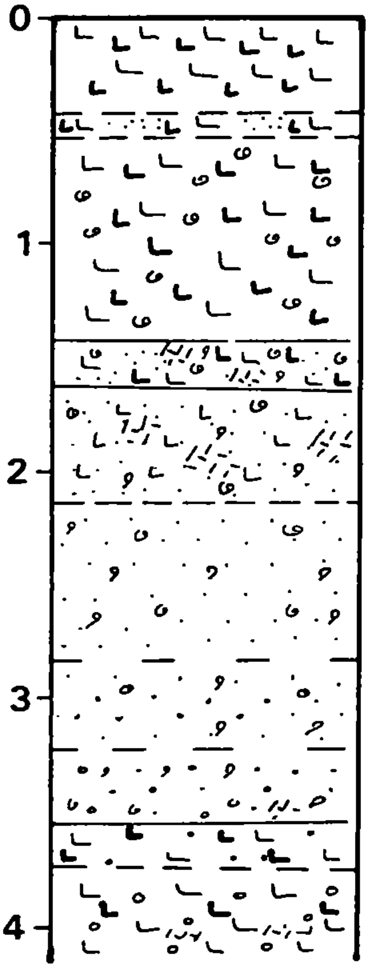
SANDY GRAVEL shells and some organic material
5Y4/2 dark yellowish brown, 5Y4/1 dark grey, 2.5Y3/1

COARSE SAND decreasing gravel size, shells and organic material
2.5Y4/2 very dark grey

SAND organic material and shells
5Y4/2 dark greyish brown

FINE SAND bands of macrofossils betweeen 6.9-7m, a few shells
5Y4/1 dark grey, 10YR3/2 very dark greyish brown

FIG 4.26 SEDIMENT DESCRIPTION - RM1



SILTY CLAY
10YR4/3 brown

SILTY CLAY with sand lenses
10YR4/4 dark yellowish brown, 10YR5/3 brown

SILTY CLAY organic material between 0.7-1.3m, 1.3-1.4m small gastropods, mottling
5Y6/1 grey, 10YR5/3 brown, 2.5Y4/2 dark greyish brown, 5Y4/1 dark grey

SILTY CLAY and SAND shells, organic material and 1-2mm gravels
5Y3/2 dark olive grey

FINE SAND and SILT shells
5Y3/2 dark olive grey

SAND coarsening downwards, shells
5Y3/1 very dark grey, 5Y3/2 dark olive grey, 5Y4/1 dark grey

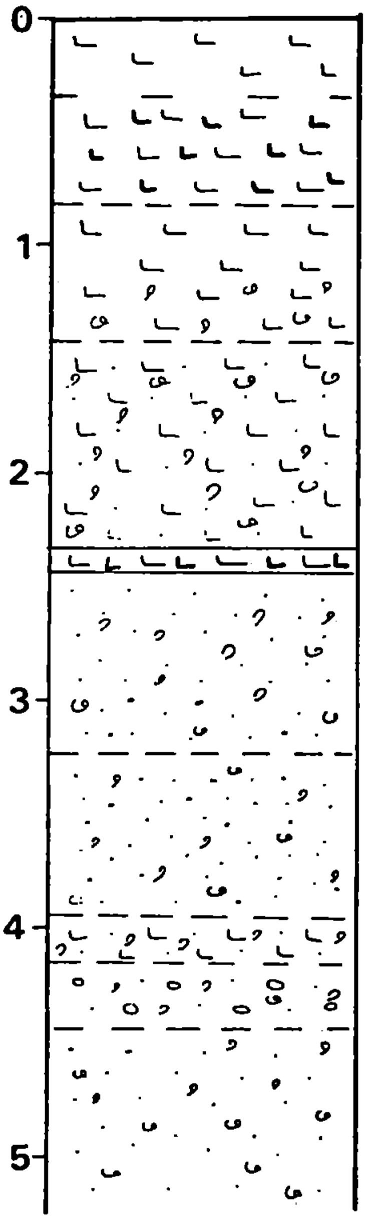
COARSE SAND shells and mottling
7.5YR4/4 dark brown in 5Y3/1 dark grey

COARSE SAND 3-4mm gravel, shells and organic material
2.5Y4/2 dark greyish brown, 10YR6/4

SILTY CLAY 3-4mm gravel
2.5Y7/2 light grey, 2.5Y8/2 white, 10YR7/4 very pale grey with lenses of 5Y3/1 very dark grey

ROUNDED GRAVEL in SILT CLAY with organic layers
2.5Y4/3 olive brown, 2.5Y7/2 light grey, 10YR 6/3 pale brown, 10YR 4/2 dark greyish brown

FIG 4.27 SEDIMENT DESCRIPTION - S1



SILT current salt marsh, roots
10YR3/3 dark brown, 10YR4/2 dark greyish brown, 10YR5/2 greyish brown

SILTY CLAY with fibrous roots
2.5Y4/2 dark greyish brown

SILT organic streaks, shells from 1.2m depth and organic layers
10YR4/1 dark grey with 2.5YN2/0 black, 5Y4/1 black

SILT/ FINE SAND occasional 2mm sized gravel beyween 1.6-2m, shells and some organic material 1.6-1.7m
5Y3/1 very dark grey, 10YR4/2 dark greyish brown, 5Y4/1 dark grey

SILTY CLAY very organic, reddish brown
10YR5/3 brown, 10YR5/2 greyish brown

SAND shells and 2-3mm gravel between 3-3.2m, orange layers
5Y3/1 very dark grey, 2.5Y4/2 dark greyish brown, 10YR4/6 dark yellowish brown, 10YR4/4 dark yellowish brown, 2.5YN3/0 very dark grey

COARSE SAND AND GRAVEL with a few shells and grey silt lenses at 3.9m
10YR5/4 yellowish brown and streaks of 2.5Y4/2 dark greyish brown, 5Y4/1 dark grey

SILT SAND shells
5Y4/1 dark grey

SANDY GRAVEL shells
5Y3/1 very dark grey

COARSE SAND shells with some slate gravels to 1.5cm between 4.9-5.2m depth
5Y3/1 very dark grey

FIG 4.28 SEDIMENT DESCRIPTION - S2

SB1

SB1 (figure 4.11, map 4.4) has coarser material than SB2 and the two sequences of sediment are not very comparable. The top 60cm is composed of silt-fine sand bands; this overlies a unit of 20cm of sand. From 0.8-3.2m, bands of silt and sand similar to the middle units of SB2 alternate with gravel layers (absent from SB2). This overlies horizons of sandy gravel between 2.8 and 3.2m. From 3.2m to 4.7m the unit is predominantly silt with some banding, no gravel and some organic material; this can probably be correlated with similar sediments from SB2. Between 4.7m-5.6m a tough silty-clay material is present and contains up to 4cm sized granite, quartz and slate material and is similar to the tough units recognised in the tributary valley at the base of the cores.

BH6, A1, A2, A3, A4

In boreholes 6 and A1-A4 (map 4.6) the top horizons (1.8m in 6, 1.5m in A4, 1m in A3, A2 and A1) are similar in that they are predominantly composed of fine sand, silt and silty-clay material fining downwards. In most cases they contain little or no gravel and show some mottling, varying between strong brown to yellowish brown in colour.

BH6

The upper layers of BH6 (figure 4.12, map 4.6) are mainly of silt and fine sand. Between 1.85 and 3.05m in BH6 a black organic silty-sand (sand=50%) is present containing twigs and bark. From 3.25-4.05m, 2mm sized slate (33%) and quartz (67%) are present in a silt (65%) matrix. At 4.25m, this changes to a silty-sand matrix with up to 3cm rounded granite (66%) and slate (34%) pebbles and also containing organic material. Between 5.05-5.25m gravel makes up 41% of the total (70% granite, 30% slate). The clasts are predominantly granite in BH6, usually accounting for c. 70% of the total. The exception is at 2.65m where 50% of the material is slate. This lower unit may be equivalent to sandy gravel units in A1-3 which contain organic material.

A1

Between 1.1m and 1.4m depth in A1 (figure 4.13, map 4.6), 1cm sized gravel in a silt matrix is present. From 2.25m in A1, a mixture of silt, sand and fine gravels occur. Rounded pebbles (up to 2cm in size) of slate, granite and quartz and lots of fragments of bark and twigs occur from 2.75m to 3.75m and it is probable that this correlates to the lower middle portion of A3 and A2. This overlies a unit of tough silty-clay from 3.75-4.15m depth with large (1-2cm) pieces of slate which is probably equivalent to lower units in A3 and A4.

A2

Between 1.4m-2.3m in A2 (figure 4.14, map 4.6), a horizon of sandy-silt grades to silty-clay with 1-2mm clasts of slate and vein quartz. This overlies a horizon grading from silt to fine sand, and sand and sandy gravel with slate gravels increasing in size from 1-2mm at 2.7m depth to 5cm at 3.8m. Organic material in the form of bits of wood occurs from 1.5m down to the base.

A3

From 0.9-3.2m in A3 (figure 4.15, map 4.6) sand and silt layers with 1mm-1cm sized rounded gravels occur; At 1.2m depth the sediment is composed of 30% gravel and 30-50% sand. Bark and twigs are present throughout this unit with an increased concentration at 2m depth. Between 3.2-4m, pale yellow and light grey silts with angular slate to 3cm size was found (gravel 36%, sand 37%), this is similar to the base unit in A1, A2 and SB1 without any large slate input. Seeds, obtained during wet sieving, were found between 0.8m to 3.9m and are most probably Scirpus or Blymus. Most of the sediment of 0.5mm size or larger is slate and vein quartz, although granite makes up 37% of the gravels and sands in the top 0.5m of the core, whilst between 3.6-4m, slate makes up 89-93% of the total. Between these two layers, slate accounts for 47-79% with varying amounts of vein quartz.

A4

Sediments from core A4 (figure 4.16, map 4.6) are of silt-sand and silt-clay horizons with a band of organic silts at 1.5-1.7m depth. Some 2-3mm sized slate occurs at the base at 3.5m. The basal horizon is a tough olive grey clay with silt. Some organic matter in the form of twigs and bark is present between 3.1-3.5m. The base unit is probably equivalent to that in SB1 and A1-A3.

BH1

In BH1 (figure 4.17, map 4.5) the top 2.3m is composed of 2-3cm rounded pebbles, mostly granitic (89%), in a sand and silty-sand matrix. Below this, between 2.3-3.3m, smaller 2-3mm sized gravel occurs in a finer silty (32-36%) sand (50%) matrix. This overlies a unit of 1-3cm sized gravel (21%) in sand (44%) and silt. Sediment from the middle part of the core was too saturated to collect. At 6.3m a reddish yellow silty-sand containing 3cm rounded pebbles of granitic and slate rocks, with up to 10% clay and 37% gravel is present. This horizon may be equivalent to the base layers as described in the cores above, although it is different in colour and the gravels are more rounded.

BH4

Sediments from BH4 (figure 4.18, map 4.5) are comparable to those from the tributary valley. The top 1.4m was not collected because of waterlogging. The units from 1.4m to 3m are of sand with 2-3mm slate and granitic gravels, decreasing in size with depth to a silt with little gravel. From 3m to 4.4m, a silt to silty-sand horizon with organic material was found; this may be considered as equivalent to the 1.85-3.05m horizon in BH6. Between 4.4m-6m, sand, silt and gravel horizons with rounded pebbles of granite, slate and quartz to a maximum diameter of 3cm are present; the pebbles become more angular at 5.6m. This unit may be equivalent to the lower unit of BH6.

BH7

Core BH7 (figure 4.19, map 4.5), on the opposite side of the valley to BH1, has an upper fine layer of silt (66%) and clay (17%). This overlies a mixture of sand (25-42%) and silt (14-49%) dominant units which contain up to 2.5cm rounded gravels. These continue to 5m depth, where gravel makes up 42% of the total; this horizon is possibly equivalent to the gravel horizon in BH4. BH7 is composed of mainly granitic material which varies from 62-89% of the total; slate accounts for 39% at 3.7m.

BH9

The top 1.5m of BH9 (figure 4.20, map 4.5) was not collected because of difficulties in drilling. BH9 contains silt-sand units in the upper part of its core between 1.5-3.5m, with small 1-3mm sized gravel. At 1.5m, clay makes up 12% of the total, silt 44-39% and sand 41-55%, thus it is probably comparable to the upper fine units in some of the other cores. These change to coarse sandy gravels (26-38% gravel, 56-44% sand and 13% silt) between 3.7m-4.3m where pebbles of up to 3cm occur; this is probably equivalent to the gravel horizons in cores BH4 and BH7.

BH11

The top 1.2m of BH11 was not collected (figure 4.21, map 4.5). From 1.2-2.2m silt and clay (16%) predominate with some rounded pebbles of 3cm at 1.5m. Between 2.2 and 3.2m, silt-sand (40% sand, 44% silt, 11% clay) containing 2-3mm gravel is present, with a sand layer at 2.7m (56%sand, 6% clay). Between 3.8m-6.2m, sandy gravel is present and contains variable sized rounded gravel from 1mm to 3cm; the total gravel percentage varies between 11-35% and sand from 47% to 63%. At 4.5 and 5.5m shell fragments occur. From 6.2-7m, sand (52%) grades to silt (57%) and includes gravel to 1.5cm diameter; many shell fragments and whole shells are present in this horizon.

BH12

The top horizon in BH12 (figure 4.22, map 4.7), from 0-1.8m, grades from a silty sand with 2cm sized gravel (24%) to silt (49%) with 2mm (3%) sized gravel and 14% clay and then to a silt-sand (37% sand, 37% silt) at 1.6m. Between 1.8m-2.8m, coarse sand with 2cm rounded pebbles of granite occur (36% granite, 50% sand). From 2.8m to 5.8m, sandy gravel and silt-sand units with up to 2cm rounded pebbles of slate and granite are present; the sand percentage varies from 37-49% and silt from 27-51%. Mollusc shells and shell fragments are present from a depth of 3m; this unit must be comparable with the horizon from BH11 which also contains shells.

RM4

The top 60cm of RM4 as shown in figure 4.23 (map 4.7), is composed of sand and silt bands with some granitic gravel, these grade to silt with fewer clasts between 0.8 and 1.4m. From 1.4m to 3.6m depth sand and sand-gravel horizons are present.

RM3

The top 1m of RM3 (figure 4.24, map 4.7) is composed of sand and silt with little gravel. This becomes sandy gravel at 1.1m and sandier between 2.5-3.6m. Between 3.6-5.3m horizons of silt-sand with some gravel and shells from 4.7m occur and from 5.3m-6.5m shelly silt is predominant with some 1cm sized gravel.

RM2

The top half metre of sediment from RM2 is of silt and sand (figure 4.25, map 4.7). Sandy-gravels are present for the upper part of the sediment in RM2 with shell fragments from at least 2.6m depth. This is characterised by bands of silt and sand with gravels varying from 2mm to 2cm in size. From 3.7m most of the core is silt rich, with occasionally 2mm-1cm sized slate gravels and many shell fragments.

RM1

The top 2.8m of RM1 (figure 4.26, map 4.7) is composed of sandy gravel containing 2cm sized rounded granitic and slate pebbles. This overlies coarse sand to 5.7m depth containing some gravel bands; after which there is a general decrease in particle size to sand between 5.7m and 7.3m. Molluscan shell fragments are present from 3.1m and occasionally pieces of wood are found.

S1

The top 1.4m of S1 (figure 4.27, map 4.8) is silty-clay with some small amounts of wood fragments and no gravel. Between 1.4m and 3.2m silt grades to coarse sand. Mollusc shell and shell fragments are common 1.3m depth. At 3.2m there is a distinct change to a horizon of coarse sand with 3-4mm slate fragments; this grades to a silty horizon with rounded pebbles.

S2

The top horizon of S2 (figure 4.28, map 4.8) is predominantly silt and silty-clay, at 1.3m a change to shelly silt-sands takes place, with a distinct silt clay layer between 2.3-2.4m. Shelly-sands occur between 2.4m-3.2m where coarse sand and gravel sediments with few shells is present followed by coarse sand at 4.3m. Large slate gravels occur at the base of this core at 5.2m.

4.3.2 Size Analysis

The weight and percentages of the different sized fractions have been calculated and are presented as histograms and cumulative frequency graphs in figures 4.29-4.43. Summary diagrams of the change of particle size with depth for each borehole are shown in figures 4.44 and 4.45; they are divided into textural classes of gravel, sand, silt and clay according to the Wentworth Scale. These summary data are provided in appendix 1.

These diagrams show that in cores BH6, BH7, BH9, BH11 and BH12 the clay fraction decreases with depth. In BH1 the clay percentage is fairly uniform throughout the core with an increase at the base where some pinkish-red clay with large clasts was found. The clay and silt fractions were not separated out from cores SB2 and A3. The silt fractions similarly decrease with depth in BH1, BH7, BH9 and BH6 initially due to an increase in the sand content and then an increase in gravel at the base of these cores. Core SB2 has very little gravel content, with a slight increase at the base, it is predominantly sand with an increase in silt between 2 and 3m OD. Changes in the silt and clay content in core A3 are due to increases in gravel at 1.5, -0.5 and -1m OD. In BH11

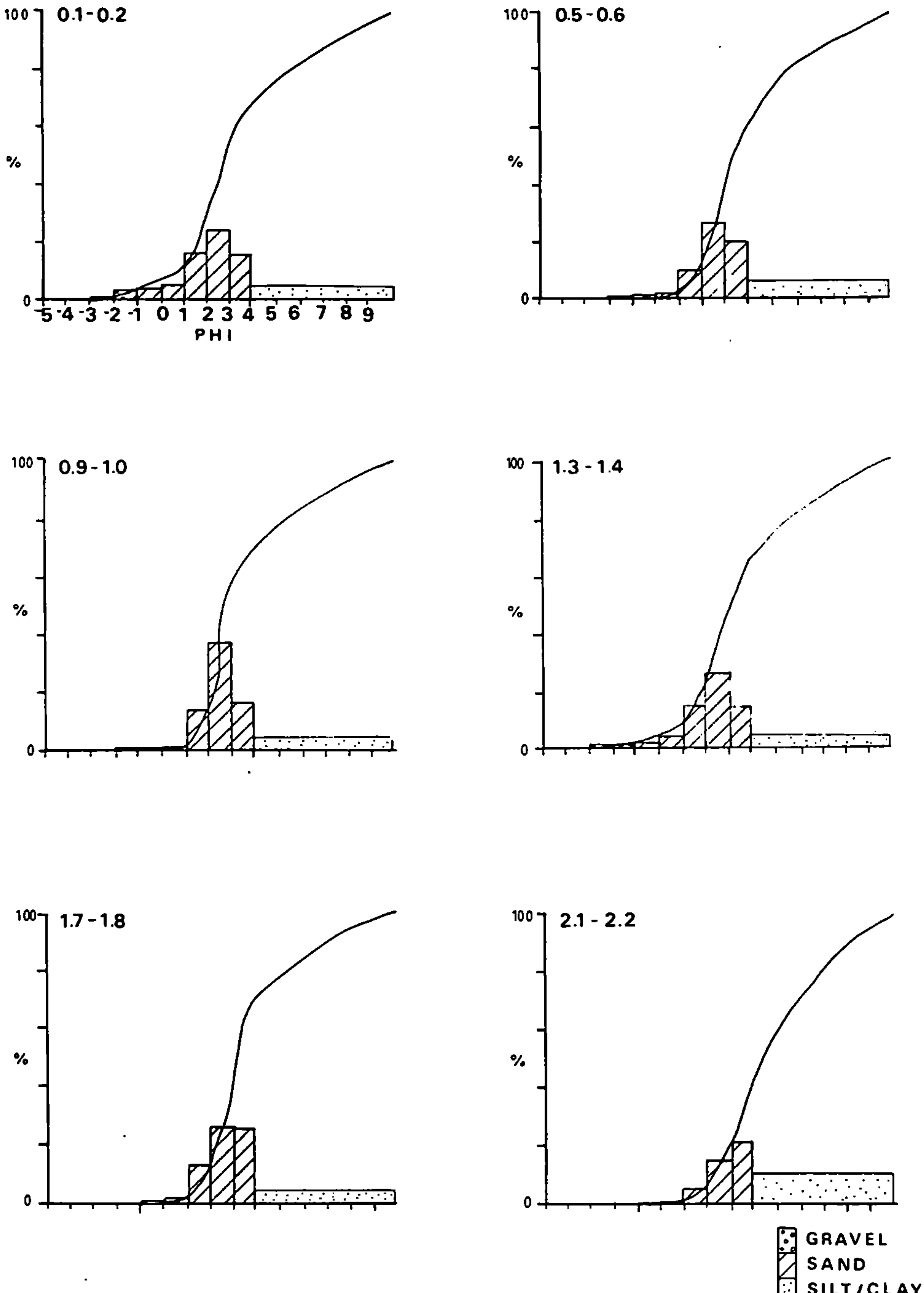


FIG 4.29 Particle size distribution for sediments from core SB2

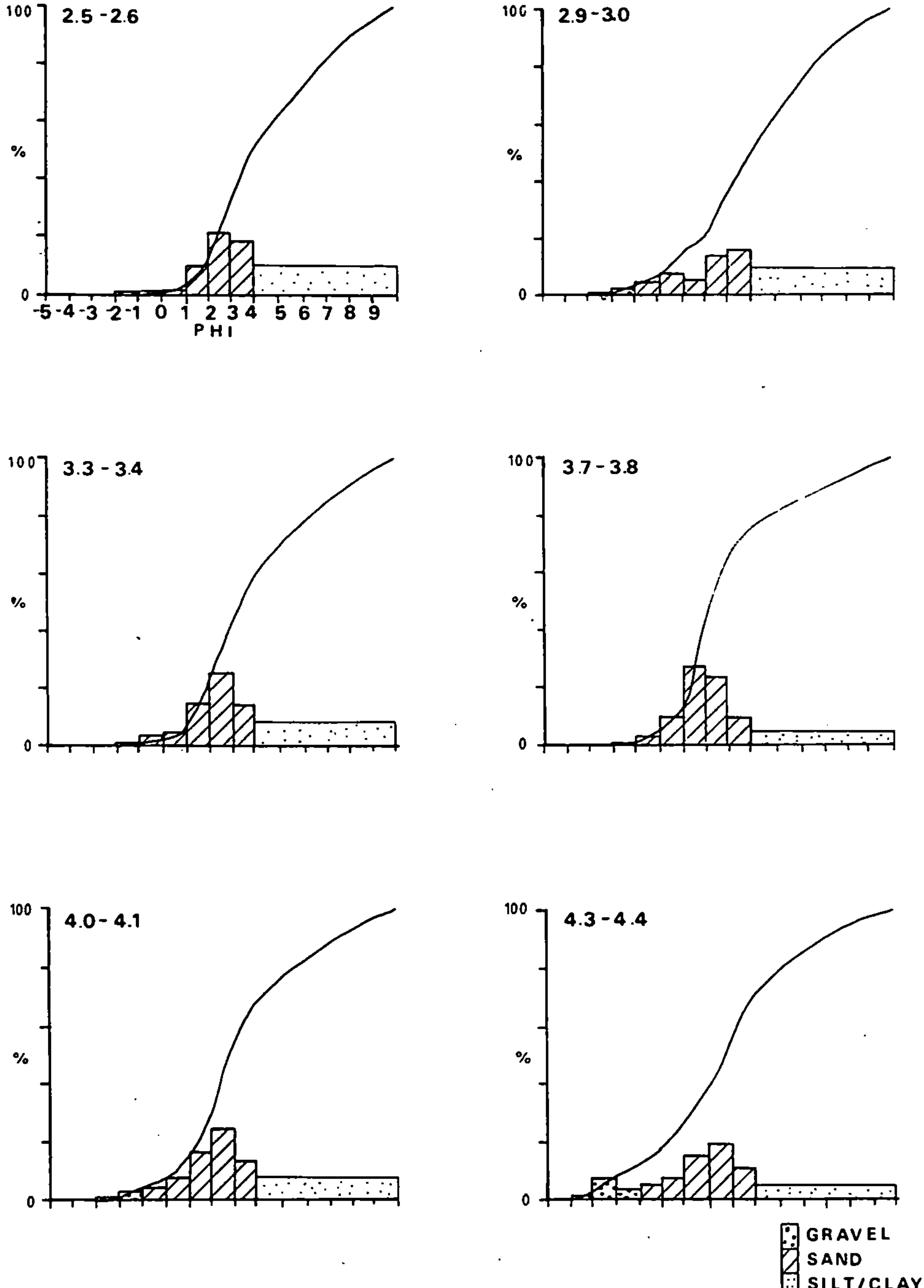


FIG 4.30 Particle size distribution for sediments from core SB2

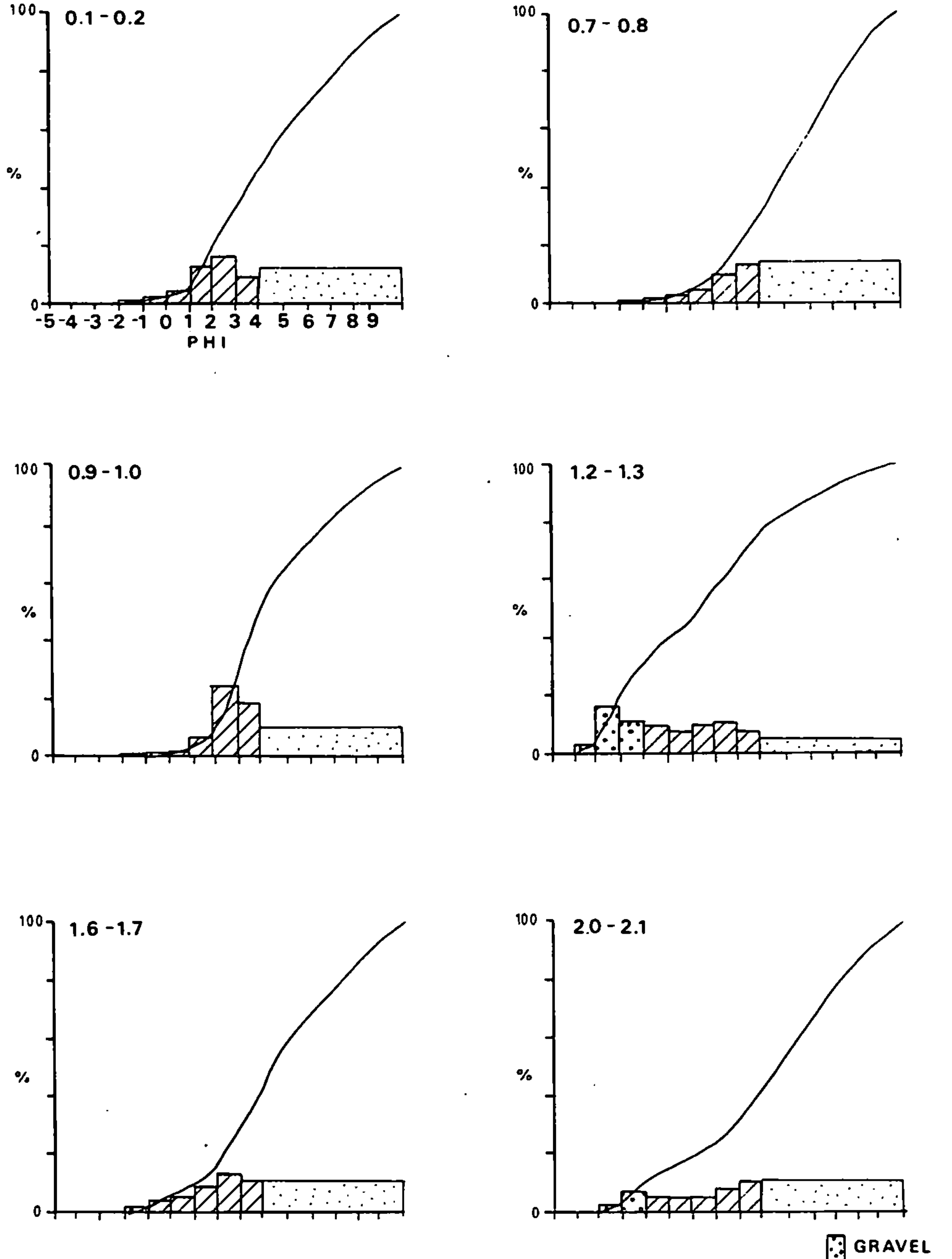


FIG 4.31 Particle size distribution for sediments from core A3

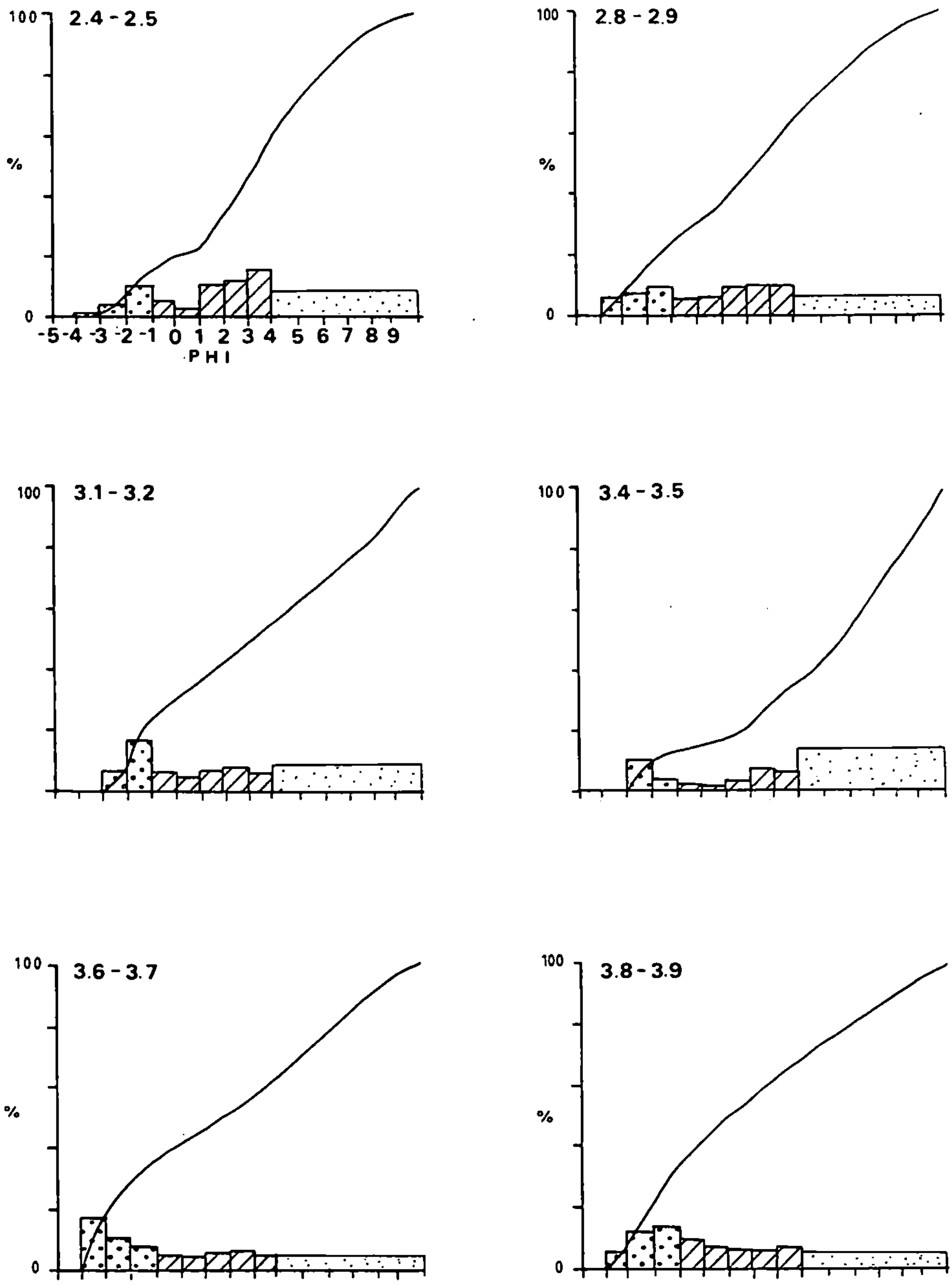


FIG 4.32 Particle size distribution for sediments from core A3

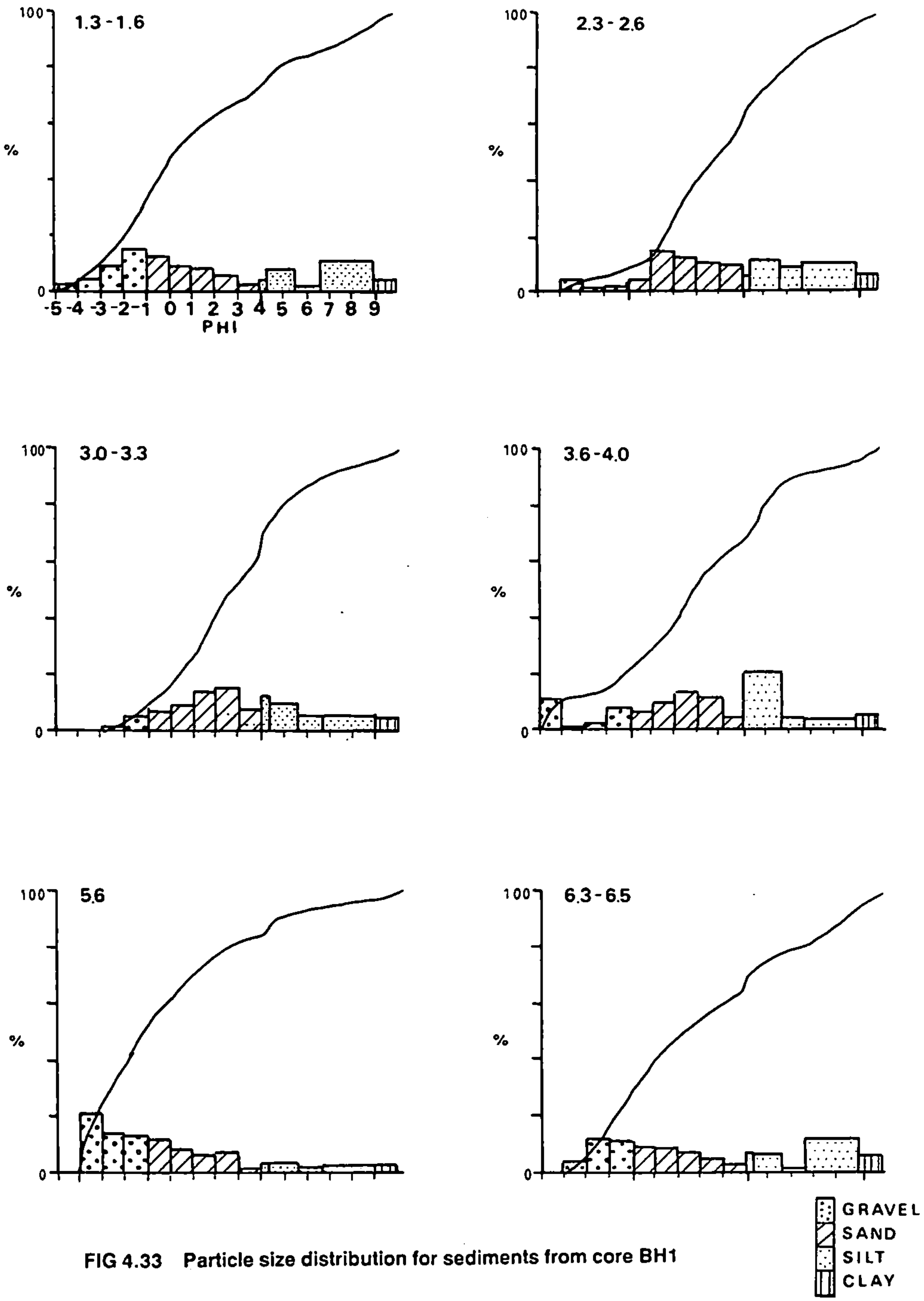


FIG 4.33 Particle size distribution for sediments from core BH1

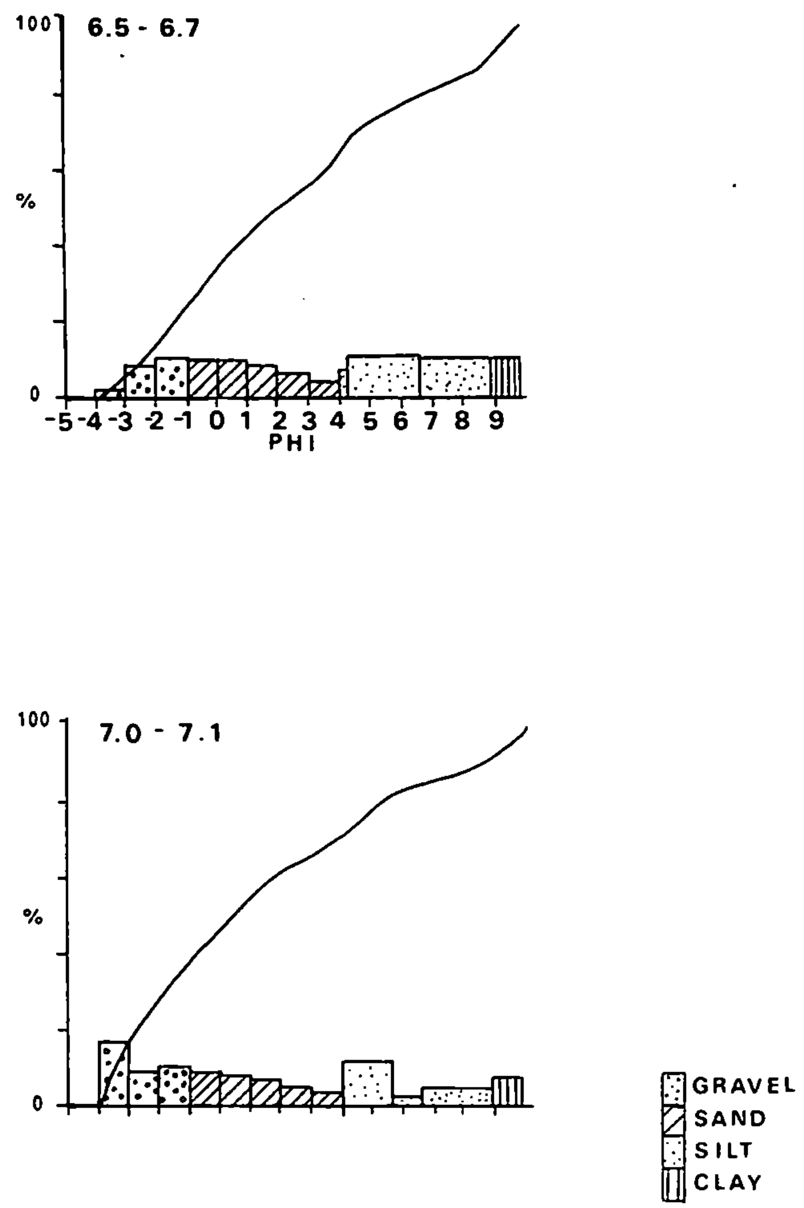


FIG 4.34 Particle size distribution for sediments from core BH1

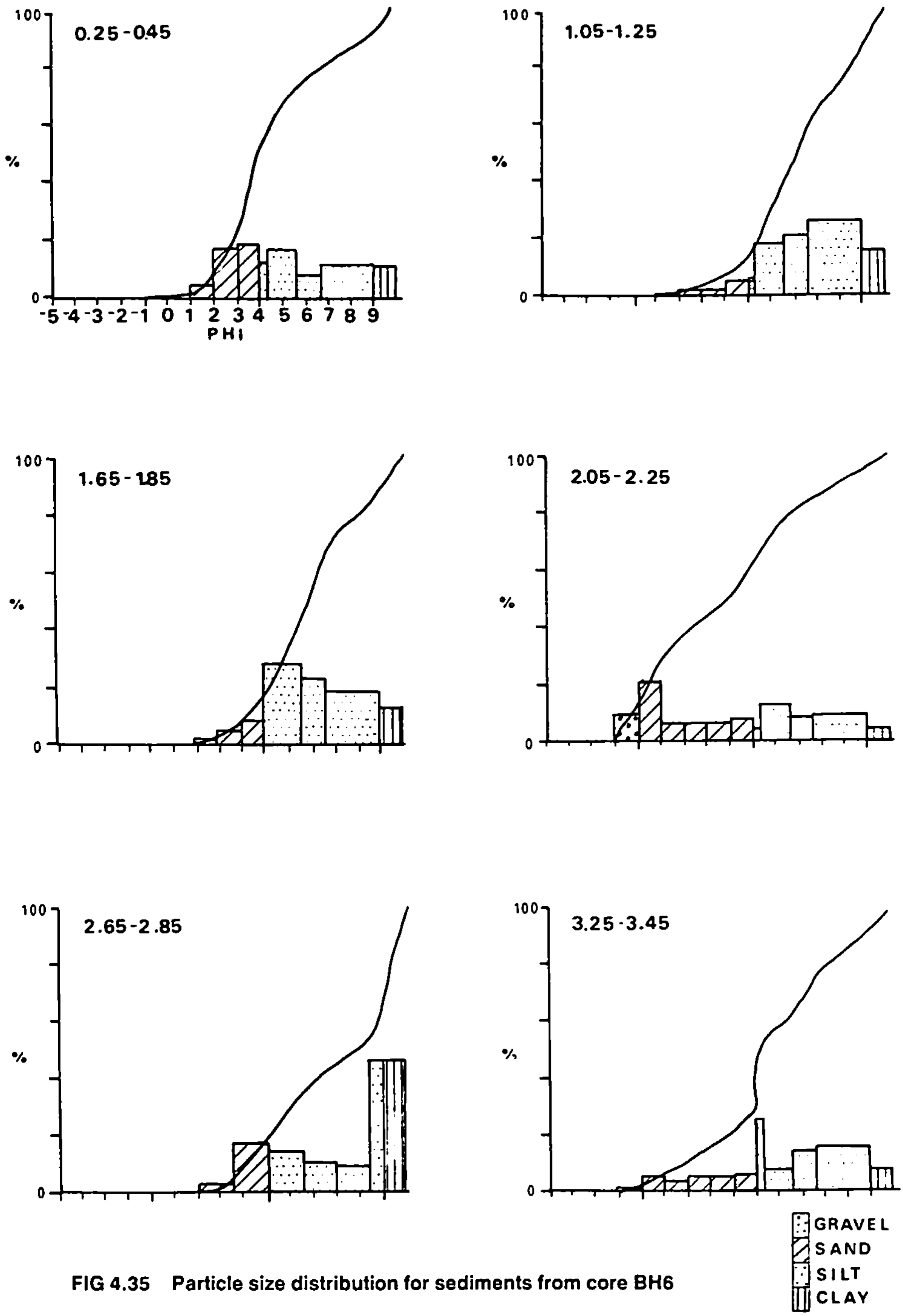


FIG 4.35 Particle size distribution for sediments from core BH6

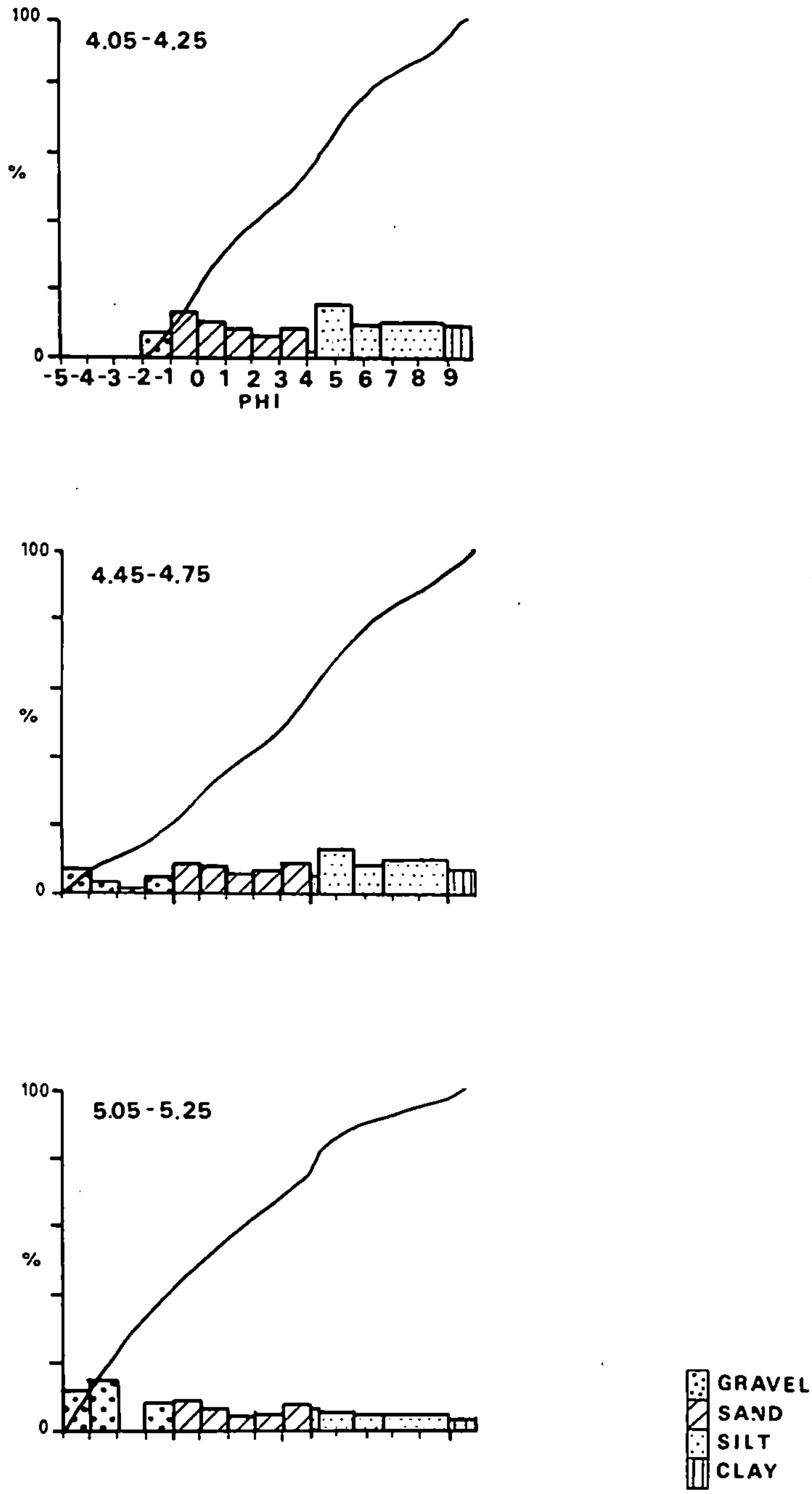


FIG 4.36 Particle size distribution for sediments from core BH6

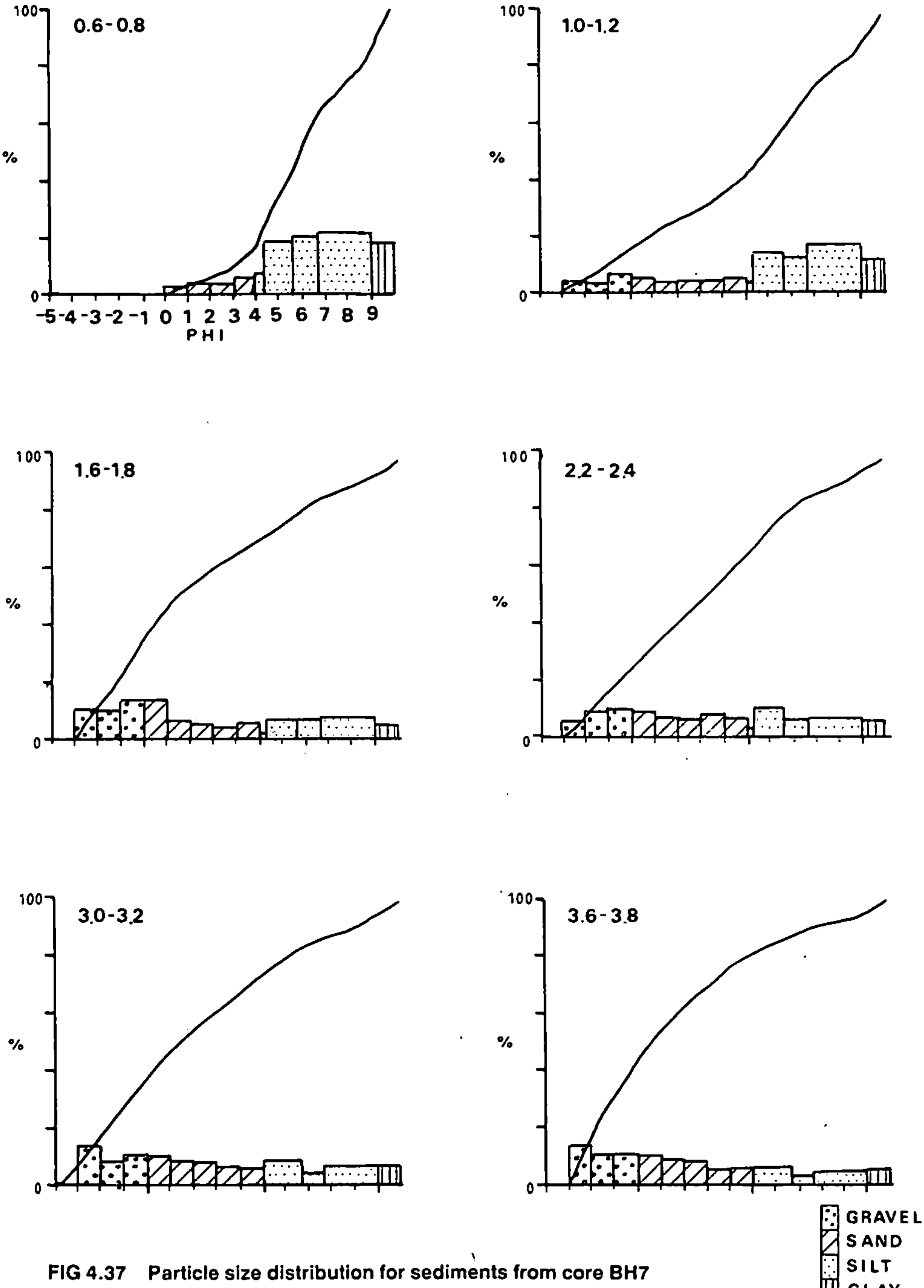


FIG 4.37 Particle size distribution for sediments from core BH7

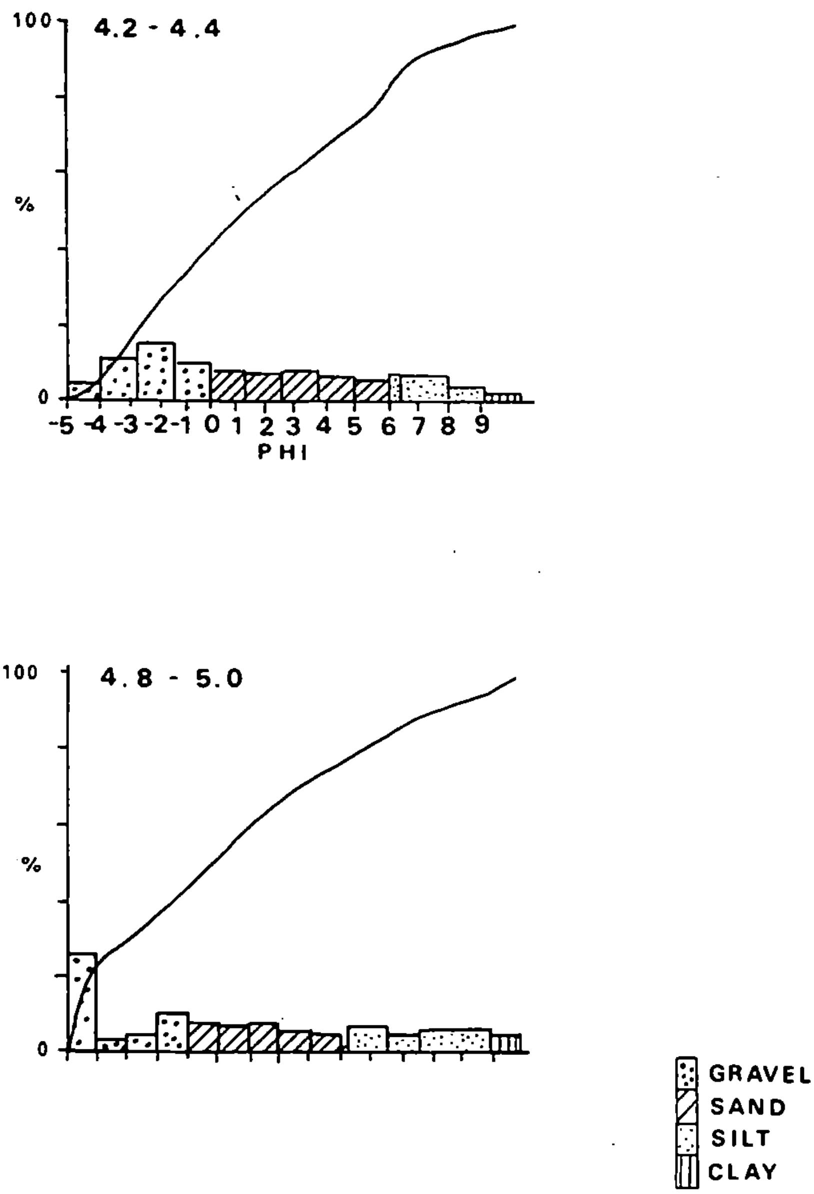


FIG 4.38 Particle size distribution for sediments from core BH7

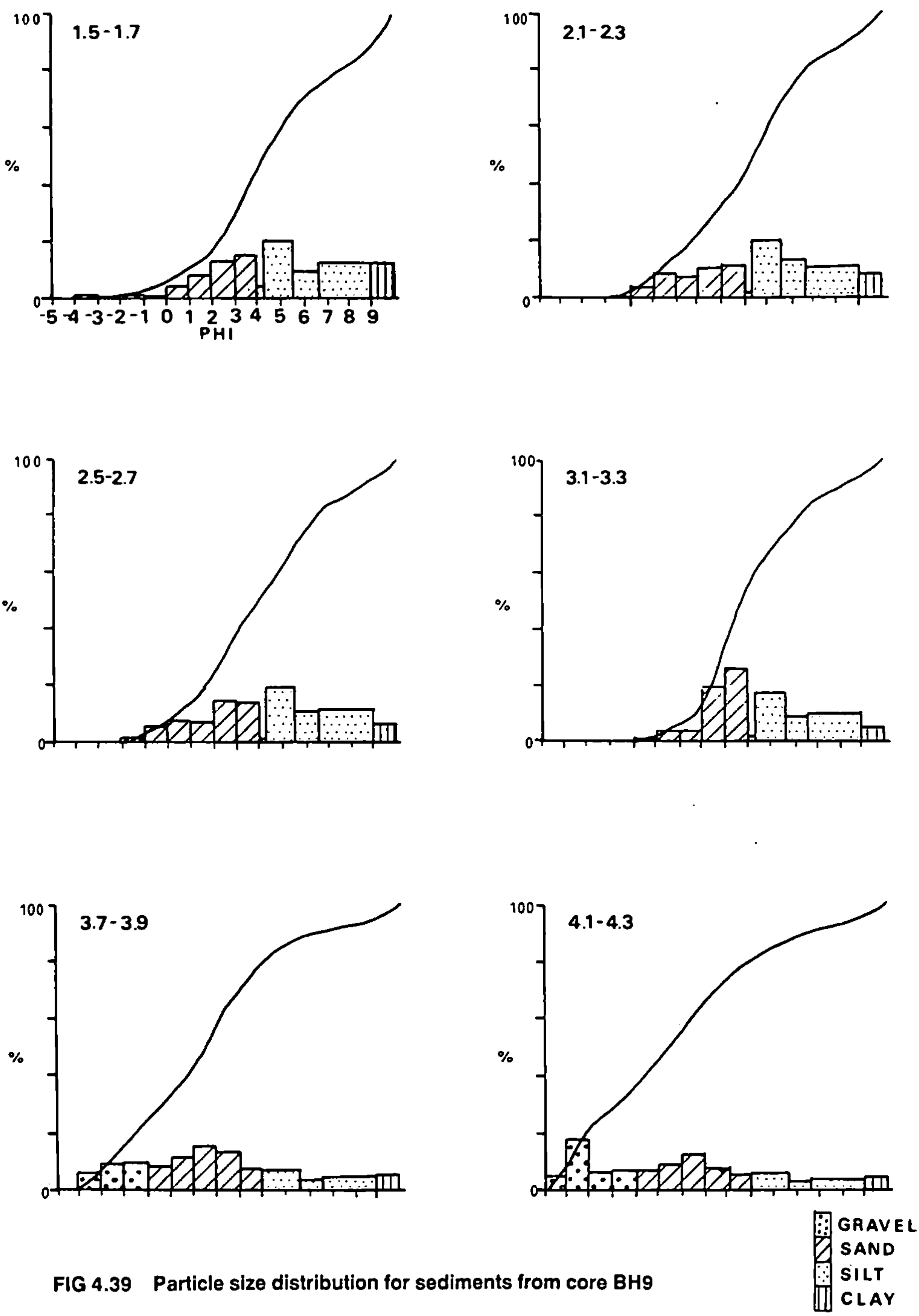


FIG 4.39 Particle size distribution for sediments from core BH9

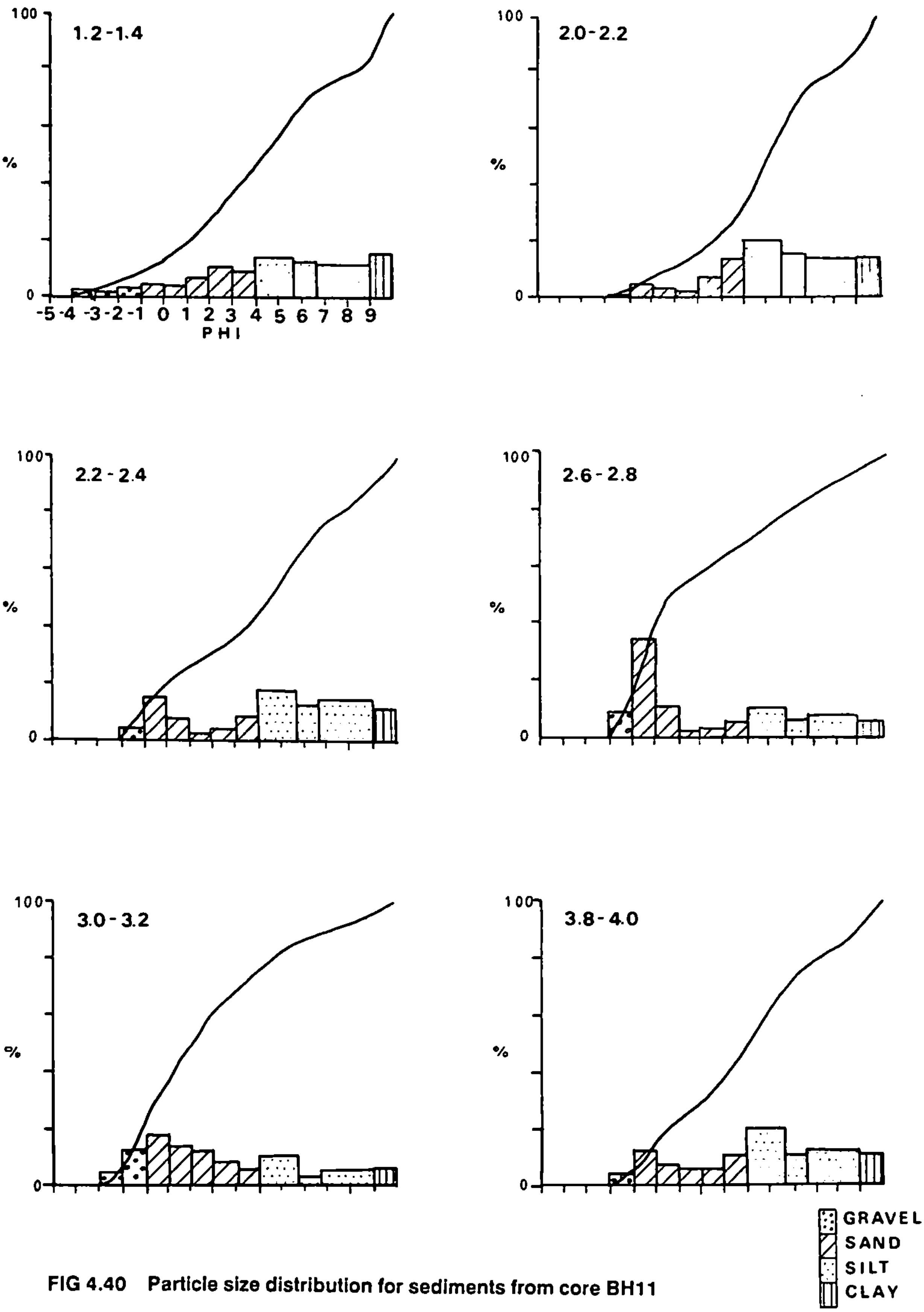


FIG 4.40 Particle size distribution for sediments from core BH11

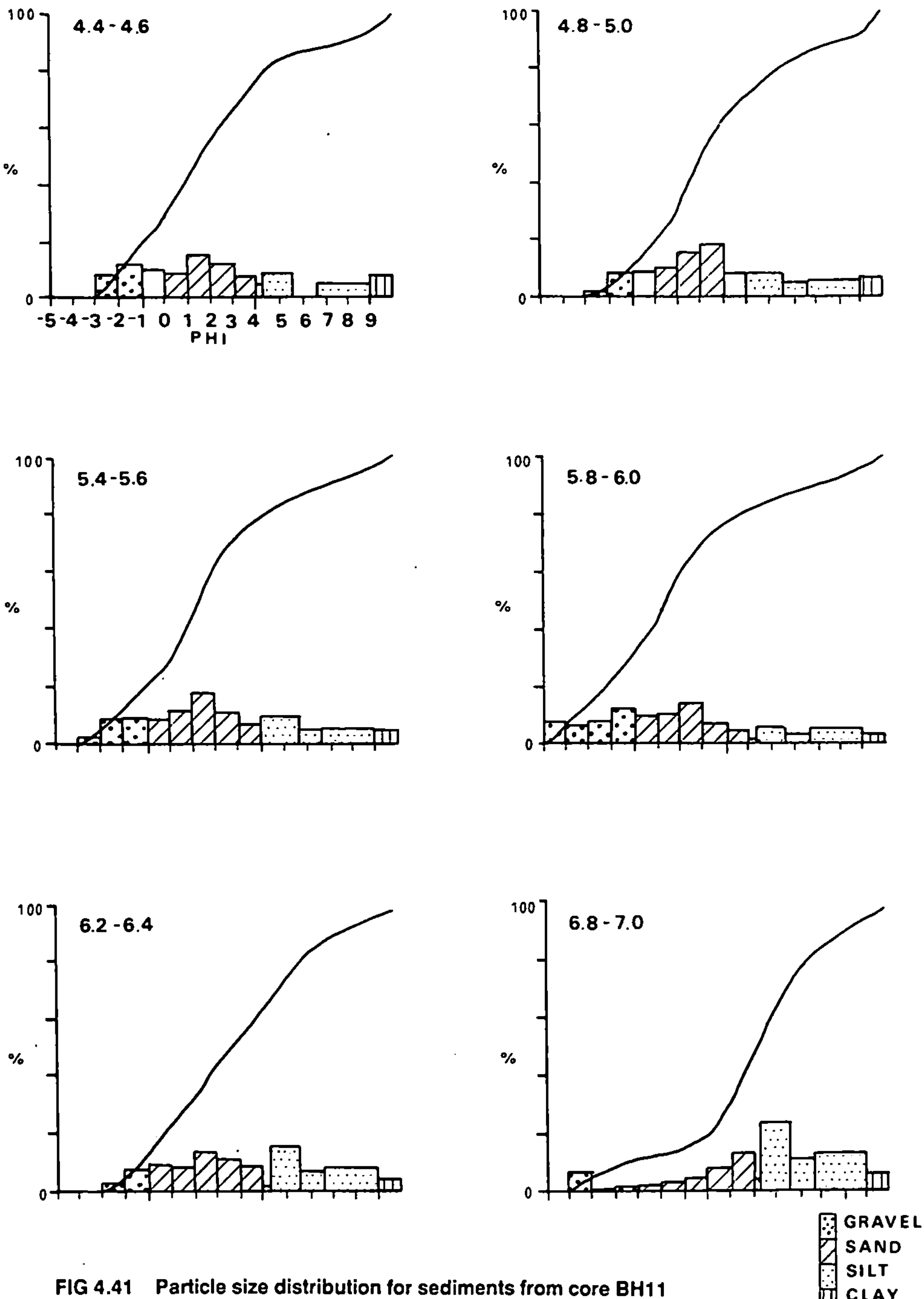


FIG 4.41 Particle size distribution for sediments from core BH11

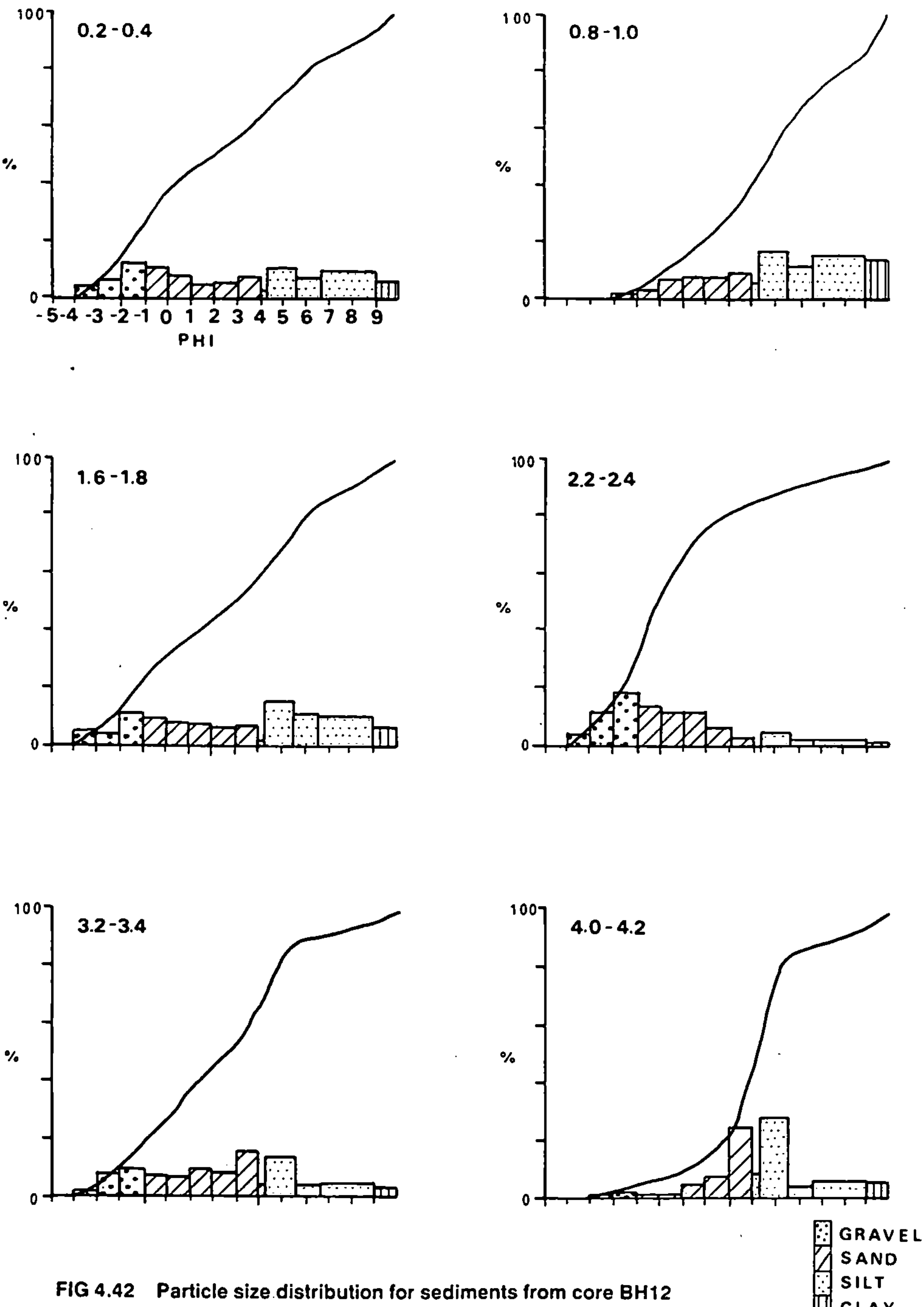


FIG 4.42 Particle size distribution for sediments from core BH12

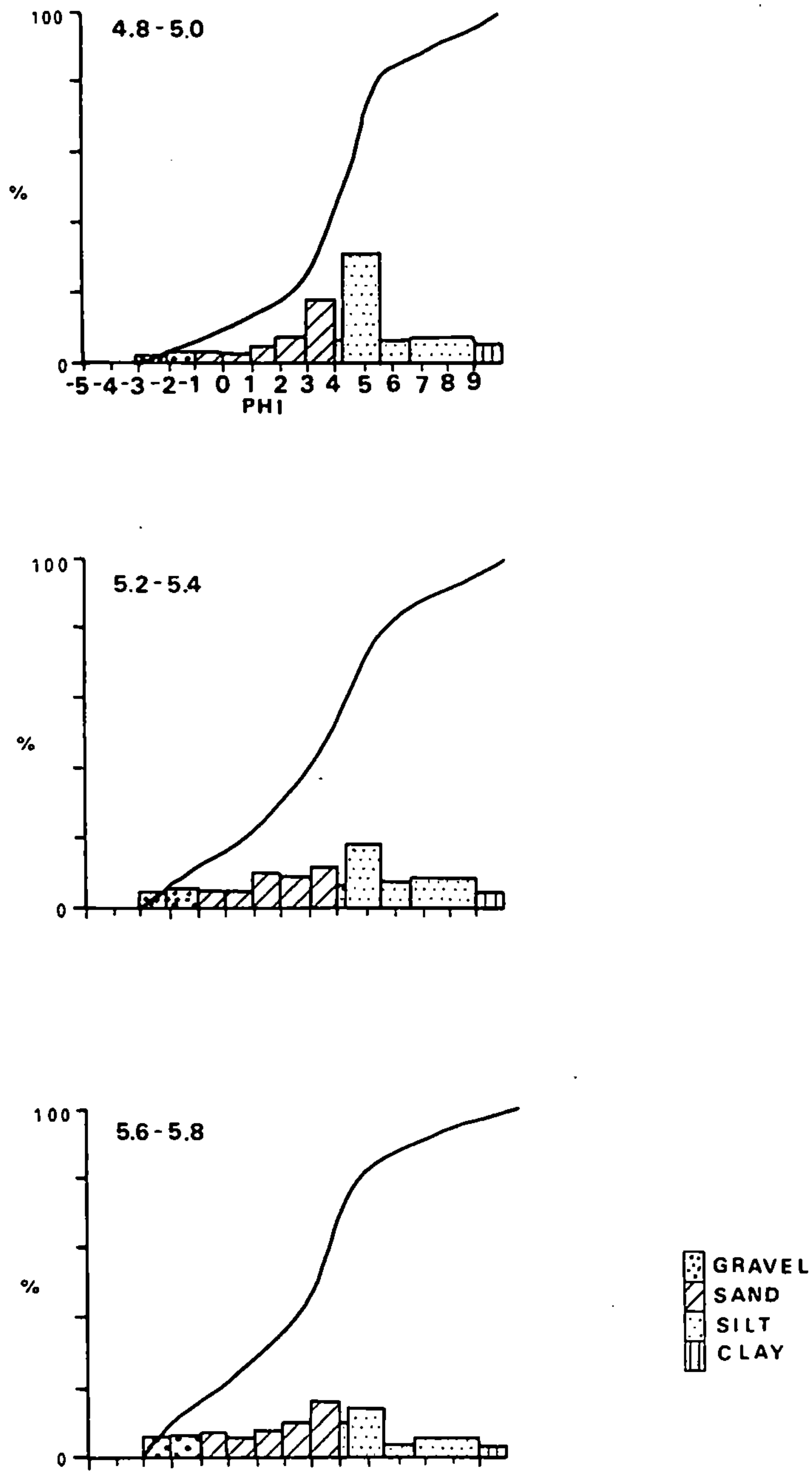


FIG 4.43 Particle size distribution for sediments from core BH12

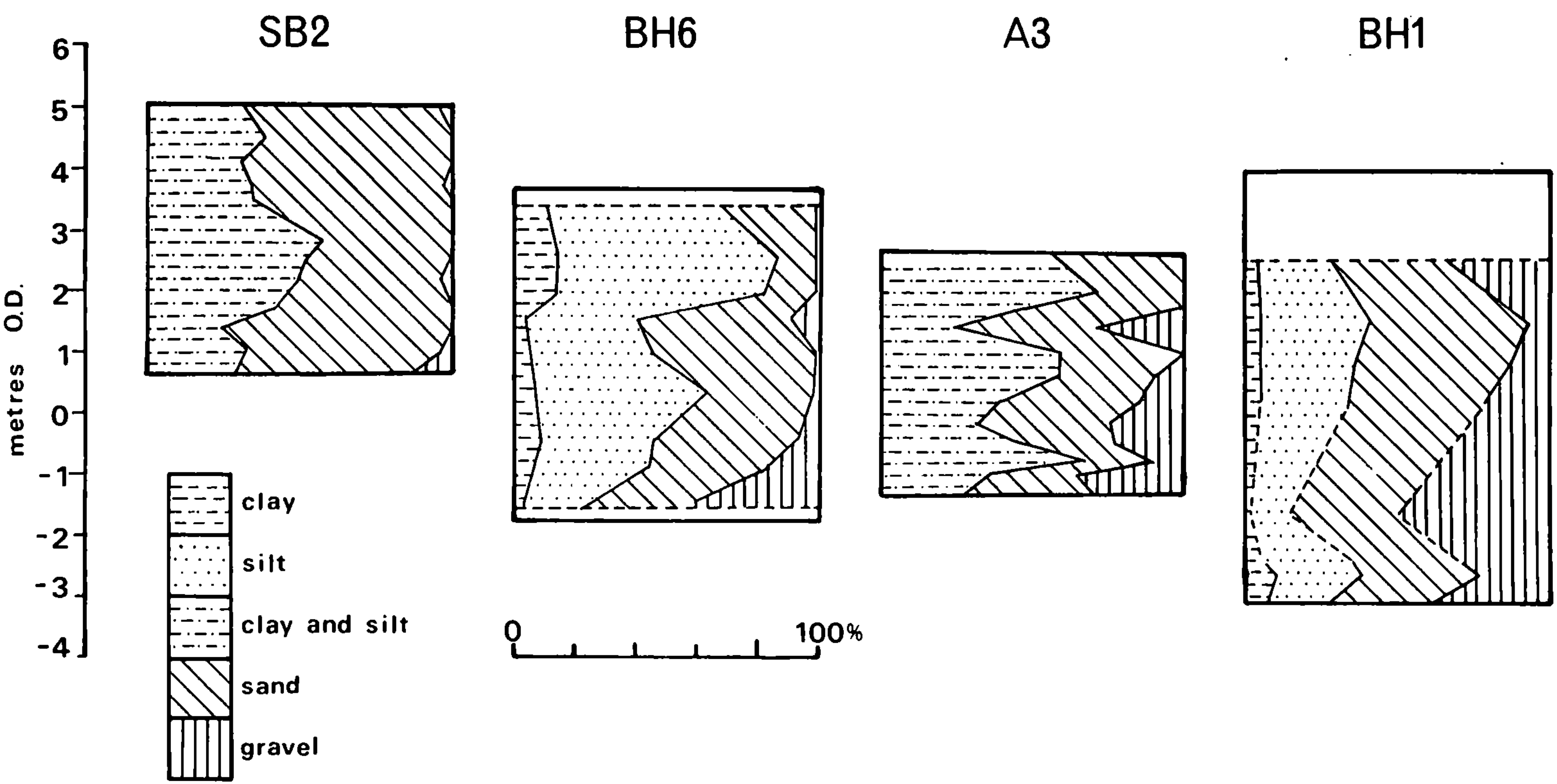


FIG 4.44 Summary of sediment size analysis for SB2, BH6, A3 and BH1

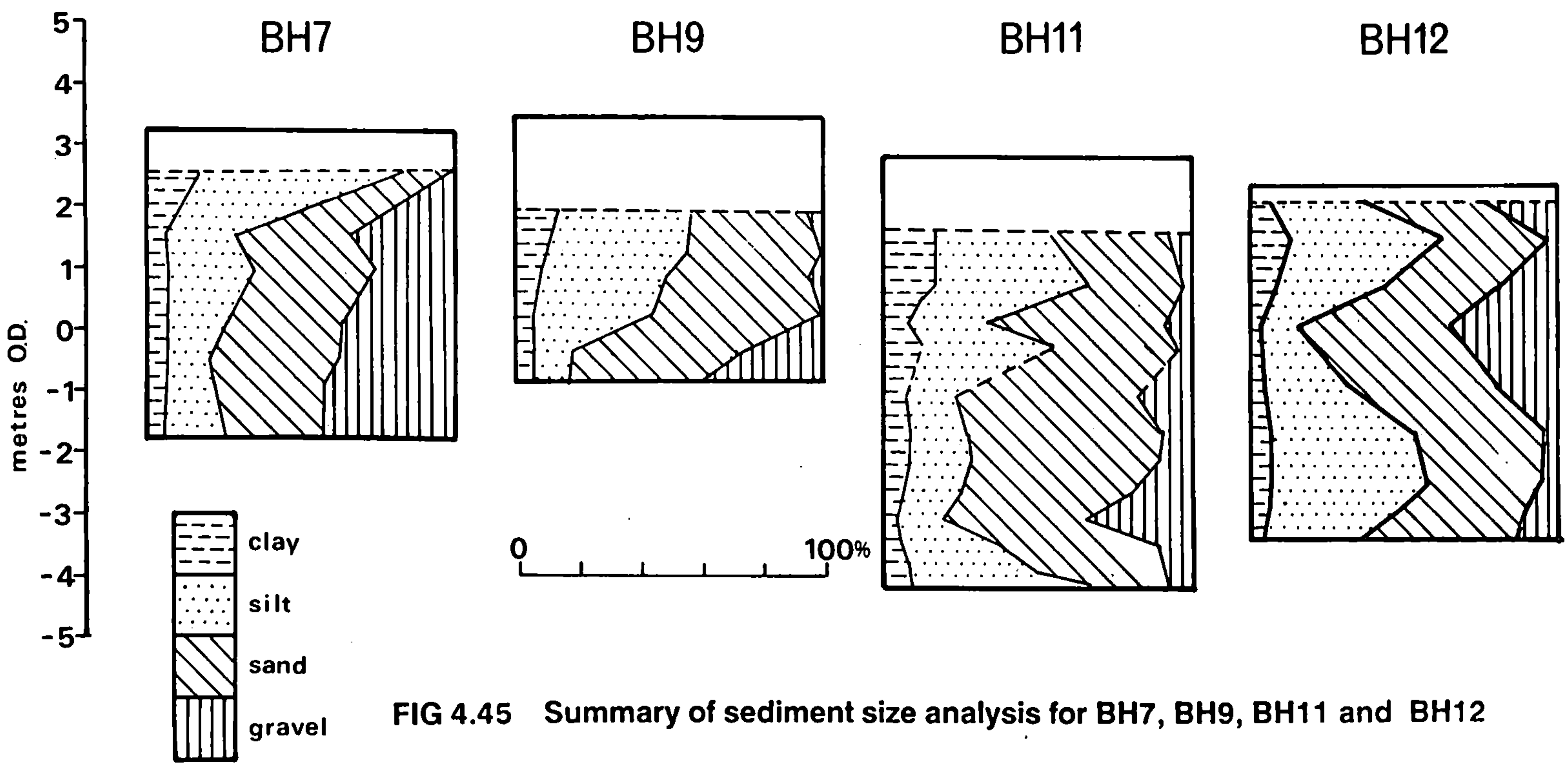


FIG 4.45 Summary of sediment size analysis for BH7, BH9, BH11 and BH12

and BH12 increases in gravel occur at 0m OD and in BH11 at -1m and -3m OD. Towards the base of core BH11, silt increases whereas in BH12 the silt content decreases.

Some of these increases in gravel content can be traced between a number of the cores: at 1.5m OD gravel increases in SB2, BH6, A3 and BH7, at 0m OD in BH11 and BH12 and at -1m in BH6, A3, BH1, BH9 and BH11.

The values for the mean, sorting, skewness and kurtosis have been calculated, and are shown in table 4.3. The formulae used are as follows:

Mean

$$Mz=\frac{\Phi16+\Phi50+\Phi84}{3}$$

Sorting

$$Kz=\frac{\Phi84-\Phi16}{4}+\frac{\Phi95-\Phi5}{6.6}$$

Skewness

$$sk.1=\frac{\Phi16+\Phi84-2\Phi5\Phi}{2(\Phi84-\Phi16)}+\frac{\Phi5+\Phi95+\Phi2\Phi5}{2(\Phi95-\Phi5)}$$

Kurtosis

$$Kg.=\frac{\Phi95-\Phi5}{2.44(\Phi75-\Phi25)}$$

These are the mean, the inclusive graphic standard deviation, the inclusive graphic skewness and graphic kurtosis after Folk and Ward (1957).

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
BH6				
0.25-0.45	4.85	2.50	0.39	1.03
1.05-1.25	6.37	2.26	0.06	0.87
1.65-1.85	6.10	2.26	0.10	0.95
2.05-2.25	2.86	3.35	0.06	0.76
2.65-2.85				
3.25-3.45	4.65	2.92	0.14	1.36
4.05-4.25	3.53	3.57	0.05	0.79
4.45-4.75	3.03	4.14	-0.11	0.96
5.05-5.25	0.44	4.22	0.23	0.77
BH1				
13-1.6	1.49	3.96	0.36	0.87
2.3-2.6	3.36	3.24	0.09	0.97
3.0-3.3	2.91	2.95	0.06	1.25
3.6-4.0	1.88	3.84	0.01	1.10
5.6	-0.14	3.47	0.40	1.01
6.3-6.5	2.08	4.18	0.29	0.79
6.5-6.7	2.66	4.14	0.25	0.78
7.0-7.1	1.14	4.25	0.31	0.79
BH7				
0.6-0.8	6.27	2.46	0.03	0.88
1.0-1.2	4.10	4.12	-0.24	0.81
1.6-1.8	1.36	4.12	0.37	0.80
2.2-2.4	2.11	3.94	0.09	0.81
3.0-3.2	1.06	4.25	0.29	0.87
3.6-3.8	0.89	4.03	0.32	0.94
4.2-4.4	0.32	3.35	0.19	0.73
4.8-5.0	0.36	4.61	0.25	0.70

TABLE 4.3a DESCRIPTIVE STATISTICS FOR SEDIMENT SIZE ANALYSIS

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
BH9				
1.5-1.7	4.88	2.95	0.16	0.96
2.1-2.3	4.43	2.92	0.01	1.0
2.5-2.7	3.90	2.94	0.07	1.04
3.1-3.3	4.20	2.33	0.30	1.19
3.7-3.9	1.36	3.54	0.15	1.16
4.1-4.3	0.64	4.02	0.17	0.92
BH11				
1.2-1.4	4.63	3.83	-0.04	0.92
2.0-2.2	5.45	3.08	0.01	1.01
2.2-2.4	4.13	3.69	-0.09	0.70
2.6-2.8	2.08	3.44	0.63	0.76
3.0-3.2	4.08	3.64	-0.04	0.80
3.8-4.0	1.73	3.33	0.39	0.98
4.4-4.6	1.78	3.41	0.18	1.04
4.8-5.0	2.61	3.31	0.27	1.14
5.4-5.6	1.83	3.51	0.20	1.12
5.8-6.0	0.79	3.82	0.17	1.16
6.2-6.4	2.71	3.27	0.12	0.94
6.6-6.8	3.75	3.23	0.04	1.21
6.8-7.0	4.38	3.41	-0.15	1.49
BH12				
0.2-0.4	2.43	3.95	0.15	0.79
0.8-1.0	4.95	3.28	0.05	0.85
1.6-1.8	2.83	3.90	-0.03	0.81
2.2-2.4	0.46	3.02	0.36	1.19
3.2-3.4	2.16	3.37	-0.08	0.98
4.0-4.2	4.05	2.30	0.02	1.97
4.8-5.0	4.08	2.60	-0.07	1.87
5.2-5.4	3.28	3.23	-0.12	1.13
5.6-5.8	2.61	3.13	-0.18	1.12

TABLE 4.3b DESCRIPTIVE STATISTICS FOR SEDIMENT SIZE ANALYSIS

All of the means of the sediments analysed lie in the coarse silt and sand range on the Wentworth Scale, except for BH11 2-2.2m which has a mean of medium silt size and BH7 0.6-0.8, BH6 1.65-1.85 and BH6 1.05-1.25 which have means in the fine silt range.

If a distribution is symmetrical, then the mean and the median will be equal. Most of the samples have medians differing from the mean by 1 phi or 0.5 phi; BH11 1.3-1.6, BH7 1.6-1.8 and BH11 2.6-2.8 show a greater difference between the mean and the median differing between 1-2 phi.

Folk and Ward (1957) suggested a verbal scale to describe the sorting characteristics of a sediment; values between 2-4 are suggested to be very poorly sorted, and values greater than 4, extremely poorly sorted. All the sediment in the cores collected are either very, or extremely poorly sorted. This suggests that the sediments are multi-component and thus include sediments of different origins.

Skewness is a measure of the deviance of the median from the mean; BH11 2.6-2.8m has a higher skewness value than most of the sediment analysed. Most of the samples have tails of fine material rather than coarse material.

Kurtosis measures the peakedness of a distribution; values of between 0.7-1.5 occur for these samples, except for samples BH12 4.8-5 and 4-4.2m which are between 1.8-2; thus being more peaked than the others.

4.3.3 Mineral Composition

The results of the analysis of mineral composition of the cores are shown in figures 4.46 and 4.47. They have been plotted as mineral group against depth in the core. There was found to be no difference in mineral type between the size fractions and hence results for the different size ranges have not been displayed separately.

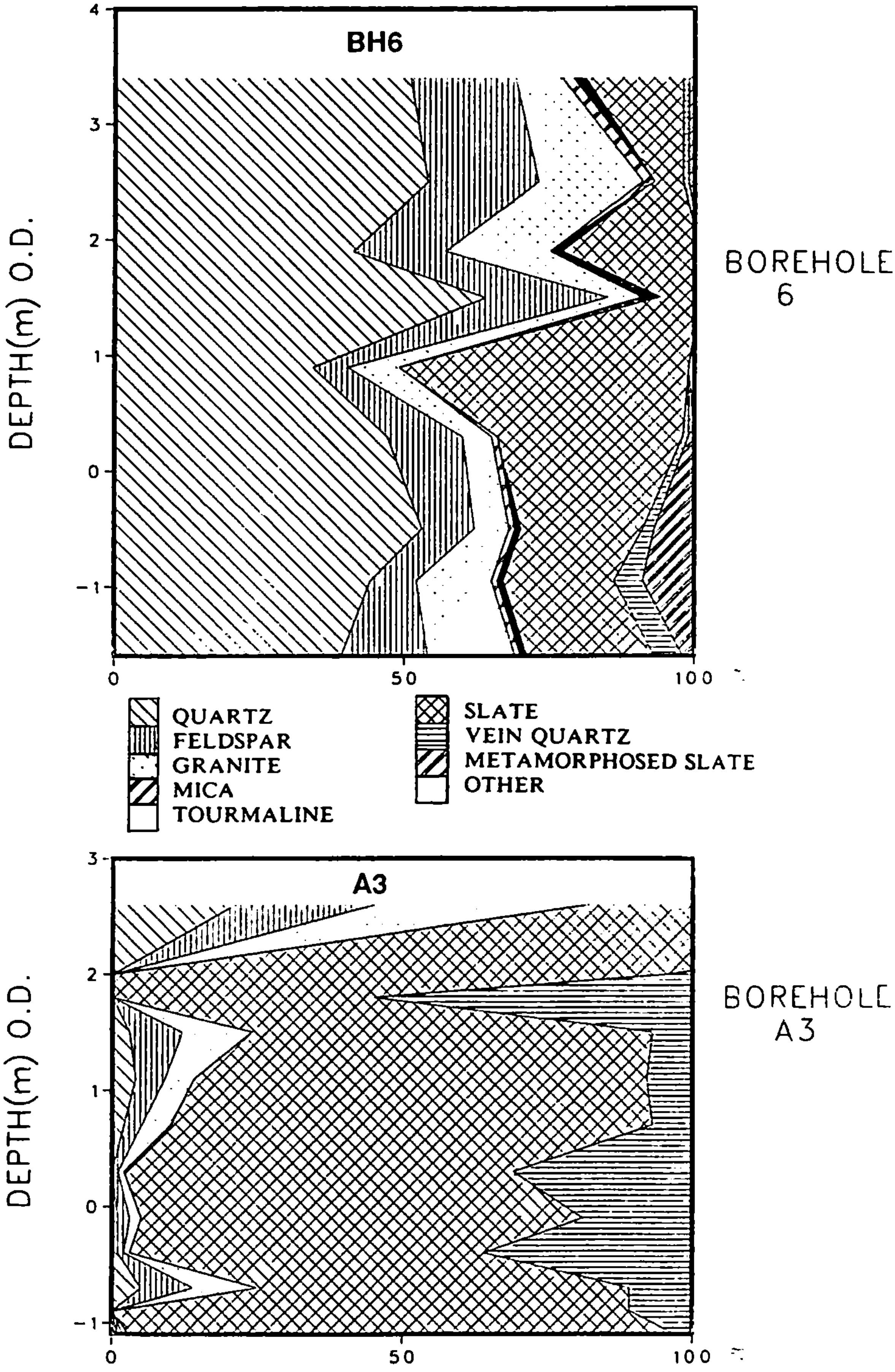


FIG 4.46 Mineral composition of sediment with depth

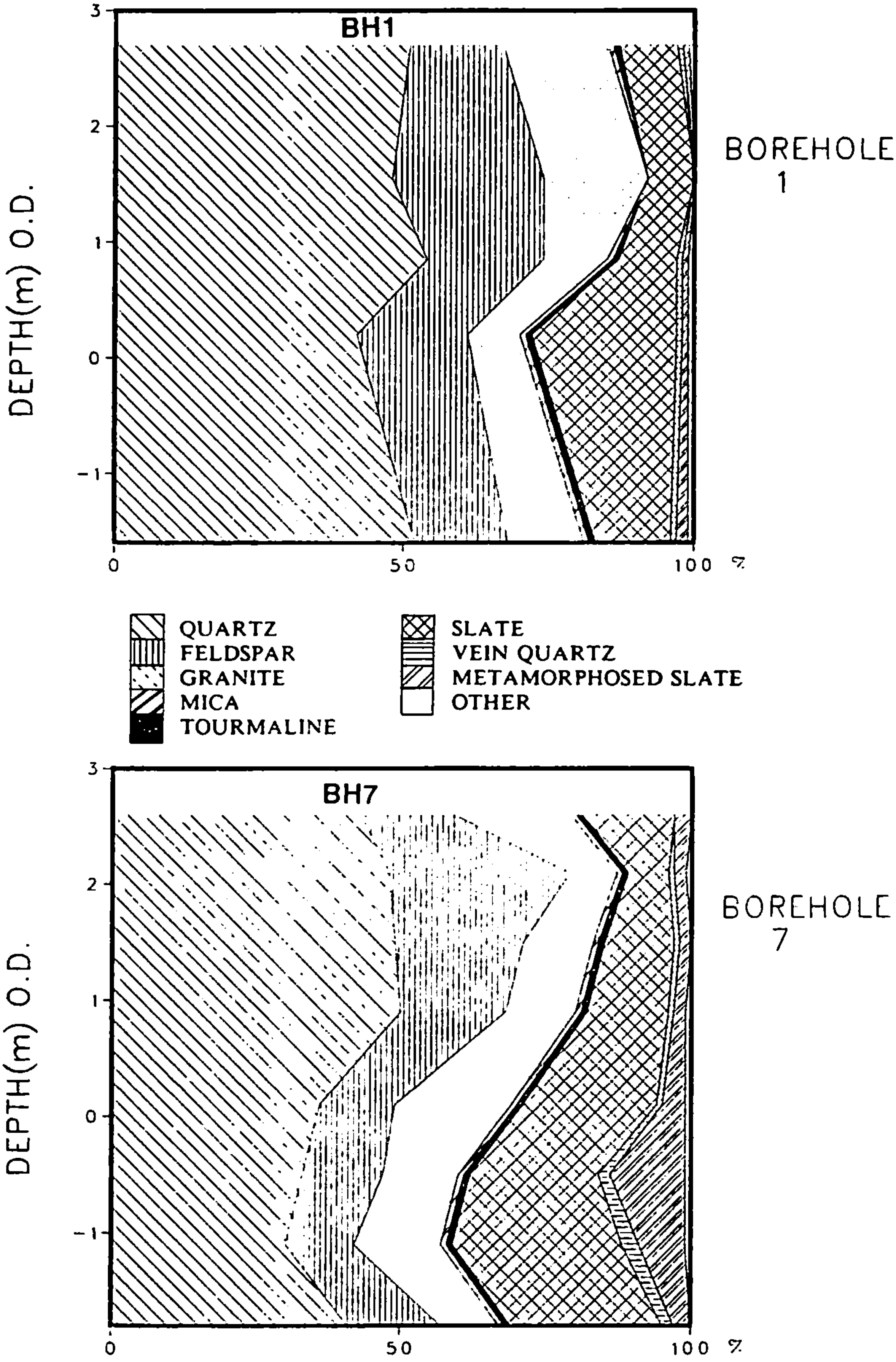


FIG 4.47 Mineral composition of sediment with depth

Quartz and quartz related sediments make up most of the composition of the cores, apart from sediments from core A3 which are predominantly of slate origin (figure 4.46). This short tributary valley of the Erme drains mainly Devonian slates. No foreign clasts were found in any of the samples analysed.

The top horizons in all the four cores examined were of granitic sediments including those from A3. The 'other' category included calc-flinta, banded sandstone and limestone, all of which outcrop in the catchment area. In BH1, BH6 and BH7 clasts derived from slate bedrock increase at around 0m, -1m and 0.5m OD respectively at the expense of the granitic derived clasts.

These can be compared with the summary particle size diagrams to see if there is a relationship between particle size and rock type. At 2.5m OD in BH6 the sediments are mainly silt and the clasts granitic. At 2m OD there is an increase of slate clasts although there is no corresponding change in grain size. At 1.5m an increase in the sand content matches a return of granitic sediments. An influx of slate just below 1m OD does not appear to have any significant affect on grain size and around 0m OD an increase in the silt content is matched by more granitic gravels. It is thus difficult to correlate changes in sediment size with mineral composition. Similarly grain size changes in BH1 do not correlate with changes in rock type. BH7 shows an increase in slate derived sediment between 0 and -1m OD and if anything a slight increase in gravel content. At 1.5m and 0.7m in A3 however, increases in granite and metamorphosed slate respectively correlate with increases in gravel sized sediment, although other variations in mineral type have no bearing on sediment size.

4.3.4 S.E.M Analysis of the Cores

Most of the quartz grains examined had the appearance of freshly weathered quartz. The surface textures present were sometimes similar to primary mechanical features such as conchoidal fractures, breakage blocks, arc-shaped steps and parallel steps. There was little rounding of any grains with the sharp corners usually preserved. The grains were compared with photographs of quartz derived from the River Traney, Northern Ireland, which drains granitic rock and thus may be a similar environment to the Erme. They were also compared with photographs of decayed granite grus and tourmalized granite from Laughter Tor Quarry on Dartmoor. The grains from Traney River were similar to those studied here and had little edge abrasion. Many of the features from the Laughter Tor samples were similar to the Erme, some 'grotty', some clean faces. Some typical grains from the samples examined are shown in plate 4.4.

Some grains were indicative of granite weathering products (grus), with occasionally several quartz grain crystals or quartz and other minerals occurring in one grain.

Higgs (1979) suggested that conchoidal fractures are indicative of either glacial environments or material freshly liberated from a crystalline source. Semi parallel steps are related to these and orientated etch pits are formed by the dissolution of quartz (Elzenga *et al.* 1987). All these features were seen in the Erme samples studied.

Evidence for fluvial erosion is often characterised by very round grains (Whalley 1979), with randomly orientated, very dense V-pitting and crescentic scars. This is suggested by Hey *et al.* (1971) to result from high energy subaqueous conditions, although Bull (1978) suggested V-pitting to be a result of time rather than high energy levels. None of the grains from the Erme samples showed substantial evidence of fluvial transport. Features said to be indicative of an aeolian environment, abraded, generally smooth surfaced, disc-shaped cavities, separated by meandering ridges and upturned plates, formed by grain to grain impacts, and a variety of chemical and precipitation features were also absent from any of the grains examined. Photographs of Nigerian aeolian deposits (Smith and Whalley 1981) and periglacial aeolian and fluvial sands (Elzenga *et al.* 1987) were compared with the Erme sediments.

PLATE 4.4

A3 0.7-0.8 x1000

Fresh quartz surface.

A3 0.7-0.8 x350

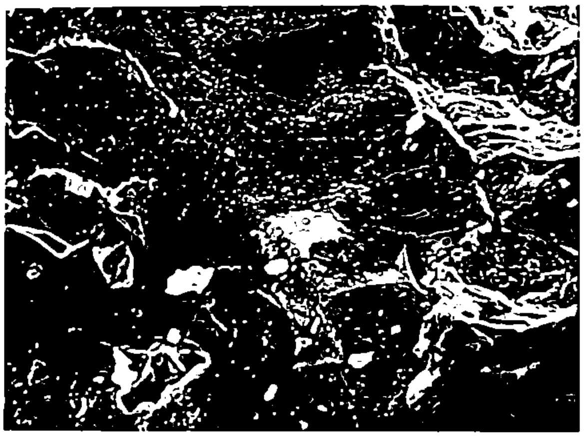
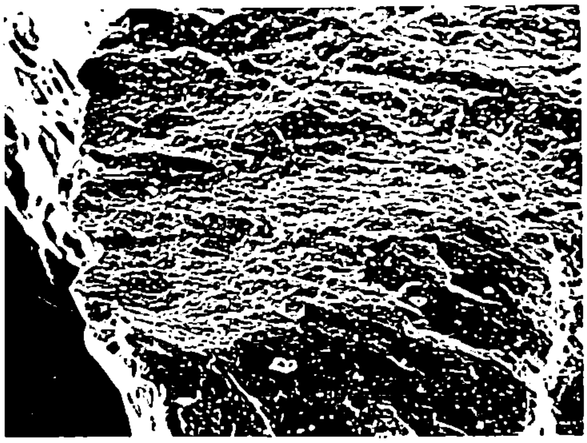
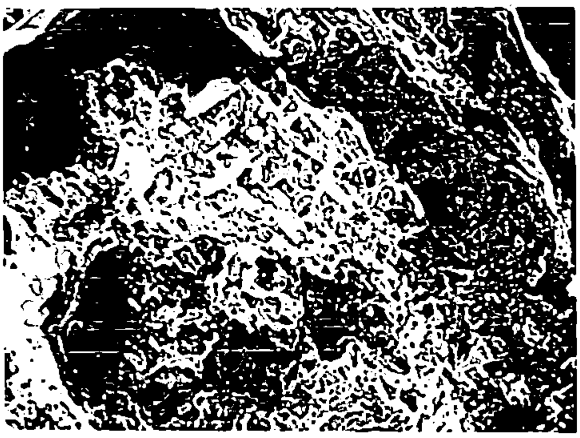
Sharp edge of a grain indicating little abrasive action.

A3 0.7-0.8 x1000

Quartz grain shows typical weathered granite grus.

SB2 0.1-0.2 x500

Shows primary mechanical surface textures and typical breakage features typical of freshly weathered Dartmoor granite.


4.4 A Brief Discussion

Final assessment of the data presented in this chapter will be made in Chapter 8 along with the results from other analyses. However, some general points will be made here.

A variety of sediments have been recovered from the top 7m or so of the buried channel of the River Erme. Depth of augering was limited because of difficulties in extracting long auger flights from the ground. The earlier drilling programme reached maximum depths of 8m below the surface which may indicate the base of the channel or a resistant boulder layer. At point 10 on transect A, a maximum depth of 5.7m was found although sediments were later extracted from a depth of 6m from nearby BH4. This may be explained either by a resistant horizon or by local variations in the bedrock channel. In the tributary valley and around the Sequer's Bridge area, shallower cores were obtained, and a sediment layer indicative of bedrock or a head or fluvial deposit near to bedrock was retrieved.

Fine silts and clays were present as the upper horizons of many of the cores. These overlie an organic unit around the Park Driving Bridge area and granitic gravels or sands at other locations. Some cores are predominantly of fine sand and silt units. In the Sheepham Brook tributary valley, sediment most probably indicating bedrock or head overlying bedrock was recovered. Seawards, the lower horizons of the cores contain molluscan shell fragments in variable matrices of gravels, sands and silts. The sediments do not appear to be derived from any parent material that does not outcrop in the Erme's catchment area.

Some of the sediments can be correlated between cores on the basis of sediment size analysis. Some show a decrease in silt and clay content with depth, others can be correlated on the basis of changing gravel input. The increase in gravel at 1.5m in some of the upper cores may be equivalent to that at 0m OD in BH11 and BH12. There appears to be little correlation between changes in sediment size and mineral content of the cores. Sediments from the tributary valley are almost exclusively of slate derived sediments whereas those from BH1, BH6 and BH7 have both granitic and slate elements.

S.E.M. analysis of some of the quartz grains suggests little fluvial rounding and no evidence of an aeolian origin for these grains. As most of the grains examined were still angular it is probable that they have not travelled very far, or have been transported in a low energy environment. If most of the quartz originated from the Dartmoor granite (the boundary of the granite being 5km from SB2) it is possible that either the quartz grains were transported in a flood, where there was little attrition, or in a very slow moving current. Some quartz may have originated from the slate, and thus would not need to have been carried very far. None of the grains showed evidence of aeolian weathering, thus suggesting there has been little incorporation of loess from the head deposits on Dartmoor and the surrounding area.

The sediments suggest that deposition has been relatively stable in the recent past. The upper fine deposits are possibly due to Flandrian land clearance as suggested by other research workers for similar valley fills. The organic sands and silts suggest either freshwater, salt marsh or backchannel swamp conditions preceding the recent alluviation. Prior to these phases, the river discharge was generally higher allowing gravels to be carried. Different conditions existed in the southern half of the study area which had a more estuarine influence. Further discussion on the sediments recovered will be presented in chapter 8, where the main sediment groups will be identified using results from all the analyses.

CHAPTER 5 A DETAILED STUDY OF DIATOMS PRESERVED IN THE BURIED CHANNEL DEPOSITS

5.1 Introduction

Diatoms (**Bacillariophyceae**) are microscopic unicellular algae with an outer shell (frustule) made of silica. They thrive in freshwater, brackish and marine environments and many species have salinity and depth preferences. Generally they live as self sufficient individuals but sometimes they form chains living as colonies for common benefit (Palmer and Abbott 1986).

The silica shell is well preserved in freshwater and marine sediments and thus diatoms are often ideal tools in environmental reconstruction. Diatoms are extremely useful palaeoecological indicators because some species have definite ecological requirements and tolerances. Many palaeoecological studies using diatom analysis have been concerned with the study of lake sediments. They have, for example, been used in studies of lake eutrophication (Battarbee 1978), zonation of Late Devensian and Flandrian diatom assemblages (Haworth 1976, Pennington 1943, Round 1961), as indicators of acid rain (Almer *et al.* 1974) and in varve analysis (Simola and Tolonen 1981). Since many species are sensitive to changing salinities diatoms have also been used for elucidating changes in water quality involving brackish, marine and freshwater sediments, and are of use therefore in sea level studies by identifying transgressive and regressive sequences. Much of this type of work has been done in Scandinavia, for example, in attempting to identify lake isolation in areas of active land uplift (eg. Miller and Robertsson 1979). Similar studies have been carried out in north-west England (Tooley 1978), the Thames Estuary (Devoy 1979), Scotland (Cullingford *et al.* 1980) and Northern Ireland (Battarbee *et al.* 1982). Diatoms have also been used to demonstrate changes in floodplain hydrology as a result of variations in river regime (Brown and Barber 1985).

It was considered that the study of any diatoms preserved in the buried channel deposits of the River Erme might provide information on both the estuarine and fluvial sediments. This would be useful in deducing the varying environmental conditions at different times during sedimentation in the Erme valley, For example, in ascertaining whether the sediment was deposited during predominantly estuarine or freshwater floodplain conditions, or whether flood events interrupted marine / estuarine sequences. The use of diatom analysis will also assist the cross-correlation of cores. Studies using diatom analysis of most relevance to this research and the various ways of grouping species to form palaeoenvironmental interpretations will be outlined below. Diatoms have been commonly grouped according to depth, salinity, based on chloride ion content, and pH preferences.

5.2 Classification and Identification

Identification and classification of diatom species is based on the shape and features of the diatom frustule. Some of the standard features are shown in figure 5.1. The frustule is composed of two valves, one of which is slightly larger and overlaps the other (figures 5.1a-b). The size of the frustule ranges from 4 microns to 1 millimetre, but in British coastal waters they are generally between 40 and 200 microns. They are seen in either girdle view (figure 5.1c) or valve view (figure 5.1d).

Classification of species is based on whether the frustules are circular (centric) or elliptical (pennate) in valve view (figure 5.1d); these comprise the two orders of diatoms - **Centrales** and **Pennales** as recognised by Hendey (1964). Further subdivision depends on the nature of the raphe (a longitudinal groove down the middle of each valve). The raphe is absent in Centrales but in Pennates, lines the centre with an interruption in the middle for the centre nodule and terminates at the ends by polar nodules, as illustrated in figure 5.1e. The Pennates are divided into suborders depending on the nature of the raphe; **Biraphidineae** have a proper raphe on both valves such as *Navicula* spp. and *Pinnularia* spp. (figure 5.1e), **Monoraphidineae** have a raphe present on the hypovalve and a pseudoraphe on the epivalve, as in

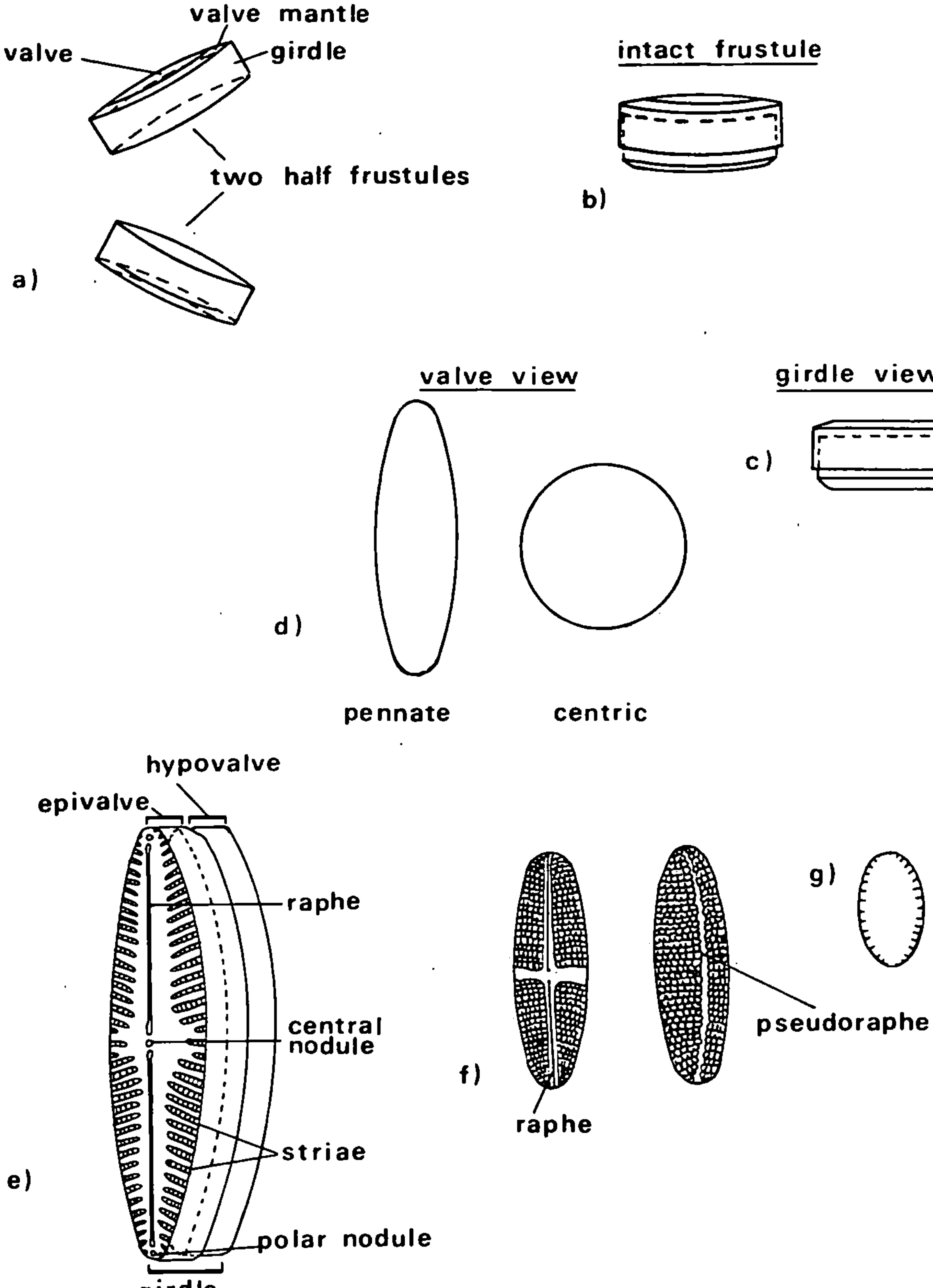


FIG 5.1 Diatom terminology (partly after Brazier 1980)

Achnanthes spp. (figure 5.1f) and **Araphidineae** have pseudoraphes where there is a space in the axial area, for example *Fragilaria* spp. (figure 5.1g).

Further classification and identification is based on the structure of the frustule, the arrangement of punctae (simple holes, some occluded by sieve membranes - thin transverse plates with numerous holes), reticulations (areolae) and canals and ribs (costae) on the valve. Arrangement of punctae in lines give rise to the striae, sometimes separated by imperforate ridges (costae) (Brasier 1980). Some of these characteristics can be seen in the diatoms in plates 5.1-5.4 which show some of the main species encountered during this study.

5.3 Ecological Groupings of Diatoms

Diatoms can be grouped according to whether they are planktonic, benthic or epiphytic. Planktonic diatoms are free floating, benthic taxa and live attached to hard substrates or in fine sediments, and epiphytic species live as floating masses of aquatic plants or on leaves of aquatic plants. Pennate diatoms dominate freshwater planktonic and epiphytic niches, although they also thrive in benthic marine habitats, whereas centric diatoms thrive as plankton in marine waters. Stream communities are often benthic or epiphytic rather than planktonic.

As diatom communities tend to be interdependent, large changes in the frequency of one taxon should not be stressed too much; overall changes in the floral assemblage should rather be noted (Tooley 1981). Various workers have overcome this by grouping species according to salinity. Hustedt (1937-39) for example, divided diatoms into five categories on the basis of pH tolerances as shown in table 5.1. Such a distribution is especially useful in the analysis of lake sediments.

PLATE 5.1

From left to right, starting top left:

Podosira stelliger (Bailey) Mann

Coscinodiscus spp.

Pinnularia mesolepta (Ehrenberg) W. Smith

Naicula avenacea De Brébisson

Diploneis interrupta (Kützing) Cleve

Rhaphoneis amphiceros Ehrenberg

Cyclotella meneghiniana Kützing

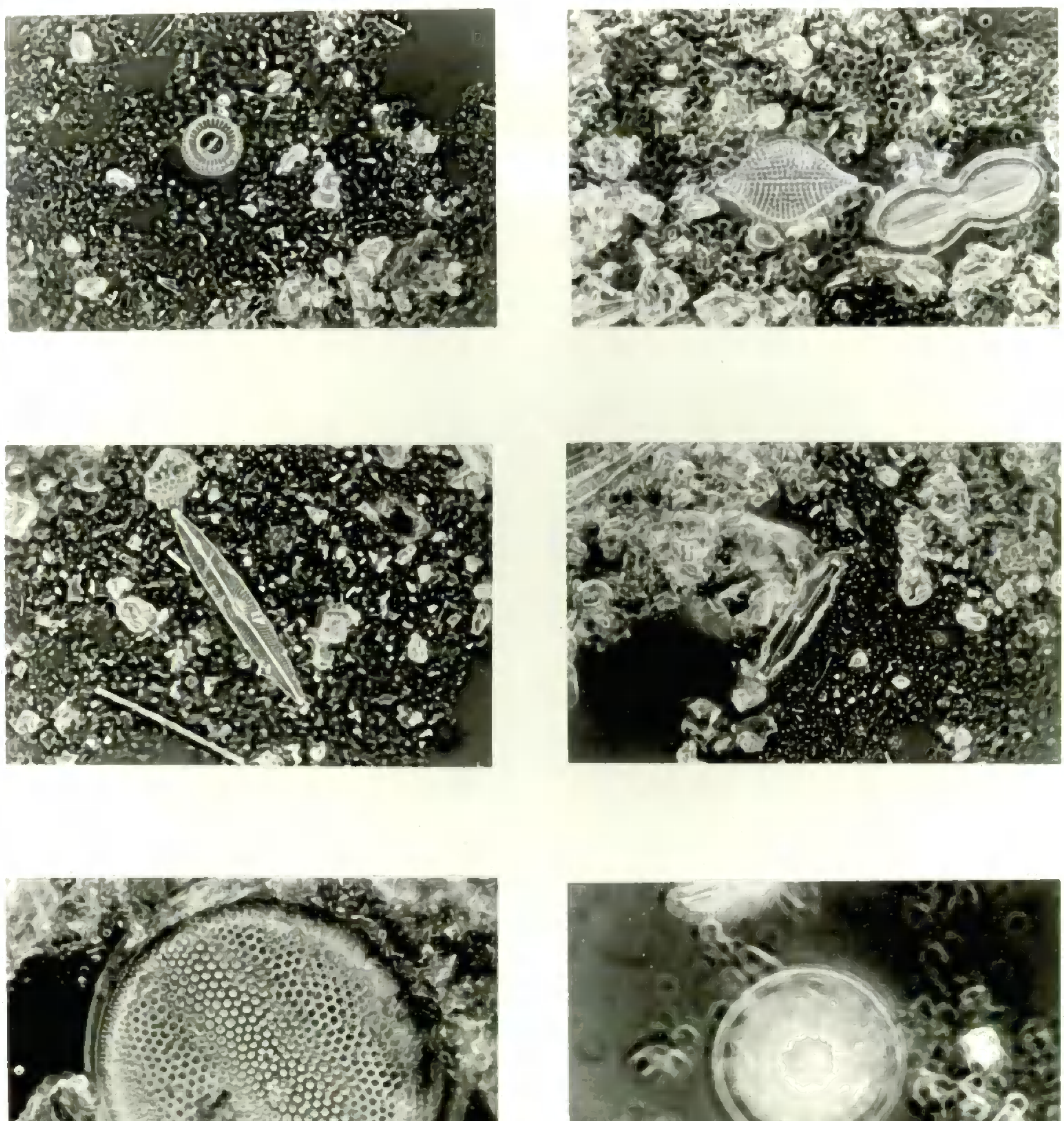


PLATE 5.2

From left to right, starting top left:

Diploneis didyma (Ehrenberg) Cleve

Diploneis ovalis (Hilse) Cleve

Pinnularia viridis (Nitzsch) Ehrenberg

Achnanthes microcephala (Kützing) Grunow

Navicula peregrina (Ehrenberg) Kützing

Opephora martyi Héribaud

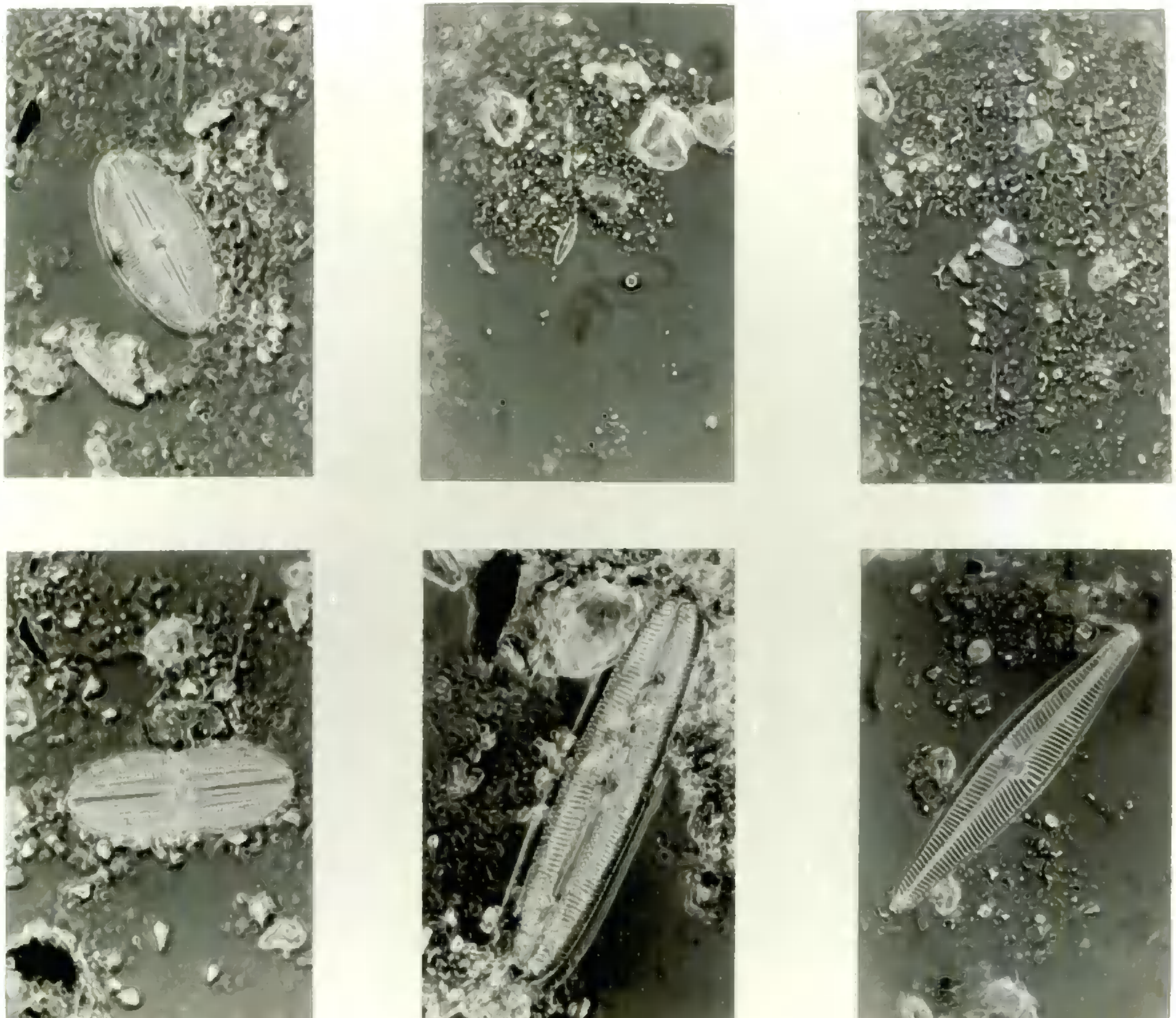


PLATE 5.3

From left to right, starting top left:

Diploneis smithii (De Brébisson) W. Smith

Caloneis formosa (Gregory) Cleve

Achnanthes brevipes Agardh

Melosira sulcata (Ehrenberg) Kützing

Amphora ovalis Kützing (*var libyca* (Ehrenberg) Cleve)

Gomphonema gracile Ehrenberg

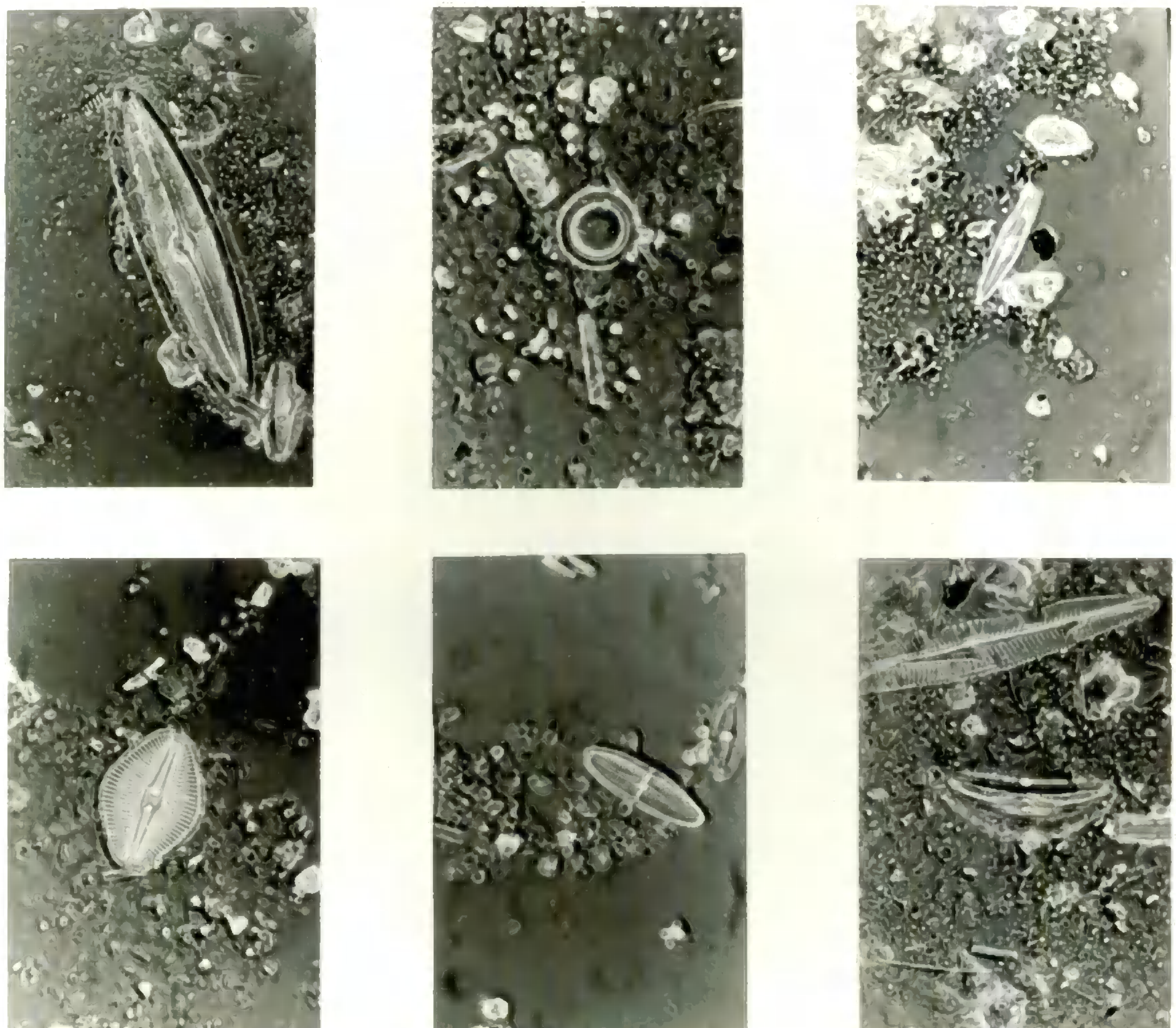


PLATE 5.4

From left to right, starting top left:

Cymbella ventricosa Kützing

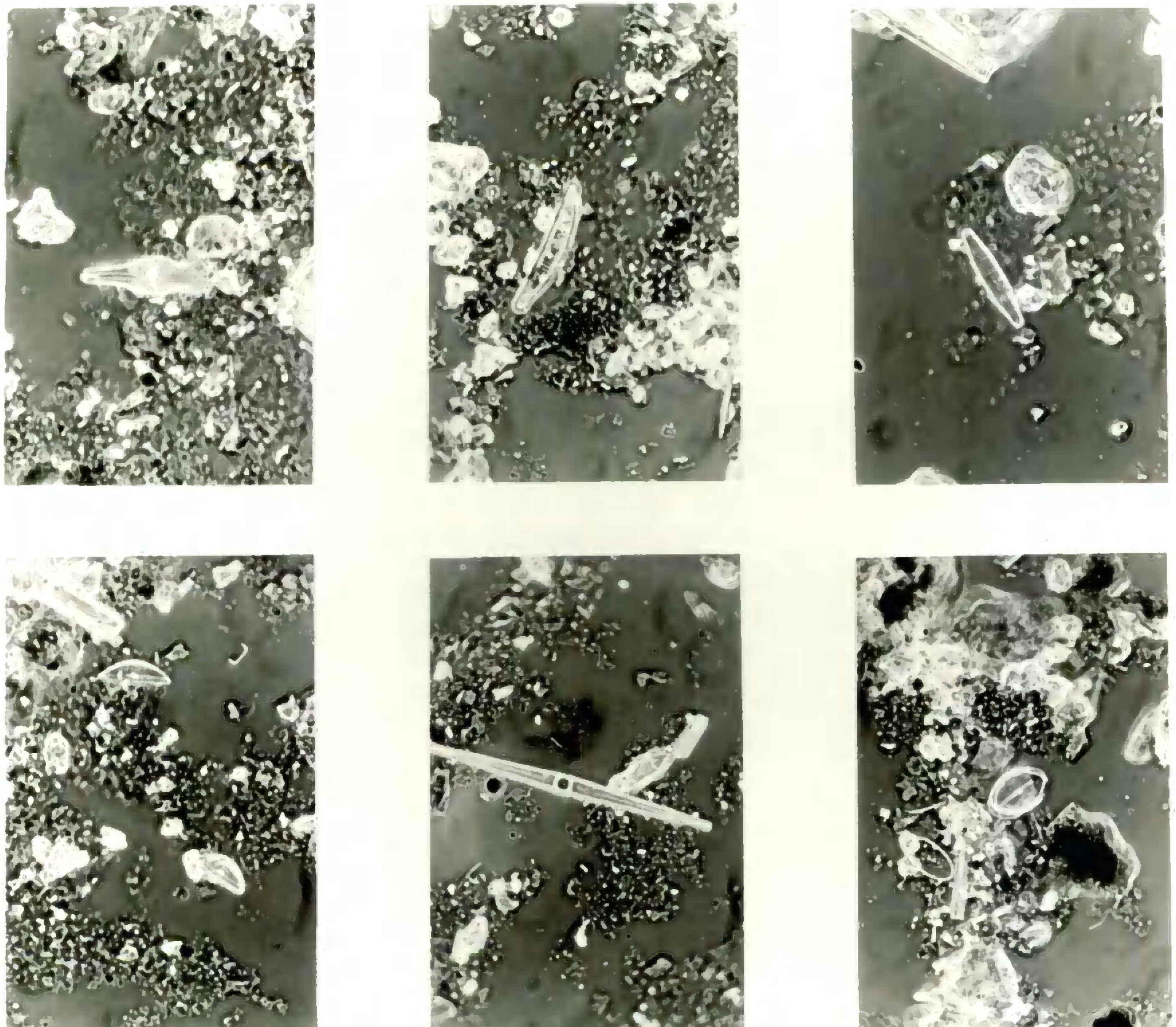
Gomphonema constrictum (Ehrenberg)

Synedra pulchella (Ralfs) Kützing

Eunotia pectinalis (Dillwyn) Rabenhorst

Cocconeis placentula Ehrenberg *var euglypta*

Fragilaria virscens Ralfs



CATEGORY	pH
Alkalibiontic	>7
Alkaliphilous	c. 7 but with widest distribution at >7
Indifferent	Equal occurrence on both sides, pH=7
Acidophilous	pH about 7 with widest distribution at > 7
Acidobiontic	<7, with optimum distribution at pH=5.5 and under

TABLE 5.1 HUSTEDT'S (1937-39) DIATOM CATEGORIES BASED ON pH

Many species of diatoms can also be classified according to their salinity preferences; Kolbe (1927) and Hustedt (1957) developed the following ecological groupings shown in table 5.2.

CATEGORY	ENVIRONMENT	SALINITY (parts/000)
Polyhalobian	Marine	> 30
Mesohalobian	Brackish	2-30
Oligohalobian (÷ into Halophilic and Indifferent)	Freshwater	< 2
Halophobe	Freshwater	0
Euryhaline	Broad Range of Salinity	

TABLE 5.2 CLASSIFICATION OF DIATOMS ACCORDING TO SALINITY after Kolbe (1927) and Hustedt (1957)

Miller (1964) also identified a similar set of salinity groups of marine, euryhaline marine brackish, brackish, halophilous and freshwater shown in table 5.3.

CATEGORY	SALINITY parts/000	COMMENT
Marine	30-40%.	
Euryhaline marine-brackish	5-40%.	
Brackish	5-20%.	
Halophilous	<5%.	Upper Brackish Stages
Freshwater	<2%.	Indifferent or Halophilous

TABLE 5.3 CLASSIFICATION ACCORDING TO SALINITY
(after Miller 1964)

Similarly Van der Werff and Huls (1958-74) have identified seven salinity groups according to the chloride ion content of water as shown in table 5.4.

CATEGORY	CHLORIDE ION CONTENT (mg/L)
Marine	>17,000
Marine-Brackish	10,000-17,000
Brackish-Marine	5,000-10,000
Brackish	1,000-5,000
Brackish-Fresh	500-1,000
Fresh-Brackish	100-500
Fresh	< 100

TABLE 5.4 CLASSIFICATION OF DIATOMS
(after Van der Werff and Huls 1958-74)

By summing the proportion of taxa within each halobian category and expressing these values as a percentage of the total number of species in the sample a measure is obtained of changes in water quality and direction of change in a freshening or progressively saline succession. This manner of approach has been successfully applied by a number of workers to elucidate environmental changes across a range of environments.

Berglund (1964) used diatom analysis in a study of post glacial shoreline displacement in Sweden. His data were divided into six groups varying between freshwater and marine. Similarly Miller and Robertsson (1979) produced an ecological diagram grouping taxa into nine categories according to the halobian system of Kolbe (1927) and Hustedt (1957). This approach was also followed by Kjemperud (1981).

In north-west England, deposits at Lytham (Downholland Moss) have been studied by Huddart *et al.* (1977) and Tooley (1978, 1985c). The latter grouped data according to the Marine-Brackish-Freshwater (M-B-F) system of Van der Werff and Huls (1958-74); this showed three brackish to strongly brackish tidal clay layers separated by phragmites peat layers which formed in times of decreasing marine influence.

Devoy (1979) carried out a biostratigraphical study of interleaved Flandrian biogenic and inorganic deposits of the lower Thames estuary. Taxa were grouped according to the M-B-F system and the halobian system of Hustedt. This latter approach divided the taxa into planktonic, benthic and epiphytic species within the five salinity groupings (polyhalobian, mesohalobian, oligohalobian halophile, oligohalobian indifferent and halophobe).

In Scotland, diatom studies have been used for identifying early land and sea level changes in Lower Strathearn (Cullingford *et al.* 1980), the Firth of Tay Carselands (Smith *et al.* 1985) and Beauly Firth (Haggart 1986).

Brown and Barber (1985) used diatom analysis in a study of prehistoric vegetation change and the effects on a lowland catchment (Ripple Brook); this identified changes in the hydrology of the site, showing perhaps increasing floodplain wetness and flooding.

Thus by using one of the salinity classifications above, it is possible to indicate the changing influence of freshwater, brackish and marine conditions in a sequence of deposits.

5.4 Methodology

In this section the selection and preparation of samples for diatom analysis are described.

5.4.1 Choice of Samples

Six cores from the valley fill were used for diatom analysis. These were from locations SB2, BH6, A3, BH11, RM2 and S2 (see figure 4.3 in chapter 4). The cores were chosen to enable material to be sampled from a wide variety of locations in the study area, but still be sufficiently close for correlations to be made. SB2, BH11, RM2 and S2 are fairly regularly spaced and BH6 and A3 correlate the main valley with the Sheepham Brook tributary valley.

In the selection of material from each core, sub-samples were taken from each of the major horizons. A maximum of 12 samples were analysed from each core at a minimum spacing of 40cm. This was felt to be a representative sample for the type of study involved since the sediments were obtained in units of every 10 or 20cm and cores of up to 6m are being analysed. In a more specific analysis of sea level change samples would be taken at closer intervals to identify minor fluctuations. However, in this study we are concerned more with broad environmental changes and correlations between sites.

5.4.2 Preparation of Samples

Samples were prepared for diatom analysis following the procedures outlined in Battarbee (1979). To remove any organic matter, sub-samples of 1-2g were heated with 20-30ml of 30% hydrogen peroxide. The samples were centrifuged and washed twice with de-ionized filtered water to remove the excess hydrogen peroxide. In cases where minerogenic material would have prevented good slide preparation, coarse grained material was removed by sieving.

5.4.3 Slide Preparation

The diatom solutions were diluted to an appropriate concentration with deionized filtered water and thoroughly mixed. A small amount of solution was dropped onto a cover slip using a disposable pipette and placed on a slide warming plate. Once the water had evaporated, the coverslip was mounted using Naphrax, a resin of high refractive index (R.I.=1.74).

5.4.4 Examination and Identification

The slides were examined using a magnification of x1000 under oil immersion. A camera attached to the microscope made it possible to photograph the various species encountered during counting.

Diatoms were identified using the following floras: Cleve-Euler (1951-55), Van der Werff and Huls (1958-74), Hustedt (1930), Bourelly (1981), Hendey (1964), Heurk (1896) and Patrick and Reimer (1966). The locations of unidentified species were recorded using the mechanical grid locations engraved upon the microscope stage in order to relocate them for later identification.

5.4.5 Counting

The basic counting unit was a single valve and a complete frustule was counted as two; where chains of frustules were intact each valve was counted individually. Fragments of diatoms were counted as whole if more than half remained or where a characteristic feature was seen, thus ensuring diatoms were not counted more than once. A representative section of the slide was examined by counting along continuous traverses. Diatoms generally settle out with the largest face uppermost, depending on whether the top (valve) or side (girdle) of the frustule is larger (Tooley 1981). In the case of the latter identification of the species was sometimes difficult and the species was assigned to an 'unknown' category. It is more common for species to be presented in valve view.

Battarbee (1979) recommended that a count of between 300 and 600 valves per slide was adequate for routine analysis. This was based on the fact that there are marked differences in the percentages of species between a count of 100 and 200 individuals, whilst there is little change between 400 and 500. Palmer and Abbott (1986) recommended a count of 300 valves suitable for a general impression of salinity changes, whilst Kjemperud (1981) successfully counted 200 valves exclusive of *Fragilaria* species. On this basis 400 valves were counted per slide. However, in some cases, diatoms were not well preserved and this limited the total valve counts on a few slides to 300, 200, 100 or 50 individuals.

5.4.6 Presentation of Results

To enable comparisons to be made between the cores and thus derive some conclusions as to the nature of the sediment the species encountered were grouped according to salinity. A summary diagram of change in salinity with depth for each core was produced by assigning the individual taxa to one of Van der Werff's salinity groupings (Fresh, Fresh-Brackish, Brackish-Fresh, Brackish, Brackish-Marine, Marine-Brackish, Marine). The presentation of this data is based on a similar approach used by Tooley (1978) in a study of the diatoms of the Flandrian Lytham deposits. Van der Werff's grouping was used as this was the most comprehensive flora in terms of diagrams and ecological groupings and most of the taxa identified were present in this flora. Where species were not included in the Van der Werff flora, information from other floras was used enabling the species to be assigned to one of the broad fresh, brackish or marine groups. An eighth 'Unknown' category included those taxa not identified and those whose salinity preference is not known. The proportion of each taxa within each category was then calculated and plotted as frequency versus core depth for each of the halobian categories. These are shown in figures 5.2-5.7. The left hand side of the figures indicate the depth in the core and the depth relative to Ordnance Datum. The location of each sample is indicated by a dot and the number of valves counted for each slide, if less than 400, are indicated on the right hand side of the figures.

Diatom diagrams of frequency versus depth for the predominant taxa at various levels within each core are shown in figures 5.8-5.13. These express the number of occurrences of a particular species as a percentage of the number of valves counted. Species representing 5% or more of the whole sample are included in these diagrams, after Eronen *et al.* (1987). All the species counted at each horizon are listed in appendix 2 along with a list of all the species identified from the sediments from the Erme and their ecological grouping according to Van der Werff and Huls (1954). The numbers of species in each halobian category for each sample are also given in appendix 2.

5.5 Results of Diatom Analysis

The combined salinity diagrams will firstly be discussed followed by a consideration of the diagrams showing individual taxa.

BOREHOLE SB2 - DIATOM DIAGRAM
% M-B-F TAXA

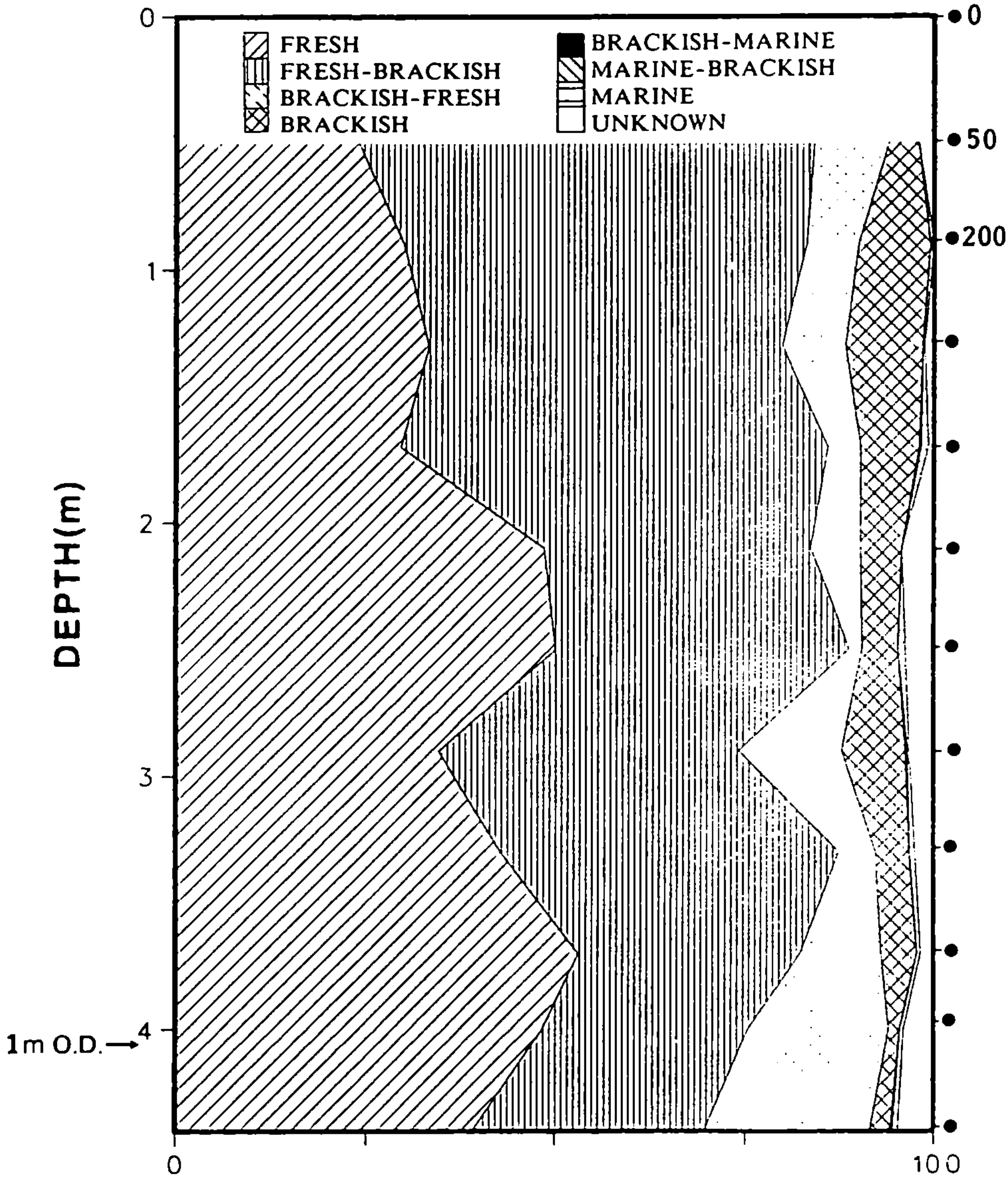


FIG 5.2

BOREHOLE A3 -DIATOM DIAGRAM
% M-B-F TAXA

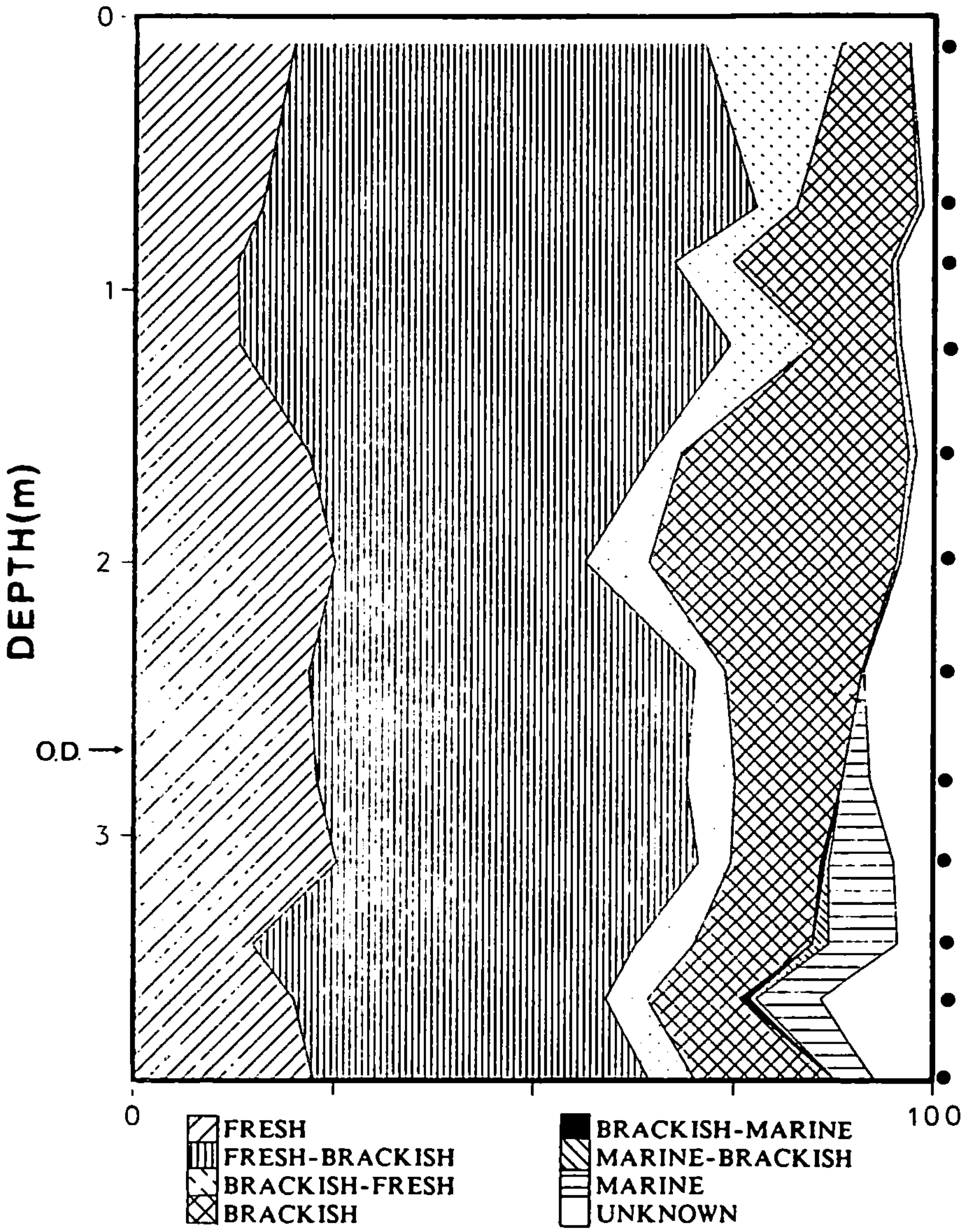


FIG 5.3

BOREHOLE 6 -DIATOM DIAGRAM
% M-B-F TAXA

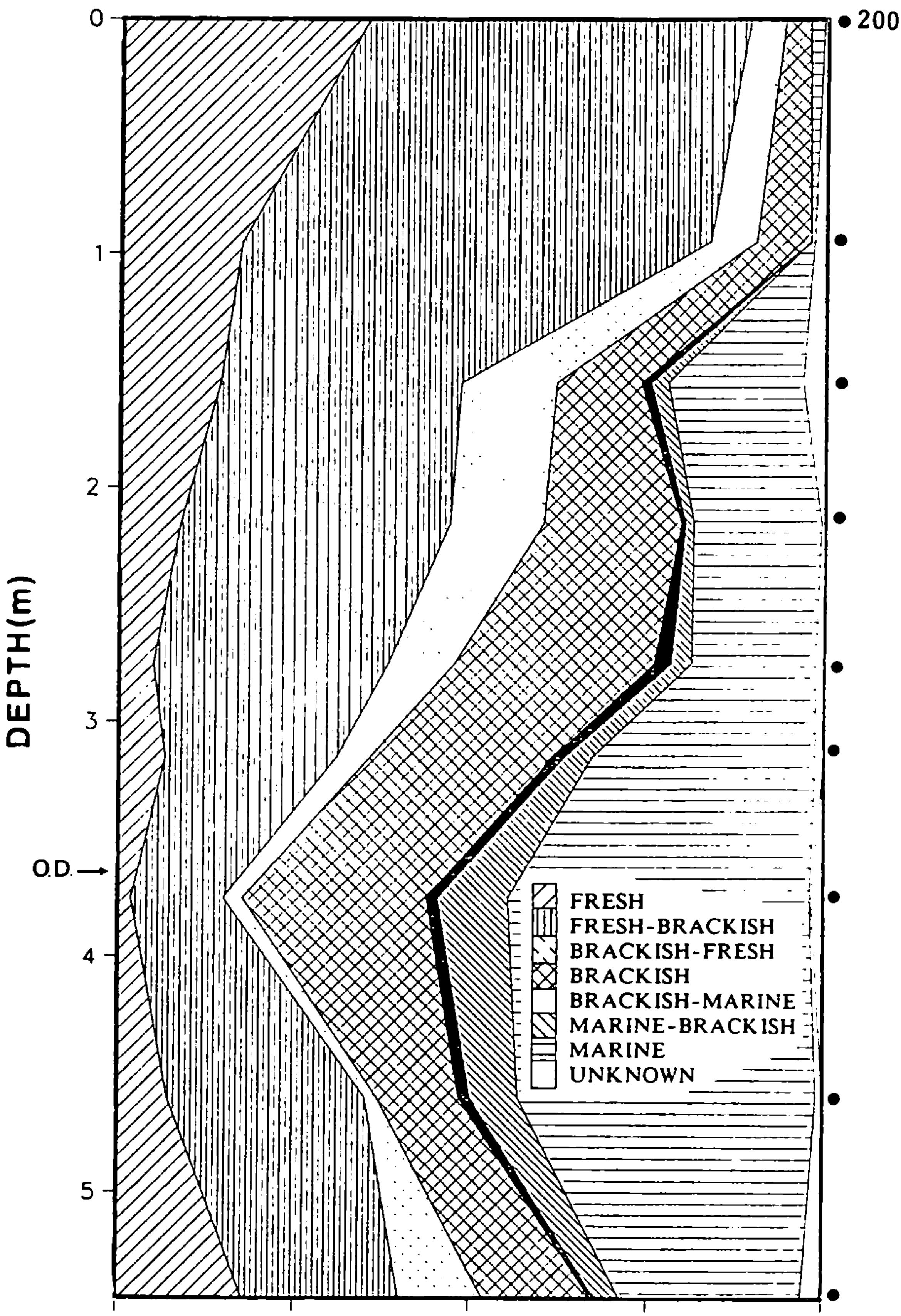


FIG 5.4

BOREHOLE 11 - DIATOM DIAGRAM
%M-B-F TAXA

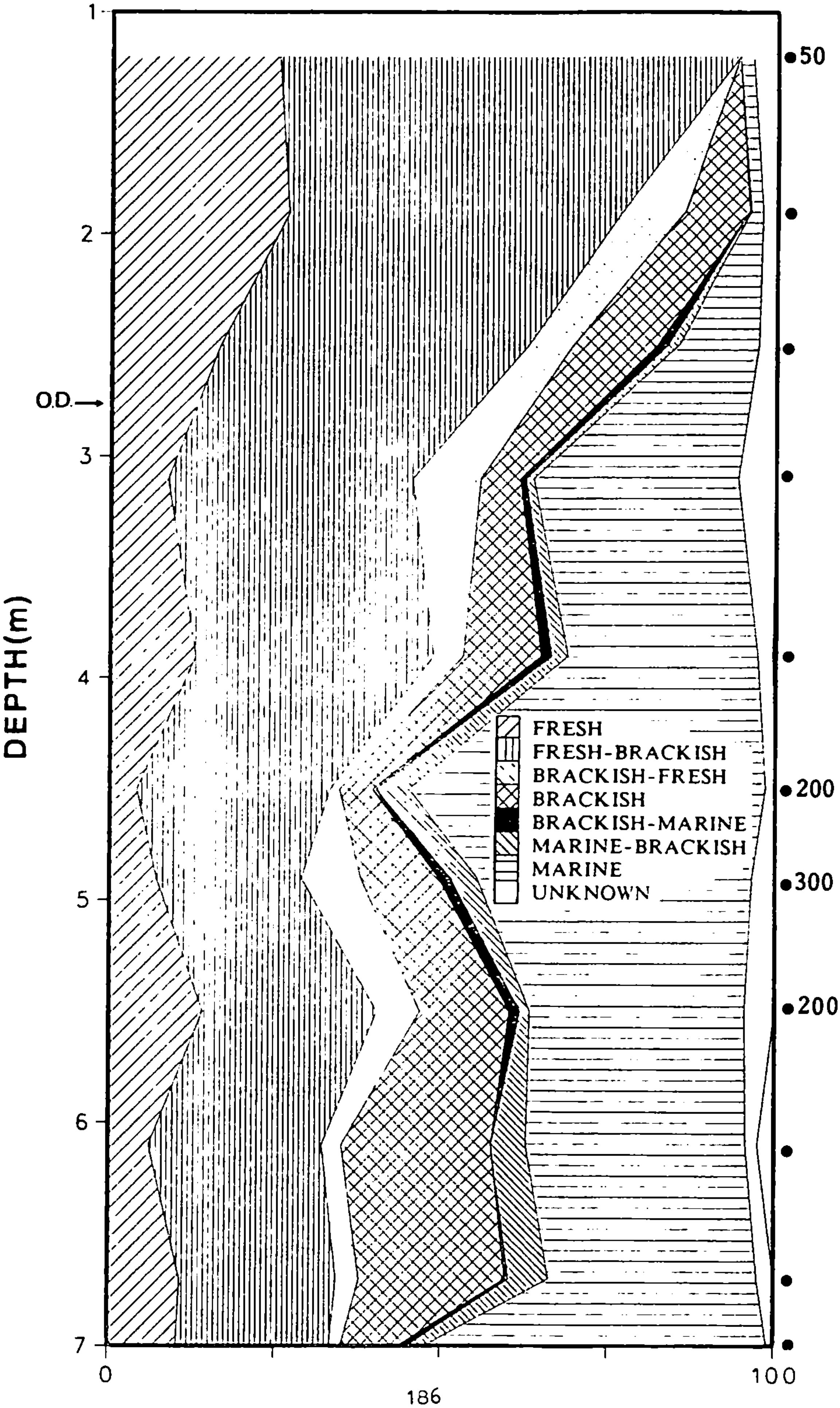


FIG 5.5

BOREHOLE RM2 - DIATOM DIAGRAM

%MBF TAXA

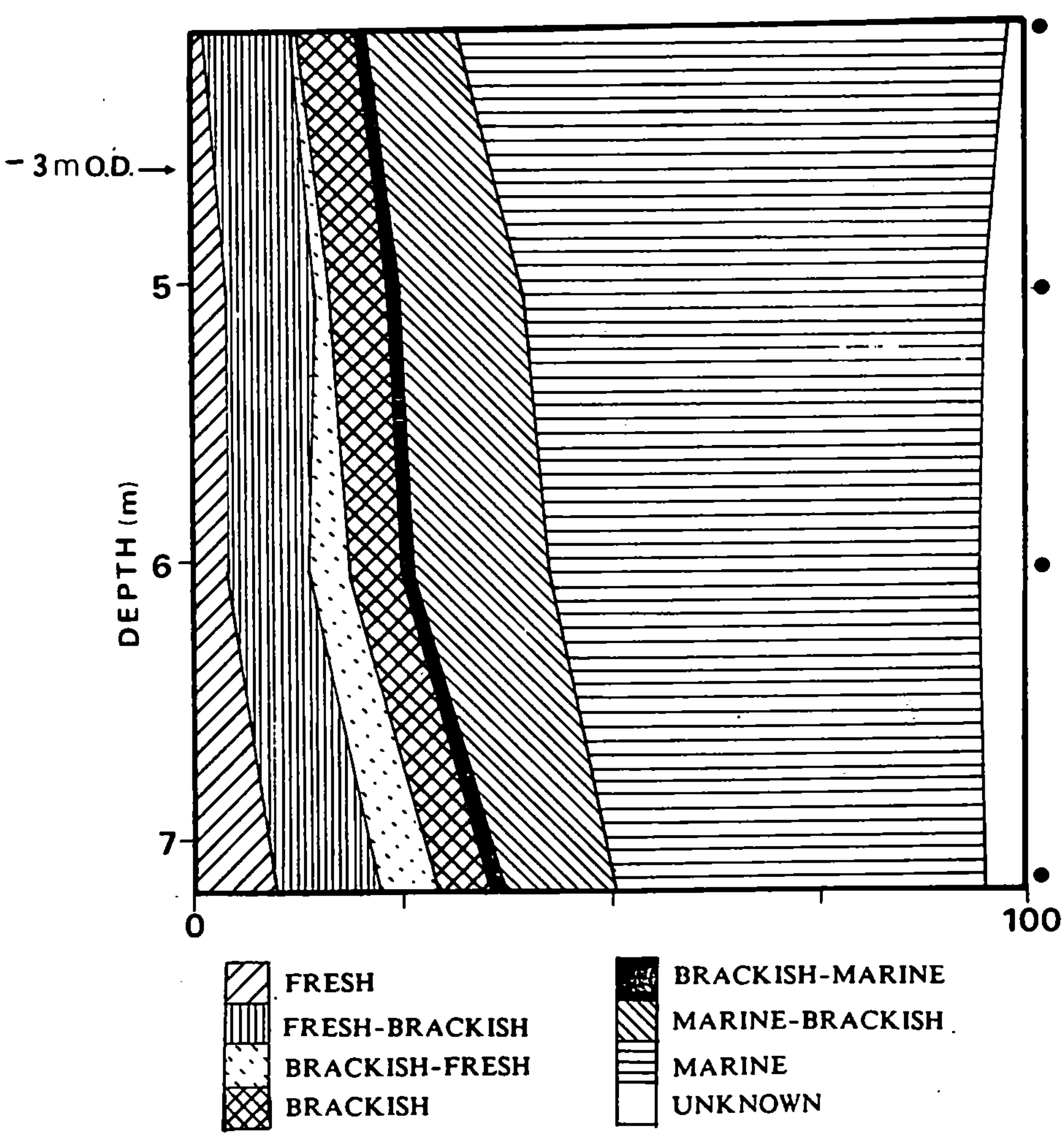


FIG 5.6

BOREHOLE S2 - DIATOM DIAGRAM
% M-B-F TAXA

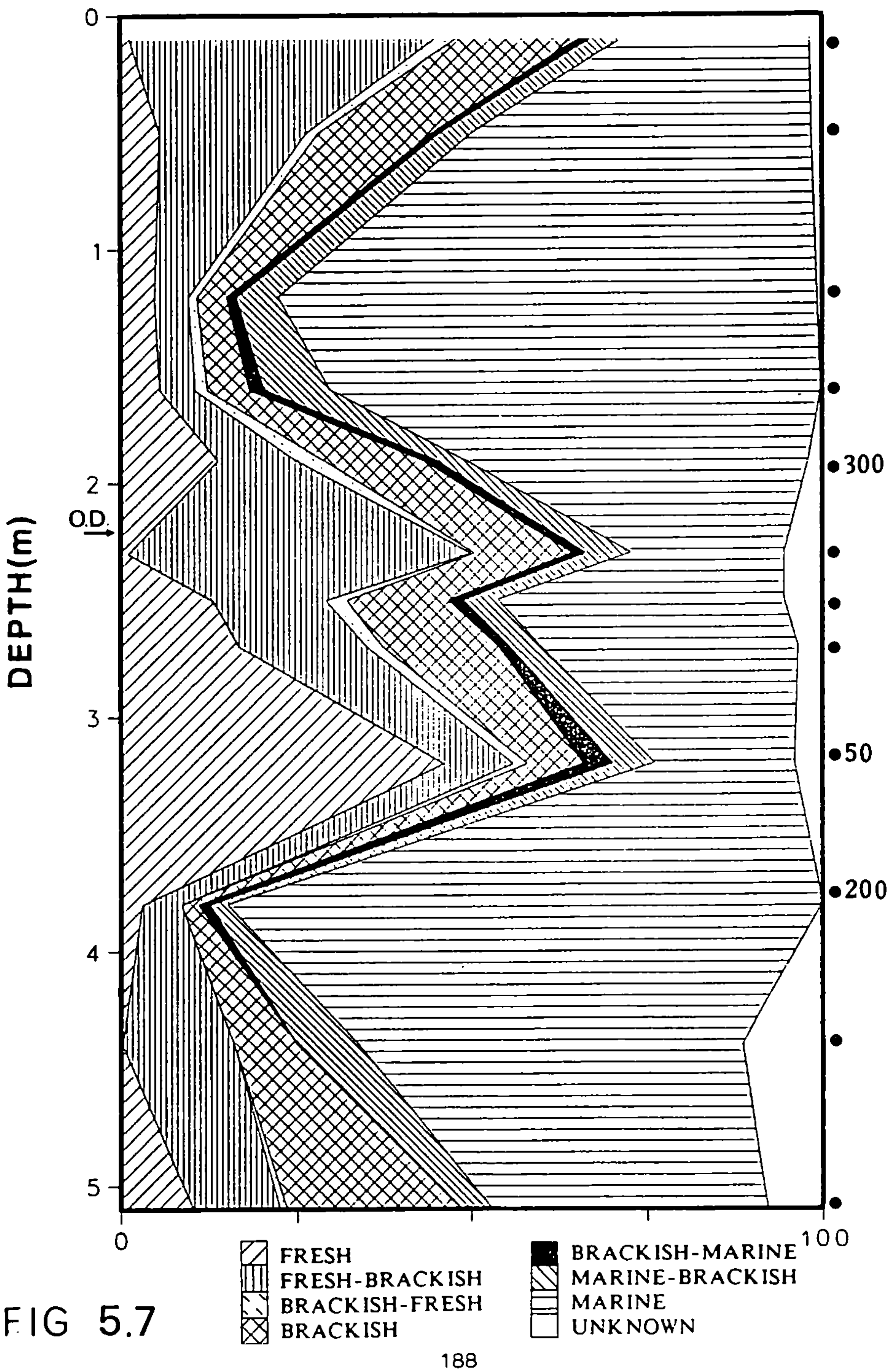


FIG 5.7

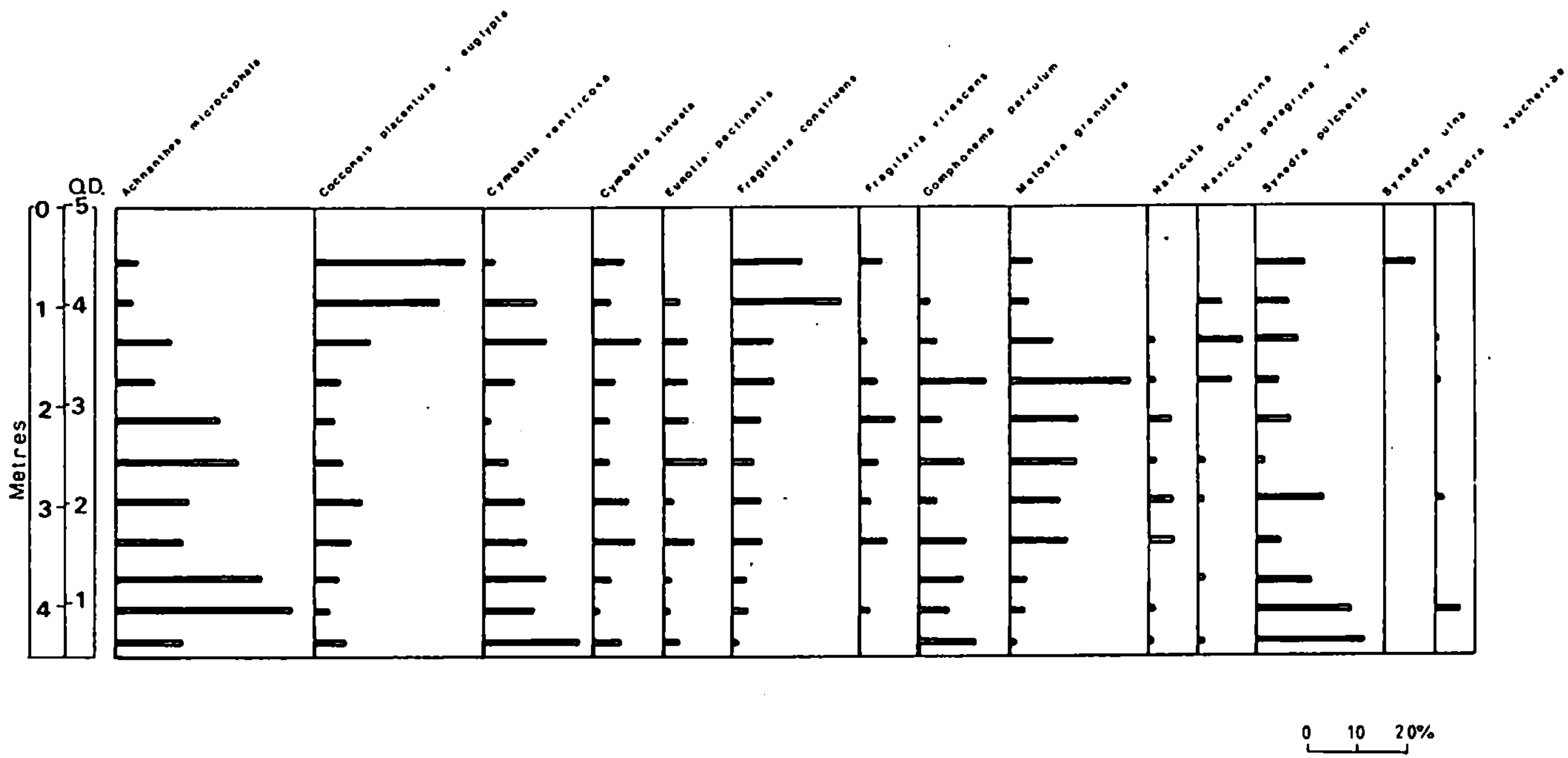


FIG 5.8 Borehole SB2 – Diatom Diagram

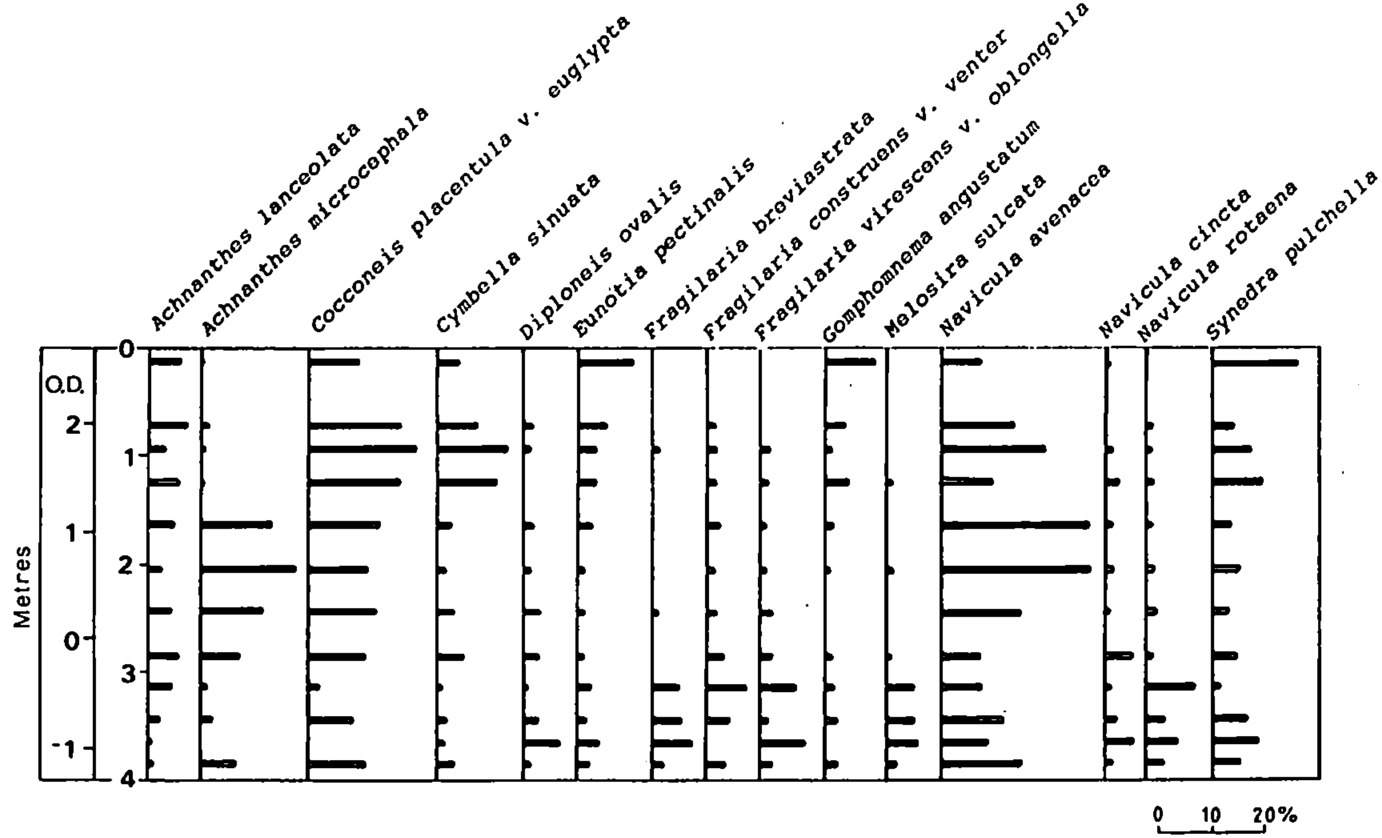


FIG 5.9 Borehole A3 – Diatom Diagram

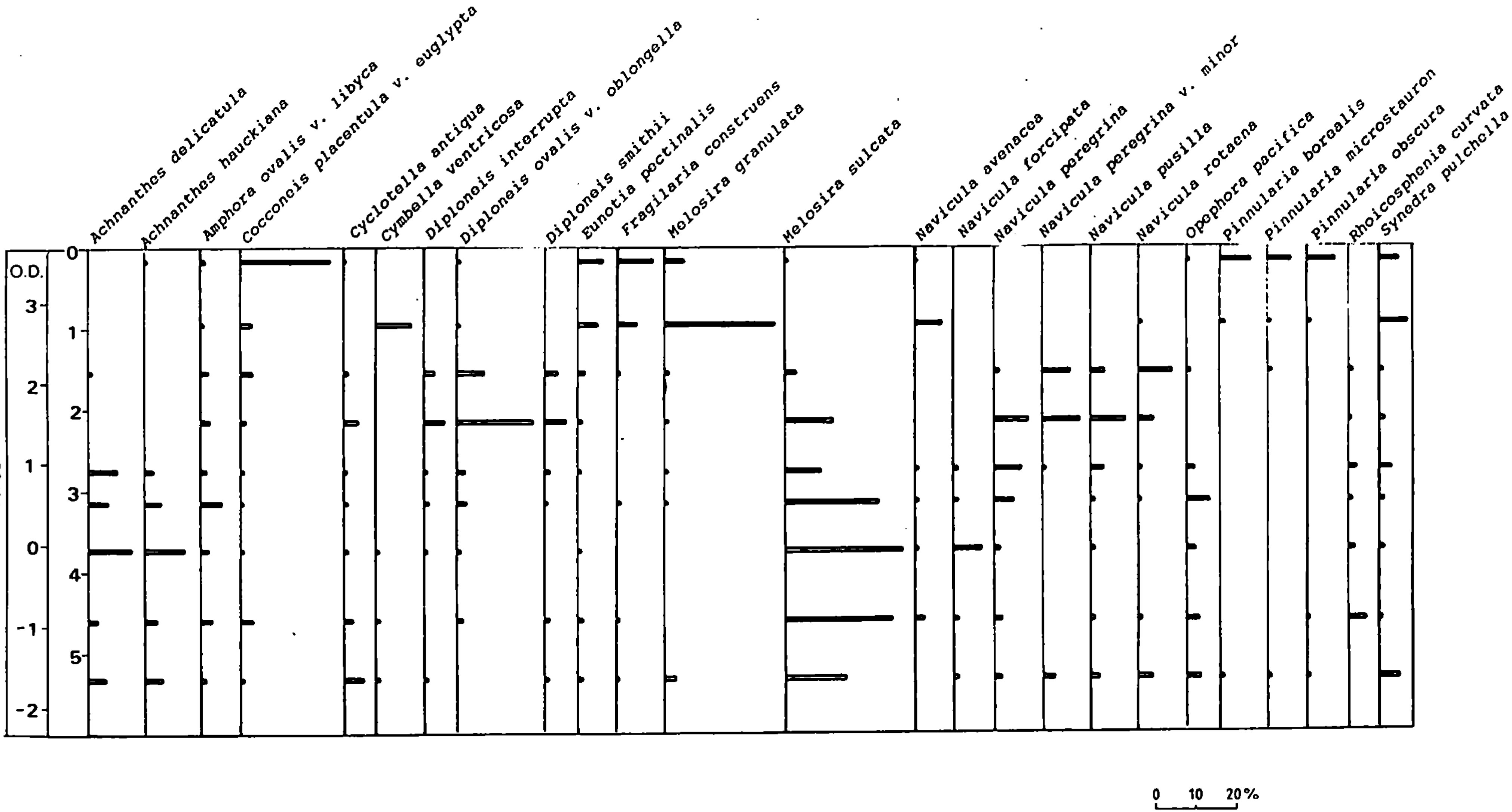


FIG 5.10 Borehole BH6 – Diatom Diagram

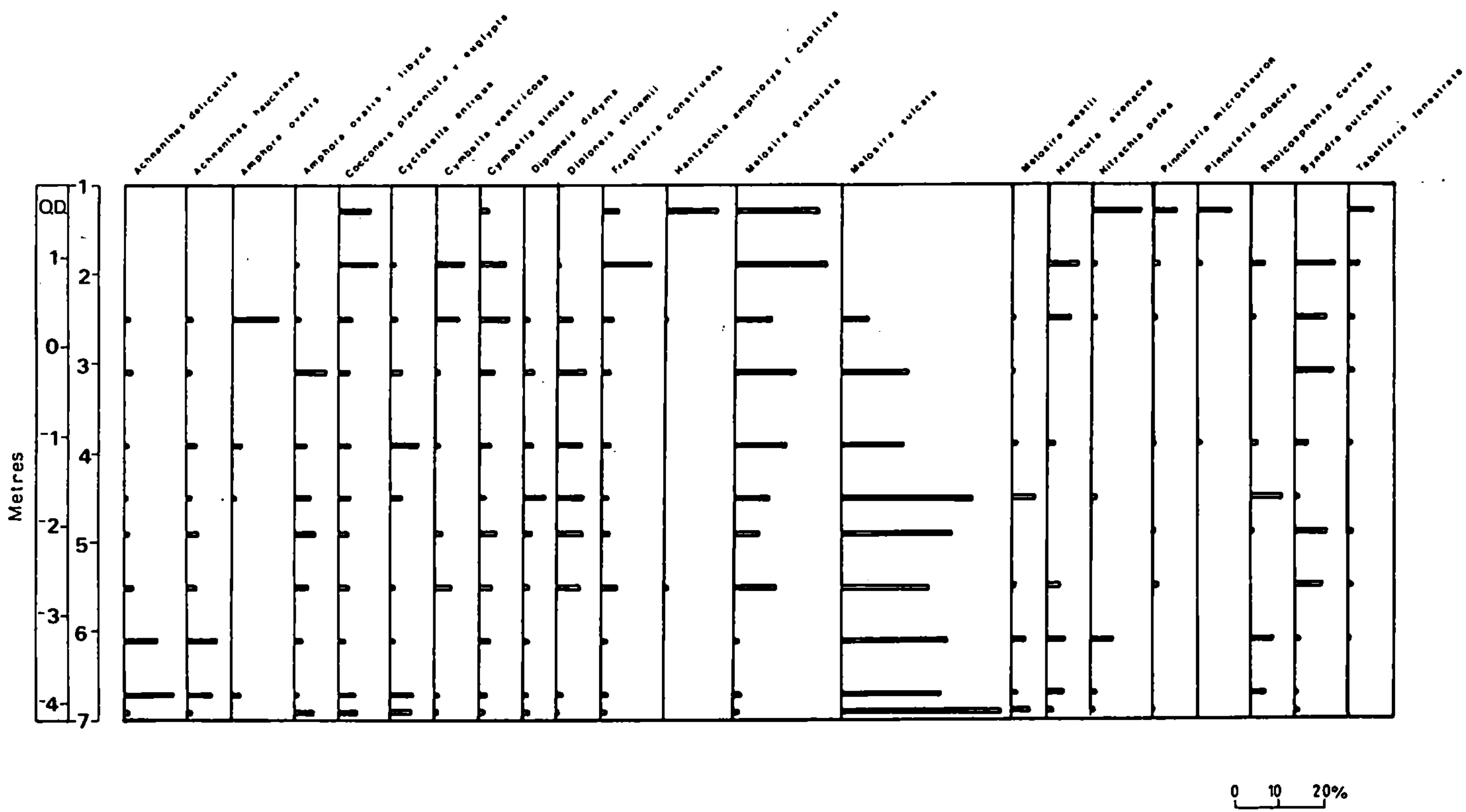


FIG 5.11 Borehole BH11 – Diatom Diagram

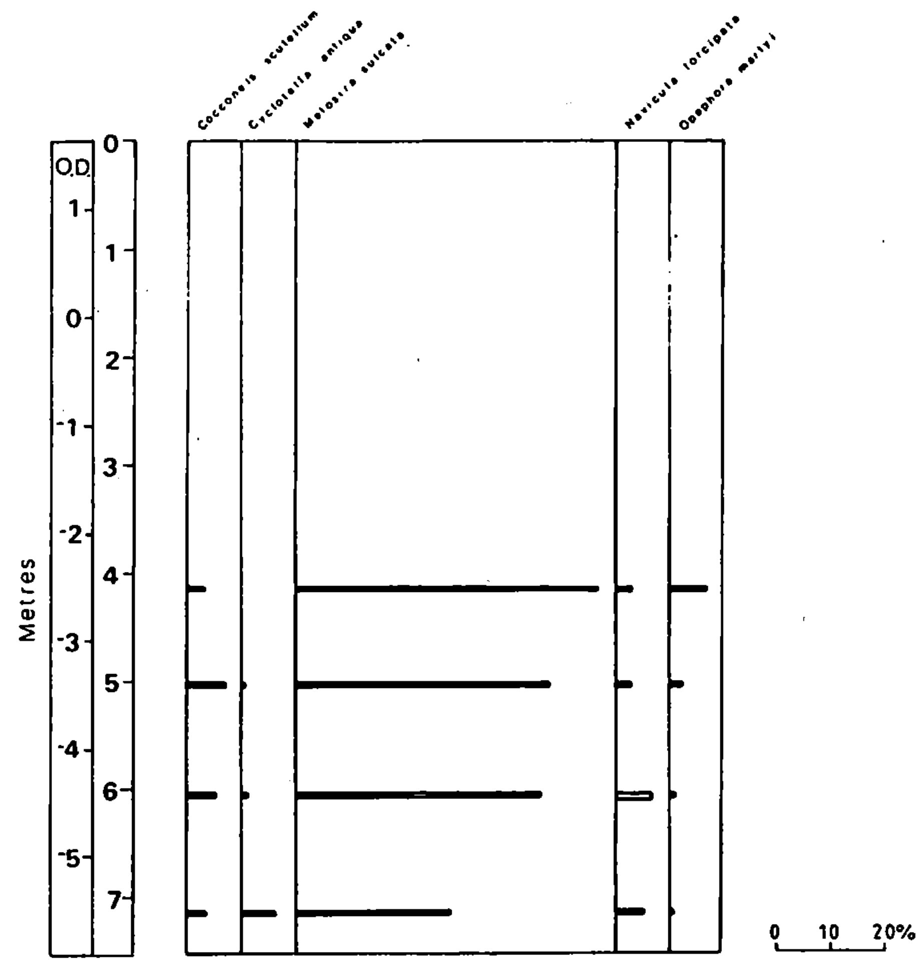


FIG 5.12 Borehole RM2 — Diatom Diagram

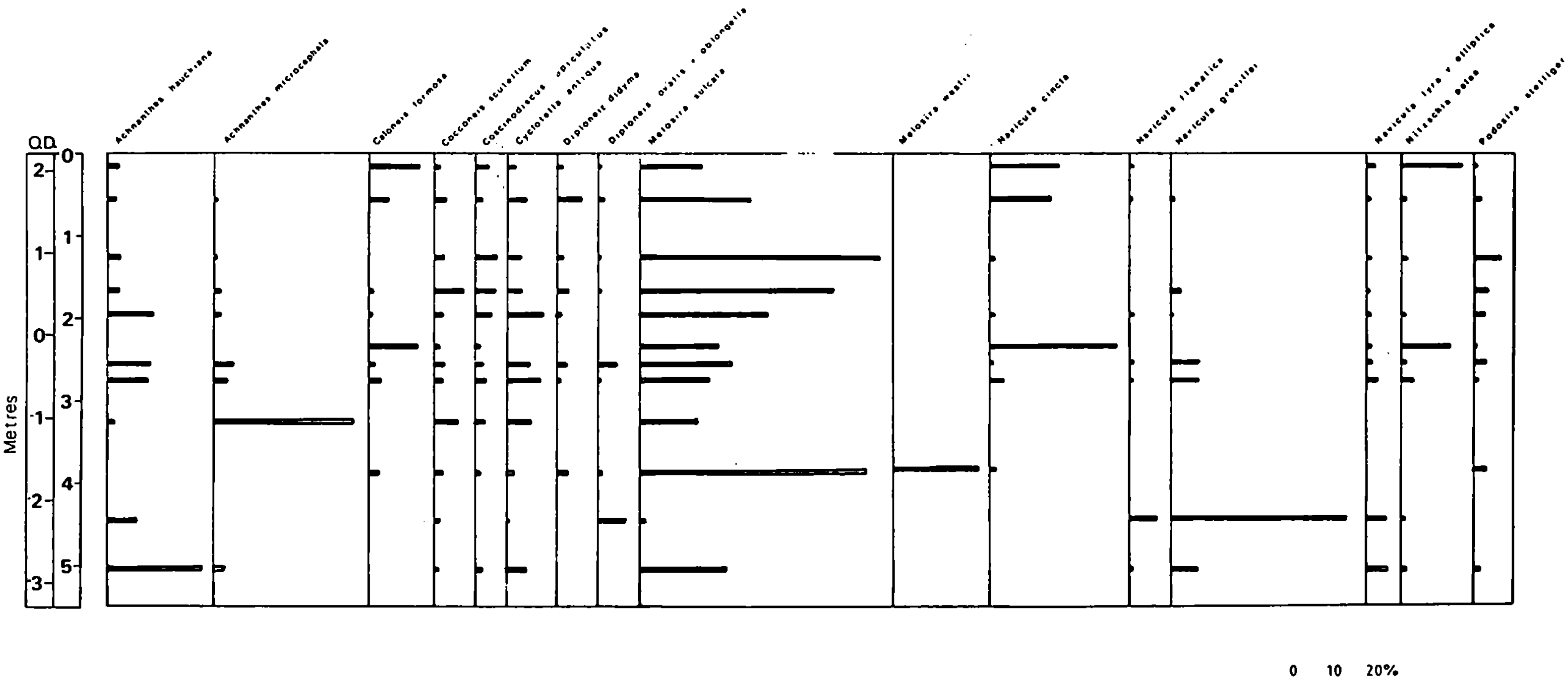


FIG 5.13 Borehole S2 — Diatom Diagram

5.5.1 Combined Salinity Diagrams

In the sediments recovered from the buried channel of the Erme, most taxa are in the fresh (F), fresh-brackish (FB), brackish (B) and marine (M) salinity groups, with the brackish-fresh (BF), brackish-marine (BM) and marine-brackish (MB) groups having noticeably smaller numbers of diatoms

The results of the diatom analysis will be discussed from north to south, that is, SB2, A3, BH6, SB2, RM2 and S2. The sediment recovered from location SB2 (see figure 5.2) contained predominantly fresh and fresh-brackish diatoms accounting for up to 80% of the total diatom count. Marine and marine-brackish species account for less than 2% of the total. The main variations in the salinity of the sediment occur between 1.6-2.8m depth (3.4- 2.2m OD) and between 3.4-4m depth (1.6-1m OD) where the fresh water group of diatoms increase as a percentage of the total. At 2.8m depth (2.2m OD) there is a small influx of brackish-fresh diatom species, and below 4m depth (1m OD) the brackish-fresh proportion increases to its greatest value in the core. In the top 1m of the sediment very few diatom valves were present and the prepared slides were covered in very fine sediment. Thus at 0.4m depth it was only possible to obtain a count of 50 valves and at 0.9m depth, 200 valves. Generally, the sediments become more fresh-brackish towards the top of the core.

The sediment analysed from location A3 (figure 5.3) is lower relative to OD than SB2, and spans 2.7m - -1.25m OD. The largest salinity group is the fresh-brackish group, which accounts for a maximum of 60% of taxa. The fresh and brackish groups account for a maximum of 30%. Below OD, the marine salinity groups make up 9% of the total species encountered. Above this level the main variations are due to slight changes at between 1.2-2.1m depth (1.5-0.6m OD) where the number of brackish diatoms increase. Up to 10% of taxa could not be identified in the samples from this core.
In the sediment recovered from BH6 (figure 5.4) between 3.6m OD and -2m OD, no main salinity group is dominant as there is a change from fresh and

fresh-brackish to marine and brackish species with depth. In the surface horizons the fresh-brackish group accounts for more than 50% of the total species counted. This decreases to 30% at 1.6m depth (2m OD) and c. 10% at Ordnance Datum. Here the marine groups make up 50% of the total and the brackish 25%. Below this the marine influence decreases to 30% and the brackish to about 15%. As with the upper sediments from SB2, samples contained a large amount of very fine material, thus permitting a count of only 200 individuals.

The upper sediments recovered from BH11 are almost exclusively of fresh and fresh brackish diatoms (see figure 5.5); this decreases to c. 50% between 2.6-3.6m depth (0--1m OD) and 25% between 4.6-6.6m depth (-2--4m OD) Correspondingly, the brackish and marine groups increase with the latter accounting for the largest proportion of the total count. As in the sediment from the upper horizons at SB2 and BH6, a count of only 50 valves was possible at the surface because of the interference of fine sediment on the slide. Around 4.6m depth (-2m OD) three samples were analysed and counts of only 200, 300 and 200 individuals were possible. In these three instances, many of the diatom valves were fragmented and considerable quantities of fine matter was present.

Eight slides were prepared from the top 4m of the sediment from RM2 but could not be counted because of interference of fine material and the absence of diatom valves. A further eight were prepared from the lower 3.2m, and because the diatom assemblages showed little difference between samples, only four of these were counted. This lower 3m of the core (shown in figure 5.6) show sediments to be 60% marine decreasing to 45% at the base. Marine brackish, fresh brackish and brackish are the next largest categories. These are uniform throughout the sequence with the fresh and brackish-fresh categories increasing in importance with depth.

The salinity diagram for sediment from S2 (figure 5.7) shows dramatic shifts between fresh and marine diatoms. The main fresh and fresh-brackish peaks occur at c. 0.2m, 2.2m, 3.2m and 5m depth (2m, 0m, -1m and -2.8m OD). The intermediate groups of brackish-fresh, brackish-marine and marine-brackish account for less than 10% of the total throughout the core. The dramatic swings at 2.2m and 3.2m depth (0m and -1m OD) may be due to flood deposits; the first peak shows an increase in fresh-brackish water species and the second fresh water species. The latter is based on a count of only 50 species which may not therefore be a true representation of the salinity of the sample. At this level and where only 200 valves were counted the slides showed mainly fragmented fresh water valves and perfect marine forms. This may be indicative of flood conditions, although broken valves need not indicate long distance transport.

Some general points can be made concerning the salinity diagrams. SB2 and A3 are mainly fresh and brackish with small variations through the sediment sequence. BH11 and BH6 are predominately fresh-brackish at the surface and show an increase in marine species with depth followed by a return to a more fresh-brackish environment. At the base of BH11, marine species once again increase. S2 has mainly marine species but with some fluvial-brackish interruptions to the sequence. The increase in marine taxa at -1.5m OD in S2 may be equivalent to that in BH11 at approximately the same level and to BH6 at 0m OD. The fluvial interruptions in S2 may possibly be equivalent to the fluvial conditions at depth in BH6 and BH11. There is little variation in the 3m of sediment analysed from RM2 and the results show a slight increase in marine sediments upwards.

There will obviously be regional variations in both the timing and effect of any changing conditions at different locations which must be considered when comparing the results from cores. A detailed look at the actual species identified within the deposits will provide more information on the environments of deposition of sediment in the buried channel.

5.5.2 Individual Species

The actual diatom species identified in the sediments from the Erme's channel will be discussed in this section.

Achnanthes microcephala is found in SB2 and A3 and at one horizon in S2. The SB2 and A3 units are probably of equivalent phases. The peak in S2 is most likely due to sudden flood conditions rather than a long term fluvial environment. Patrick and Reimer (1966) considered the species to be indicative of eutrophic conditions. Other *Achnanthes* species are present in all cores except SB2; the presence of *A.lanceolata* in A3 suggests a fluvial-brackish environment, although it occurs in a wide range of ecological conditions especially in well aerated flowing waters (Patrick and Reimer 1966). The presence of *A. haukiana* in BH6, S2 and at depth in BH11 implies slightly brackish conditions.

Achnanthes delicatula and *Opephora pacifica* are both episammic (living on sand grains), and indicate an intertidal or sub-tidal zone on sand flats and beaches (Vos and de Wolf 1988). The former is present in BH6 and BH11, and the latter in RM2.

Cocconeis placentula var euglypta is quite common in the samples from this study area and is an example of a species that has a broad salinity tolerance of fresh and brackish water (Vos and de Wolf 1988). It is present mainly in samples from SB2 and A3 and to a lesser extent in BH6 and BH11 reflecting the fluvial brackish nature of the cores. It generally peaks in the upper horizons of the cores.

Cocconeis scutellum indicates brackish lagoons and ditches; it is present in RM2 and S2.

The *Cymbella* group of species, *C. ventricosa* and *Cymbella sinuata* are most prevalent in SB2 and A3, with lesser numbers in BH6, BH11 and RM2 suggesting a fresh-brackish environment.

The presence of *Diploneis interrupta, D. ovalis, Navicula cincta* and *Navicula rotaena* in sediments from BH6, A3 and S2 suggest a large salinity range and salt marsh environment. *D. ovalis var oblongella* is indicative of a drying out area as the species is aerophilous (Haworth 1976), it can be found living in clayey sediments in an intertidal zone such as a mudflat or creek environment (Vos and de Wolf 1988). Here it is seen in samples from S2 and BH6. *Diploneis didyma* and *Caloneis formosa* were also found to occupy the same environment by Vos and de Wolf. The former is present in BH11 and the latter in S2.

Eunotia spp. tend to occur in acidic cool waters, *E. pectinalis* was the most common from the Erme sediments although *E. diodon* and *E. exigua* amongst others, indicative of bogs, springs and small streams were present in much smaller numbers.

The *Fragilaria* group of species are widely distributed in fresh water; they are indicative of freshwater lagoons, lakes, pools and ditches. *Fragilaria construens* occurs most frequently in SB2, at the surface in BH6 and BH11 and at depth in A3. *Fragilaria virescens* occurs to a lesser extent in SB2 and *F. virescens var oblongella* and *F. breviastrata* with depth in A3.

Hantzschia amphyioxys (in sediment from 1.5m depth in BH11) suggest wet soils, flood banks and salt marsh environments (Vos and de Wolf 1988). Haworth (1976) considered *H. amphyioxys* to indicate solifluction when found in Late Glacial deposits, and Brown and Barber (1985) suggested their presence indicated soil erosion.

Melosira granulata occurs throughout SB2 and BH11 and at the surface horizons in BH6; it is at a peak at 1.8m in SB2, 0.8m in BH6 and 1.5m in

BH11, it is planktonic and indicative of fluvial conditions in not too shallow freshwater (Vos and de Wolf 1988).

Melosira sulcata was frequently encountered, and present as a large percentage of the total in S2, BH11, RM2 and BH6. It also occurred as a small percentage near the base of the sediment in A3. It is found in marine-littoral environments, in particular in tidal inlets and large tidal channels (Vos and de Wolf 1988). If there is a tidal gradient between BH6 and BH11, then the peak of *Melosira sulcata* at around 0m OD in BH6 may be equivalent to that at -1.7m OD in BH11 and -1.7m in S2. The top units of S2, obviously represent a more recent phase of sedimentation within a salt marsh environment. The low numbers in A3, may suggest a slight marine influence at the same time as in BH6. An absence in SB2 suggests this was too high up the valley to have been affected by a previous tidal environment on a large scale. Hendey (1964) noted that *M. sulcata* tends to be washed ashore during storms. Vos and de Wolf (1988) grouped *Melosira westii* into the same ecological category as *M. sulcata* in a study of Holocene coastal deposits in the Netherlands. It occurs in small numbers in BH11 and S2. *Rhaphoneis amphiceros* and *R. surrirella* were also considered to be part of the same group; these occur in many of the samples analysed but never more than 5% of the total.

Navicula peregrina, N. peregrina var minor and *N. avenacea* are most visible in A3 and BH6 and imply a brackish environment. They thrive in sandy sediments in an intertidal zone (Vos and de Wolf 1988). *Navicula palpebralis* and *N. forcipata* are considered to occupy similar ecological niches by Vos and de Wolf; *N. palpebralis* occurs in brackish to marine environments (Patrick and Reimer 1966). These two species are seen in many of the samples, but form less than 5% of the total.

Navicula pusilla, present in BH6 at c. 2m depth, suggests fresh or slightly brackish water.

Opephora martyi, present in RM2, indicates lagoons, ditches and abandoned meanders (Vos and de Wolf 1988) such as shallow freshwater rivers and lakes (Patrick and Reimer 1966). *Gomphonema angustatum* and *Tabellaria fenestrata* occur in similar environments and are seen in SB2 and BH11 respectively.

Pinnularia borealis (in surface sediments from BH6) indicates cool low mineral environments and is often found in rivers (Patrick and Reimer 1966).

Synedra pulchella occurs in fresh water or slightly brackish conditions; it forms a large percentage of the total in SB2, A3, and to a lesser extent in BH11 and BH6.

The distribution of these species in the cores is discussed here.

SB2

The diatom diagram in figure 5.8 shows that the upper units are dominated by *Cocconeis placentula var euglypta* and *Fragilaria construens*; the assemblage indicates a freshwater environment with some brackish influence and some shallow ditches and ponds. Below 1m depth, *Achnanthes microcephala*, *Melosira granulata* and *Gomphonema parvulum* are present and at about 1.7m depth *Melosira granulata* becomes dominant, replaced at 2.1m by *Achnanthes microcephala*. These species suggest a deeper freshwater environment with a less brackish component than above. Below 3.5m, *Achnanthes microcephala*, *Synedra pulchella* and *Cymbella ventricosa* become dominant and indicate an increase in brackish conditions.

A3

Cocconeis placentula var euglypta and *Navicula avenacea* are the most prevalent species in this core (figure 5.9). At the surface, *Synedra pulchella*, *Eunotia pectinalis*, *Gomphonema angustatum*, *Navicula avenacea* and *Achnanthes lanceolata* are the dominant species. The first three of these decrease with depth, allowing *Cymbella sinuata* and *Cocconeis placentula var* *euglypta* to increase to around 1.3m depth. This assemblage generally suggests a fresh, slightly brackish environment with some shallow areas of ponds and ditches and some cool acidic water. Below 1.3m, the increase of *Achnanthes microcephala* and *Navicula avenacea* suggest a more eutrophic and also more intertidal environment. From 2.8m, *Synedra pulchella, Fragilaria breviastrata, Fragilaria construens var venter, Fragilaria virescens var oblongella* and *Navicula rotaena* are the main species, with *Navicula avenacea* also increasing with depth. These suggest a more freshwater environment, with some shallow ponds or ditches but also some salt marsh. The introduction of *Melosira sulcata* implies a limited intertidal influence.

<u>BH6</u>

A greater variety and number of species are found in the sediments from this core (see figure 5.10), reflecting the mixture of marine, estuarine and fluvial species. At the surface, *Cocconeis placentula var euglypta* with lesser numbers of *Eunotia pectinalis, Pinnularia* spp. and *Fragilaria construens* are present indicating a cool freshwater environment with some shallow pools or ditches. At 0.85m depth, the presence of *Melosira granulata* implies deeper fluvial conditions and between 1.5-2.3m depth *Melosira sulcata, Diploneis ovalis var oblongella, Navicula peregrina, N. peregrina var minor* and *Navicula pusilla* suggest a more intertidal influence with sand or mudflats and some salt marsh. Below this, *Melosira sulcata* is dominant with lesser numbers of *Achnanthes hauckiana, Achnanthes delicatula, Navicula peregrina, Navicula forcipata* and *Opephora martyi.* These imply a more widespread intertidal channel with sand flats, the increase of *Cyclotella antiqua* and *Melosira granulata* at the base suggest an increasing freshwater component.

<u>BH11</u>

Melosira granulata, Hantzschia amphioxys v. capitata, Nitzschia palea and *Cocconeis placentula var euglypta* are present in the upper sediments of BH11 (see figure 5.11) indicating a freshwater, shallow, floodbank environment of deposition, the occurrence of *Cymbella ventricosa, Fragilaria construens* and *Synedra pulchella* between 1.5 and 2m suggests slightly deeper conditions with a brackish influence. Between 2 and 4m depth, a mixed fluvial intertidal environment is indicated by the presence of *Melosira granulata* and *M. sulcata*. From around 4m depth, *Melosira sulcata* tends to dominate much of the remaining profile. *Diploneis stroemi* and *Melosira granulata* between 4-5.5m depth indicate mixed fluvial and tidal creek conditions. Below 5.5m *Achnanthes delicatula* and *Achnanthes hauckiana* suggest more widespread intertidal sand flats.

<u>RM2</u>

Although sixteen samples were prepared for diatom analysis from RM2, only those from below 4m depth were suitable for counting. The resultant distribution is shown in figure 5.12. *Melosira sulcata* dominates the distribution with lesser numbers of *Cocconeis scutellum, Navicula forcipata* and *Opephora martyi.* This assemblage implies a mixed intertidal environment with sand flats, tidal inlets and shallow ditches or lagoons.

<u>S2</u>

The diatom diagram for sediments from S2 is displayed in figure 5.13 and shows dramatic shifts in the assemblages through the core. At the surface *Nitzschia palea, Navicula cincta, Caloneis formosa* and *Melosira sulcata* are present and indicate tidal creeks with sand and mud flats. *M. sulcata* dominates the distribution at 1.2m depth indicating an increasing intertidal environment. The sudden appearance of *Navicula cincta, Caloneis formosa* and *Nitzschia palea* at 2.3m depth indicates deposition in a mudflat and salt marsh environment. Between 2.5-2.9m slightly brackish-freshwater conditions are indicated by the presence of *Achnanthes hauckiana* and *Cyclotella antiqua*. At 3.1m *Achnanthes microcephala* and *Cocconeis scutellum* indicate more fluvial eutrophic and ditch/lagoon conditions and at 3.8m depth, *Melosira sulcata* and *Melosira westii* suggest a massive influx of marine water perhaps as a storm event. They are replaced around 4.4m by *Navicula greveii* still indicating marine.conditions, but at 5m depth *M. sulcata* once again increases along with *Achnanthes hauckiana* to indicate mixed fluvial and intertidal waters.

5.6 Discussion

The diatom species found in the sediments from the Erme indicate a range of environments from fresh water to salt marsh to intertidal mud and sand flats. It is likely that these environments co-existed and that the diatom analysis generally implies a mixed fluvial estuarine environment with occasional influxes of marine water. Since there are a number of factors which affect diatom growth and distribution apart from salinity, the presence of some of the species encountered may be due to very localized conditions; these are considered here.

The life span of diatoms is variable: a dominant living population can be replaced by another bloom during a single season, thus responding rapidly to changing environmental conditions. However, continuous mixing of sediment, helps to reduce the importance of blooms that would otherwise bias results (Palmer and Abbott 1986). In addition, some species tend to live in mud and migrate up and down the top few centimetres, and can thus distort sampling if undertaken at a fine interval.

Temperature, light and nutrients in water determine which species develop most abundantly. For example, cooler more consistent temperatures at the headwaters of streams may be preferable to some species rather than downstream where currents are stronger and temperatures more variable. Light is determined by the depth of water, surrounding vegetation and suspended sediment. Thus flood conditions with higher sediment yield affect populations. Large beds of floating aquatic species develop if stream waters are rich in nutrients. Some species also tend to have a particular preference for a certain sediment type such as sand or silt.

In a fluvial environment large meanders and oxbow lakes encourage the development of diatom floras. Large tidal flats exposed at low tide are good for preservation of floras as withdrawal of water may allow oxidation or rapid sedimentation (Haggart 1986). Planktonic flora thrive in open parts of an estuary, and show a mixture of brackish and marine species. At shallower parts, benthic species occur. Haggart (1986) suggests that a large mixture of fluvial, brackish and marine species represents an environment high in the tidal range. BH6 and BH11 indeed have a large mixture of fresh, brackish and marine taxa. An indication of the diversity of the taxa in samples from the River Erme sediments is given in table 5.5.

CORE	>5%	>2.5%	All
SB2	14	24	102
A3	15	40	144
BH6	25	44	138
BH11	22	36	143
RM2	5	11	87
S2	16	29	82

TABLE 5.5 NUMBER OF DIFFERENT DIATOM SPECIES THAT ACCOUNT FOR MORE THAN 5%, 2.5% AND ALL OF THE TOTAL COUNT

This shows that 138 taxa were identified from sediments in core BH6 and 25 of these account for 5% or more of any one sample from the core. Thus when comparing the number of species that make up 5% or more of the total diatoms counted, it can be seen that BH6 and BH11 are the most diverse. Cores A3, BH6 and BH11 have the most diverse diatom assemblage when all species identified in the core are considered. About 40 extra species are found in these three cores compared to SB2, RM2 and S2 showing that they are more diverse and thus have a greater mixture of sediments.

Palmer and Abbott (1986) also considered that all the halobian classes should be anticipated in coastal sediments where changes of sea level are most effectively preserved. All the cores illustrate this, in particular BH11 and BH6, and even in the more freshwater cores of A3 and SB2, some brackish and marine species are present.

A major problem in palaeoecological research of diatoms in the tidal environment is the distinction between diatoms that have lived at their place of deposition (autochthonous) and those transported from elsewhere by water or wind (allochthonous) (Vos and de Wolf 1988). One method of differentiating the two populations has been to look at the degree of fragmentation of valves to indicate long distance transport. As Vos and de Wolf pointed out however, compaction and diagenesis also damage valves, and pennates tend to break more easily then centrales. An example is provided by marine and brackish taxa being carried far up into estuaries increasing the allochthonous population (Beyens and Denys 1982). Some of the samples from S2 had many fragmented pennates and perfect centrales, such as *Melosira sulcata*, and may represent sediments incorporating some long distance fluvial units that have been broken during transport. The brackish and marine species encountered from sediments in BH6 were also well preserved, and may also indicate some transport by marine waters upstream. The inclusion of allochthonous valves may explain some of the conflicts seen in the diatom diagrams where freshwater and marine intertidal species occur together.

The top metre of sediment recovered from SB2, BH11, BH6, and the top 4m of sediment from RM2 was difficult to count because of fragmented or absent diatom valves and lots of very fine sediment. This fragmentation may be due to damage by compaction, soil forming processes and agricultural practices.

An important question is the relationship of diatoms to sea level. Eronen *et al.* (1987) stated that a rich marine-brackish diatom flora can live below the limit of the level of regular highest tide; this is the approximate upper boundary of frequent salt water influence. Thus diatoms can be indicative of the upper limit of the normal tidal range and the brackish-marine sediments deposited at location BH6 may indicate this. Eronen *et al.* pointed out that exhaustive studies have not been carried out to define the vertical distribution of diatoms in present day tidal marshes, hence more specific interpretations of these diatom results for former conditions in the Erme estuary await further research.

5.7 Conclusions

The diatom analysis undertaken here has provided a useful study of the conditions under which sediment was deposited in the palaeochannel of the Erme. Overall the diatom analysis indicates more estuarine and marine conditions in the lower part of the study area with an increasing fluvial environment through time. The combined salinity diagrams show that the surface units in BH11, SB2 and BH6 were deposited during fresh-brackish water conditions. With depth BH6 and BH11 have more estuarine units. On the whole BH6, BH11 and S2 display similar trends with stronger local influences in S2. SB2 and A3 show predominantly fresh and fresh-brackish environments.

The main difficulty in comparing particular species between sites is that most of the taxa that account for a high proportion of the sample at one site, do not tend to occur as such a large percentage elsewhere and as already mentioned, since diatom populations are often very diverse, it is unwise to make palaeoenvironmental interpretations on the basis of one taxon alone (Palmer and Abbott 1986). The individual diatom diagrams show that a number of species of the same ecological groupings increase and decrease together. Environments of deposition range between marine tidal inlets, salt marsh, fresh-brackish and freshwater rivers and wet soils and floodbanks. The relationship between this study and the other analyses will be further considered in chapter 8.

CHAPTER 6 MOLLUSCAN FAUNA OF THE BURIED CHANNEL DEPOSITS

6.1 Introduction

The study of molluscan shells preserved in sediments can be used to indicate various environmental conditions such as water quality and depth at the time of deposition. Hence, if a sufficient number of species occur at different levels within a sedimentary sequence their study could be used to infer the depositional history, and in particular, whether they represent freshwater, tidal or marine sedimentation. More commonly, molluscs have been used in palaeoenvironmental studies of land deposits particularly in the chalk regions of southern and eastern England where they tend to be well preserved in solifluction sediments (Kerney 1963). However, studies by West and Sparks (1960), Anderson *et al.* (1970), Gilbertson and Hawkins (1978) and Tooley (1981) have been concerned with analysis of marine and intertidal molluscs and are therefore more relevant to this research.

During initial examination of the sediments a number of the cores obtained from the palaeo-channel of the River Erme were found to have fragments of mollusc shells. These sediments were used for a more detailed study in the hope that they would shed some light on the environment of deposition and enable cross-correlation between the cores.

6.2 Methodology

6.2.1 Extraction of Molluscan Shell Fragments from the Samples

The cores with shell fragments present that were selected for further study are from the southern part of the Erme valley at locations BH11, BH12, RM2, RM1 and S2. Cores S1 and RM3 also have mollusc fragments but those selected are considered to cover the area under study sufficiently. The highest horizon containing shell fragments in each core was identified and sub-samples were taken at intervals below this level. The number of sub-samples was determined by the original sampling interval (see Chapter 4) used in collecting sediment in the field; this was at 20cm intervals at sites BH11 and BH12, and every 10cm at sites RM1, RM2 and S2.

The samples were oven-dried at 70 degrees centigrade and then weighed. (Temperatures of greater than 100 degrees centigrade would lead to shattering of the shells (Gilbertson and Hawkins 1974)). The samples were then immersed in a solution of water and washing up liquid, which acts as an effective dispersant. Each sample was sieved through a 0.5mm mesh and dried. The molluscan shells and fragments were separated and sorted into different species from the remaining >0.5mm fraction using a low powered binocular microscope and a moistened paintbrush.

6.2.2 Counting of Species, Identification and Presentation of Results

In all cases, there were far more shell fragments than whole shells preserved. A standard method was adopted to count the fragments and whole shells; in the case of bivalves, individuals were counted when the greater part of the hinge was present and the total number was halved. Whole gastropods were counted and where shells were only partly preserved, the number of apexes or apertures were recorded. In all cases the total number of individuals did not reflect the large number of fragments present. The total number of individuals of each species has been expressed as a percentage of the total weight of each sample to enable comparisons between different horizons. An average weight of sample for each core was used for the adjustment, generally around 100g. Gilbertson and Hawkins (1974) considered that a sample of 30 individuals represents the minimum sized sample to be statistically reliable. In most cases this has been satisfied, the exception being those samples from BH11 and some from BH12.

Molluscan species present were initially identified with the help of Dr. David Gilbertson of the University of Sheffield and thereafter using standard identification keys (Beedham 1972, Tebble 1976). The most commonly occurring species are shown in plates 6.1-6.5. Some of the species could not be positively identified and if present in sufficient quantities they have been labelled with a letter. Juvenile forms of species made the identification of some of these difficult. The large amount of data from this analysis was stored on a mainframe computer using MINITAB, a statistical package designed to manipulate a large volume of data. A graphics package (TELL-A-GRAF) was used to produce graphic representations of some of the data. The number of individuals counted for each core are given in appendix 3.

Molluscan diagrams have been produced for boreholes BH12, RM2, RM1 and S2, and are displayed as variance in absolute number of species (adjusted according to weight) with depth relative to Ordnance Datum. These are shown in figures 6.1-6.4. Results from BH11 have not been plotted as so few individuals were counted in the samples analysed.

6.3 Results

The main mollusc species present in the buried channel deposits of the Erme are *Macoma balthica*, *Cardium edule*, *Hydrobia ventrosa*, *Hydrobia ulvae* and *Rissoa parva*. Their environmental significance is discussed below.

Macoma balthica lives in thick mud, muddy sand and muddy gravel in British waters from the upper regions of the tidal zone to low water. It is tolerant of low salinities and can be found burrowing in mud in shallow brackish water.

Cerastoderma edule (Linnaeus) (≡*Cardium edule*) appears to require a tidal environment (Russell 1971) and is therefore a significant environmental indicator. Its habitat is the middle to lower shore, burrowing in mud, sand or gravel in estuaries.

Rissoa parva lives on the extreme lower shore in shallow water and is usually associated with coralline seaweeds and is found under stones.

PLATE 6.1

The top 3 rows show shells and fragments of *Macoma balthica* and the bottom fragments belong to *Cardium edule*.

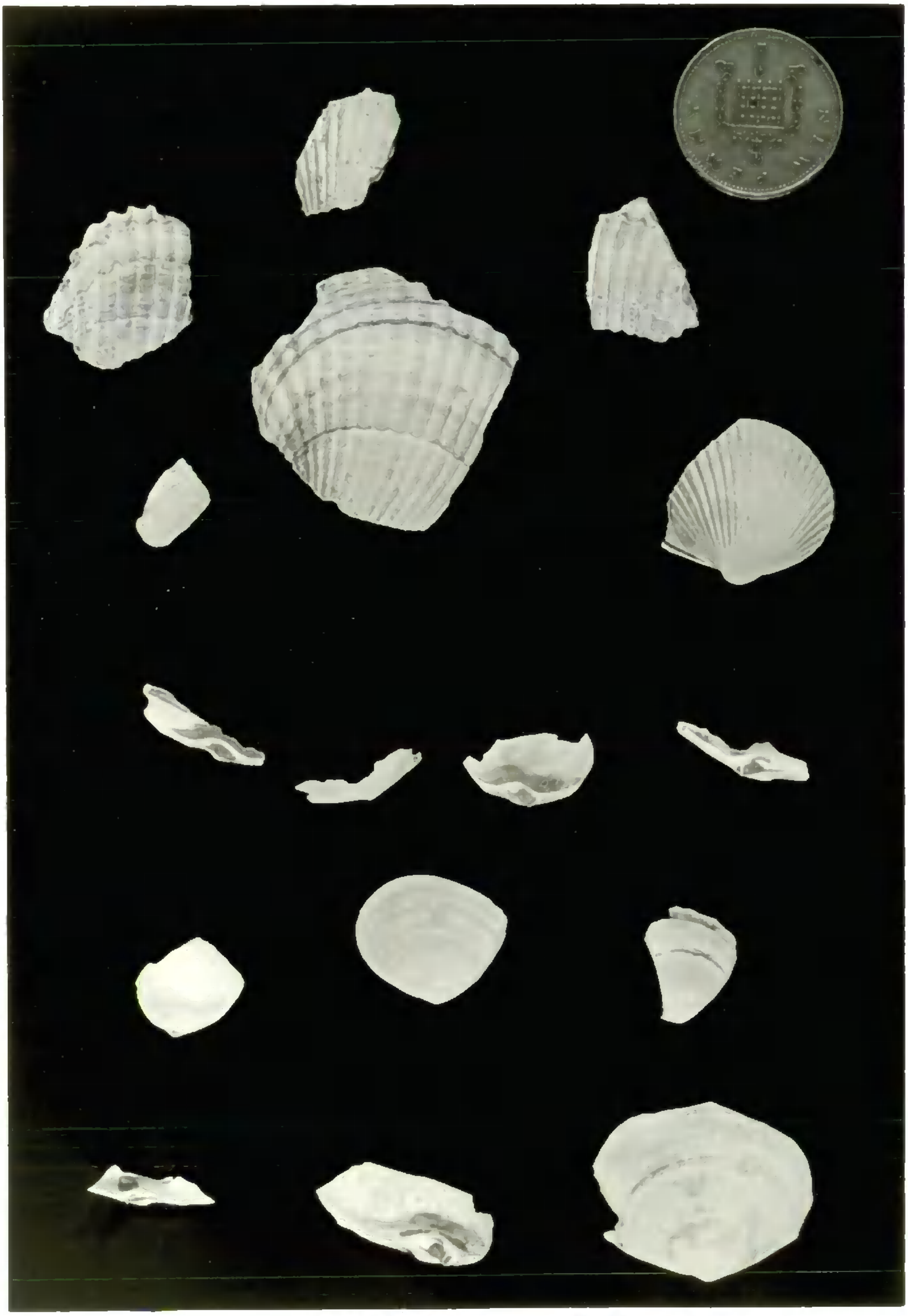


PLATE 6.2

Hydrobia ulvae (Pennant) is shown in the top two rows and *Hydrobia ventrosa* (Montagu) in the bottom two.

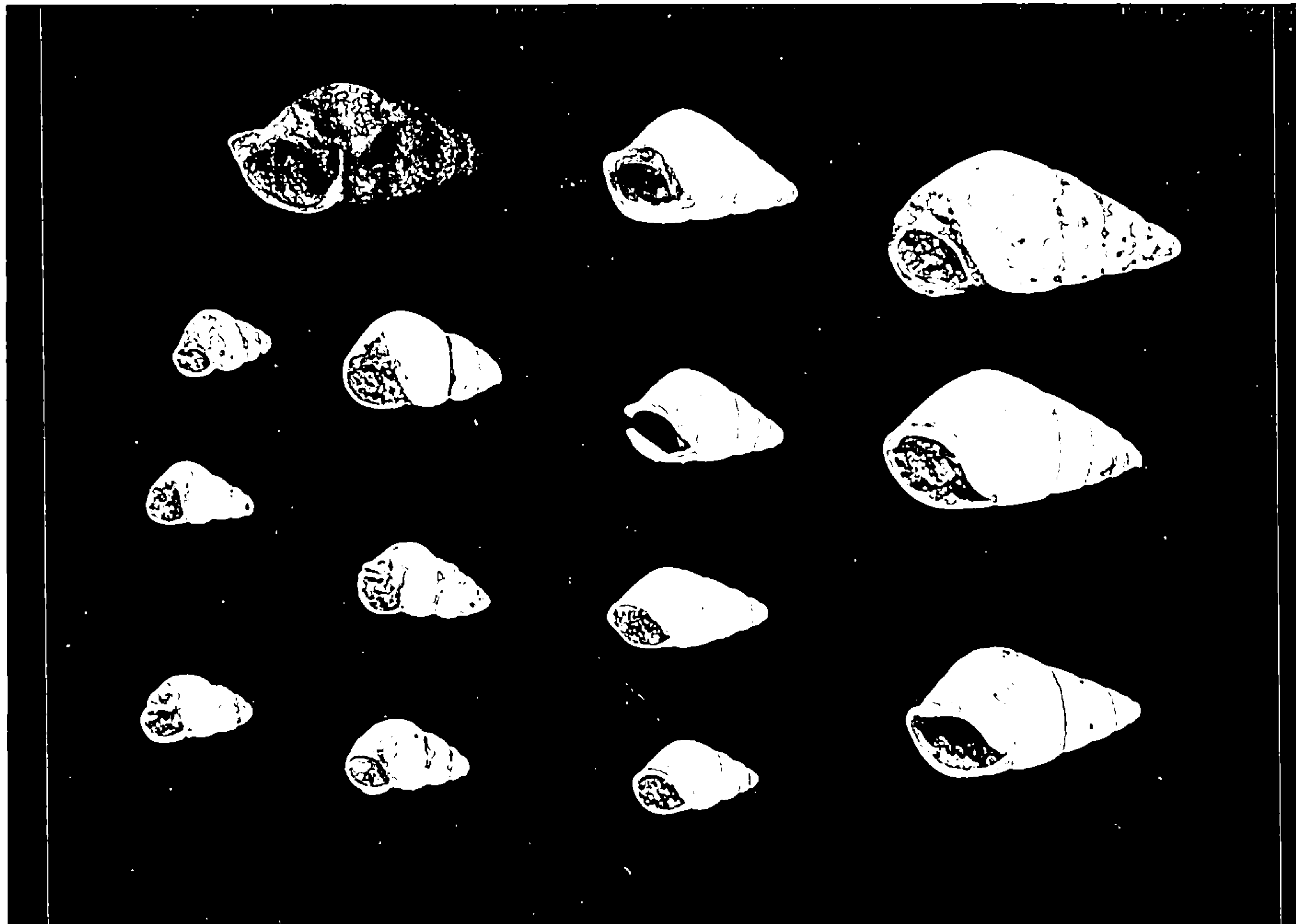


PLATE 6.3

The top two rows show *Rissoa parva* and the bottom two rows some unidentified juvenile species.

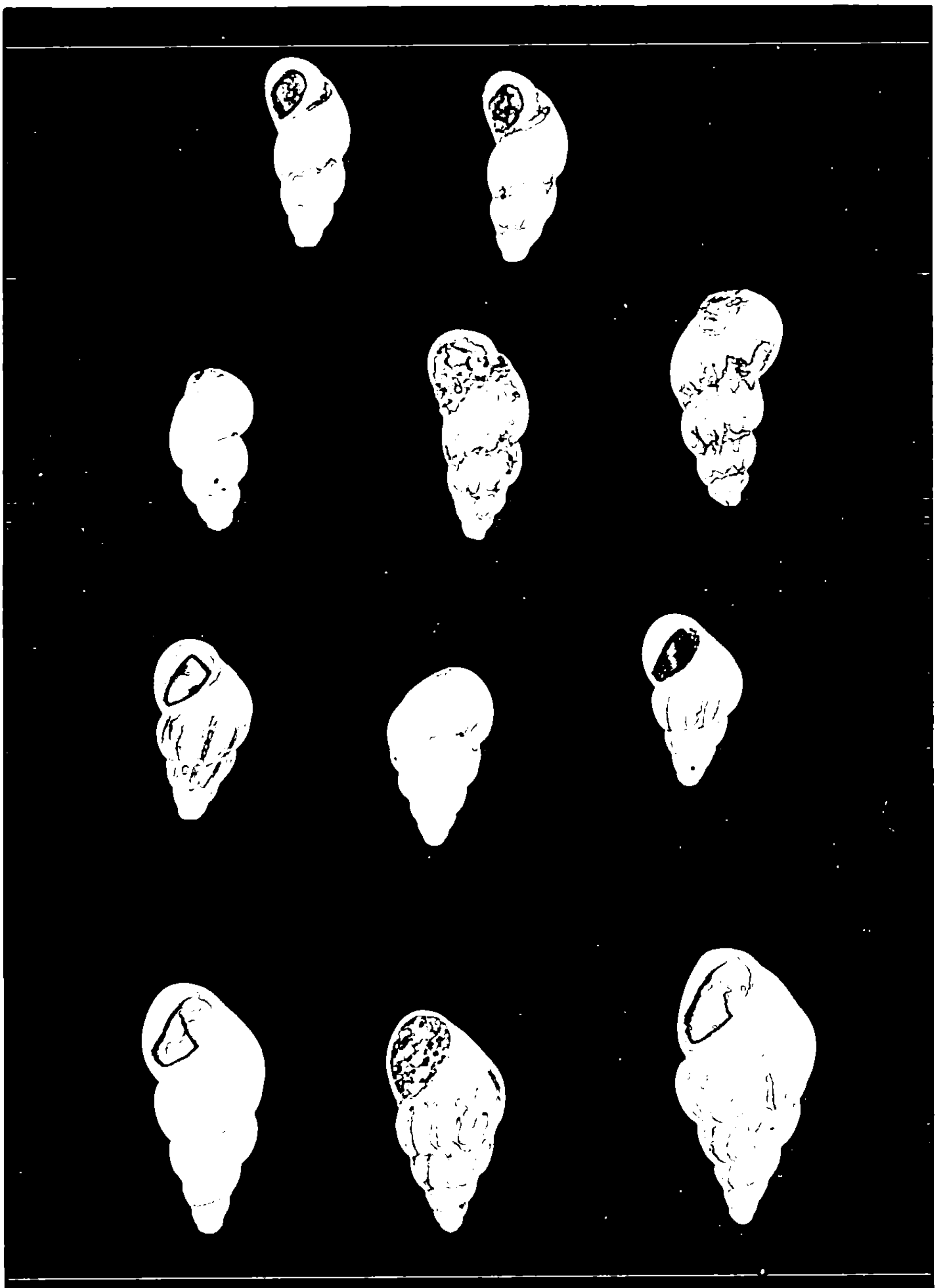
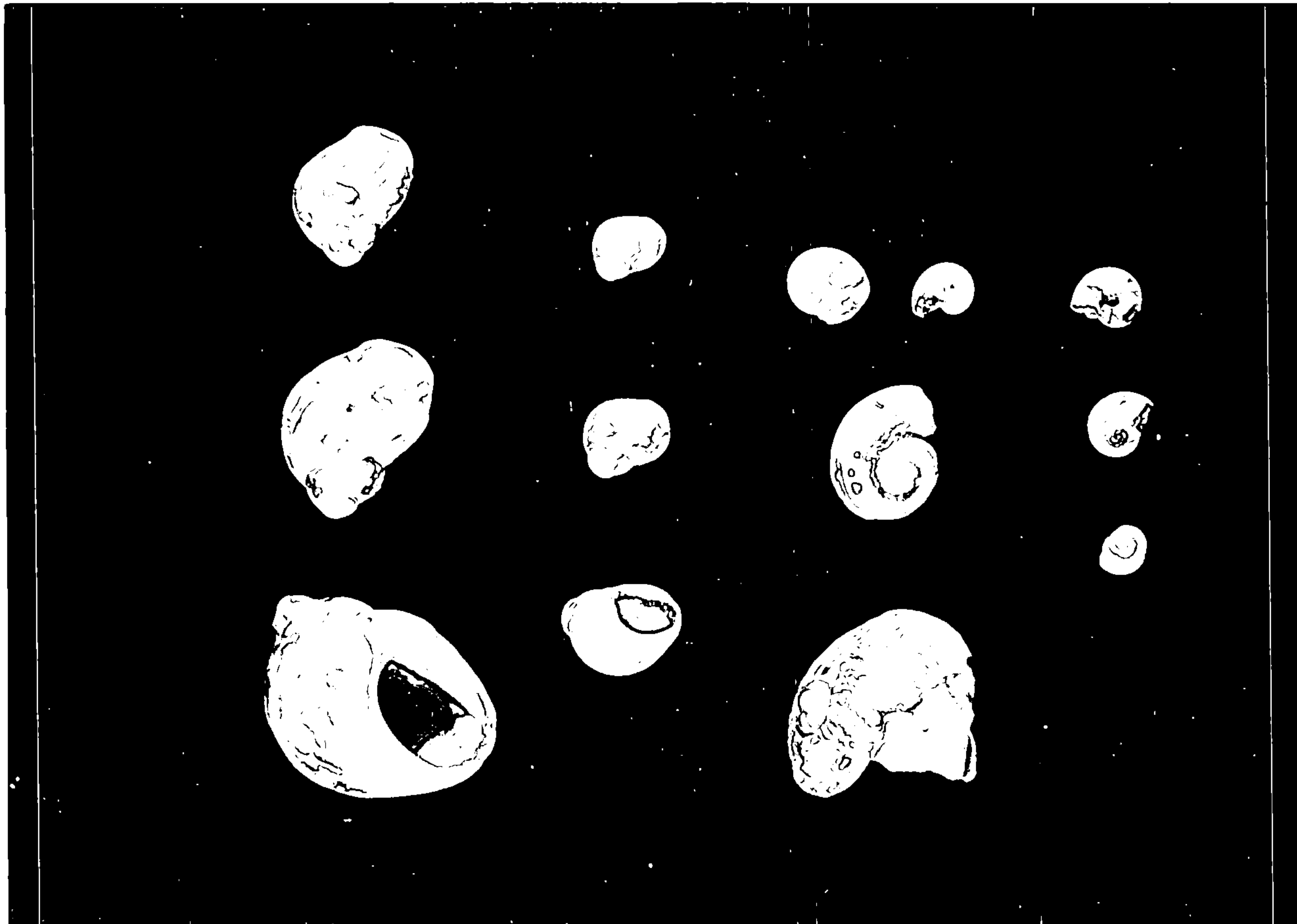


PLATE 6.4

The three largest fragments belong to *Littorina saxatilis* and the bottom 3 shells are *Turbonilla* spp.

PLATE 6.5

The top two lines show a shell with pink and white markings of *Gibberula* spp. and the bottom shells are some unidentified juvenile species.



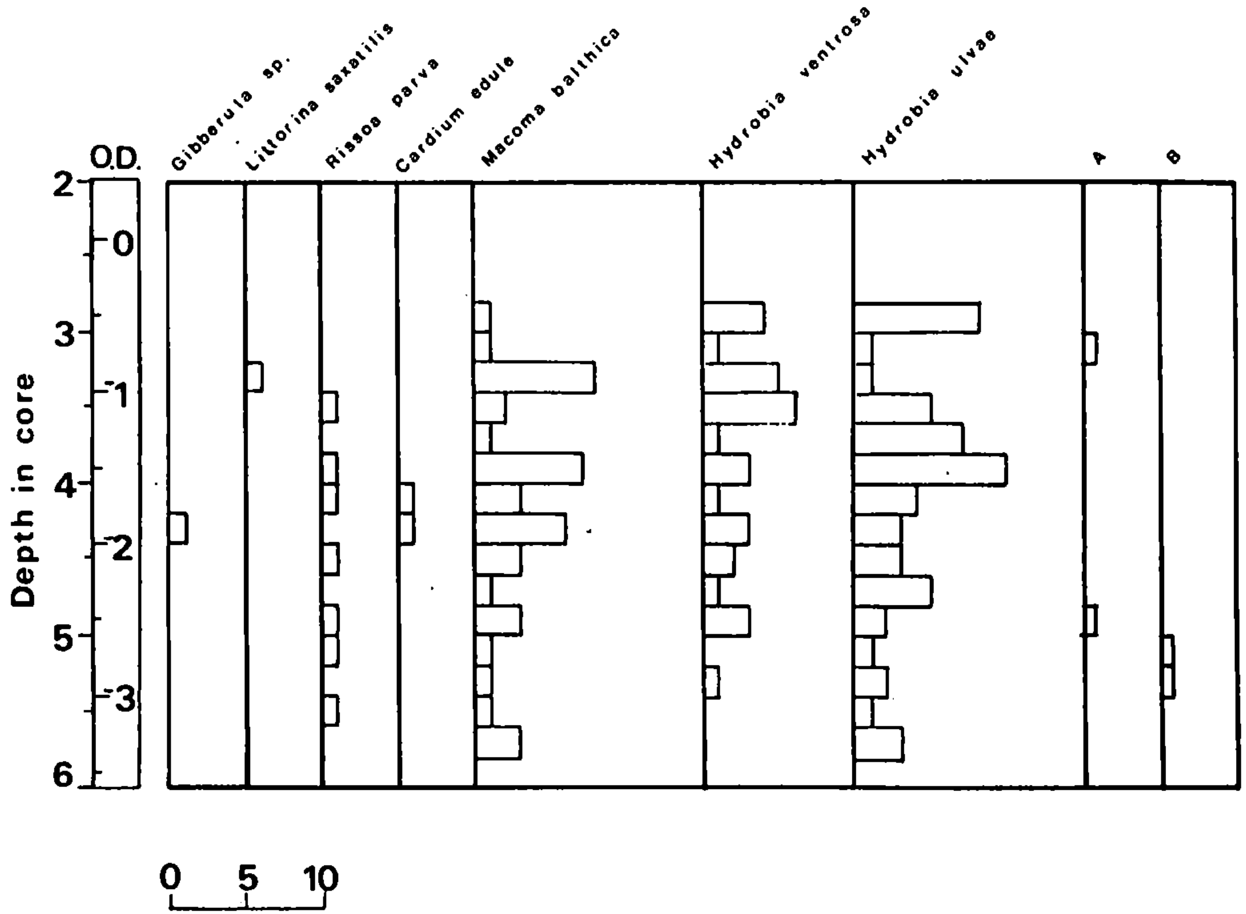


FIG 6.1 Borehole BH12 - Molluscan diagram

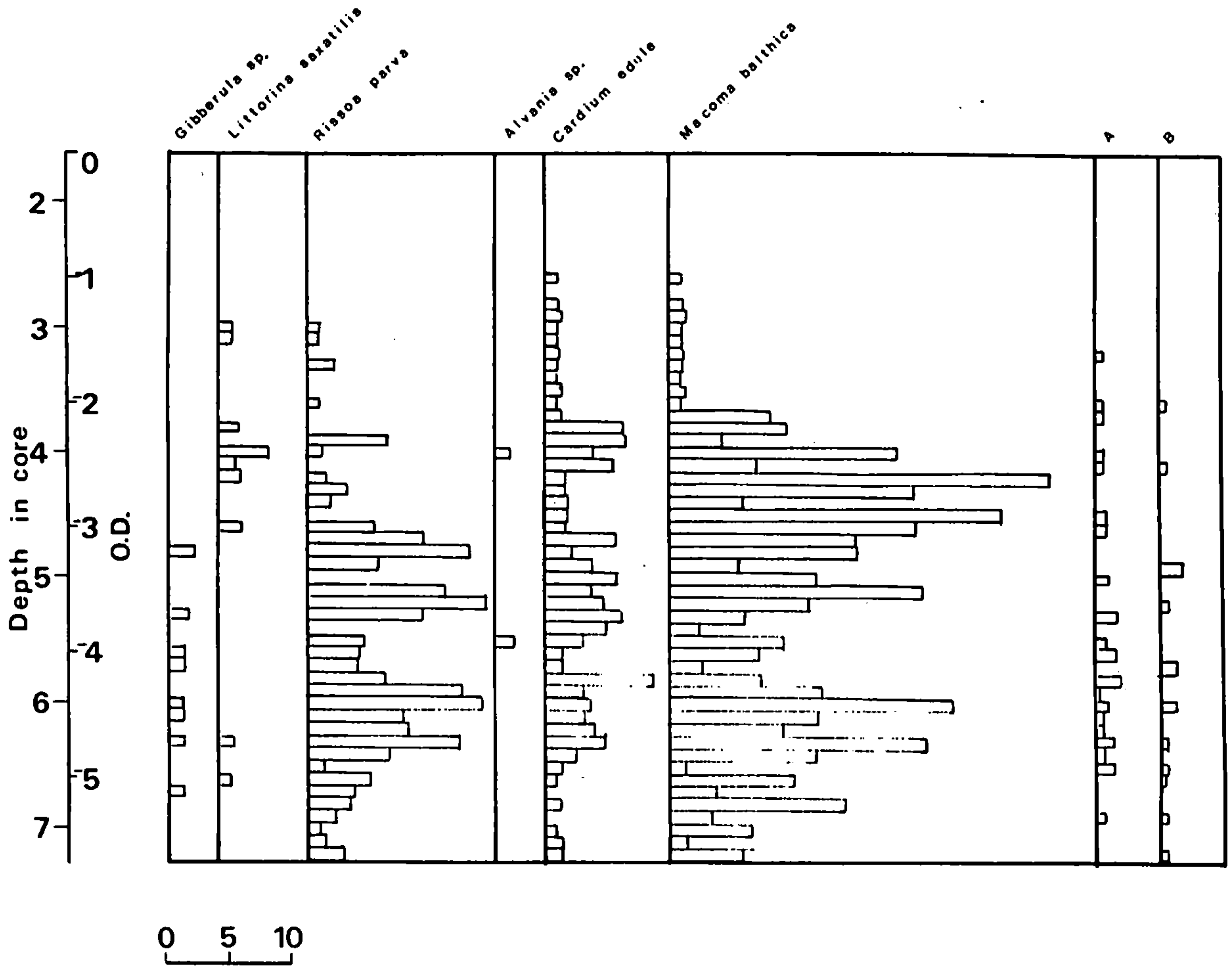


FIG 6.2a Borehole RM2 - Molluscan diagram

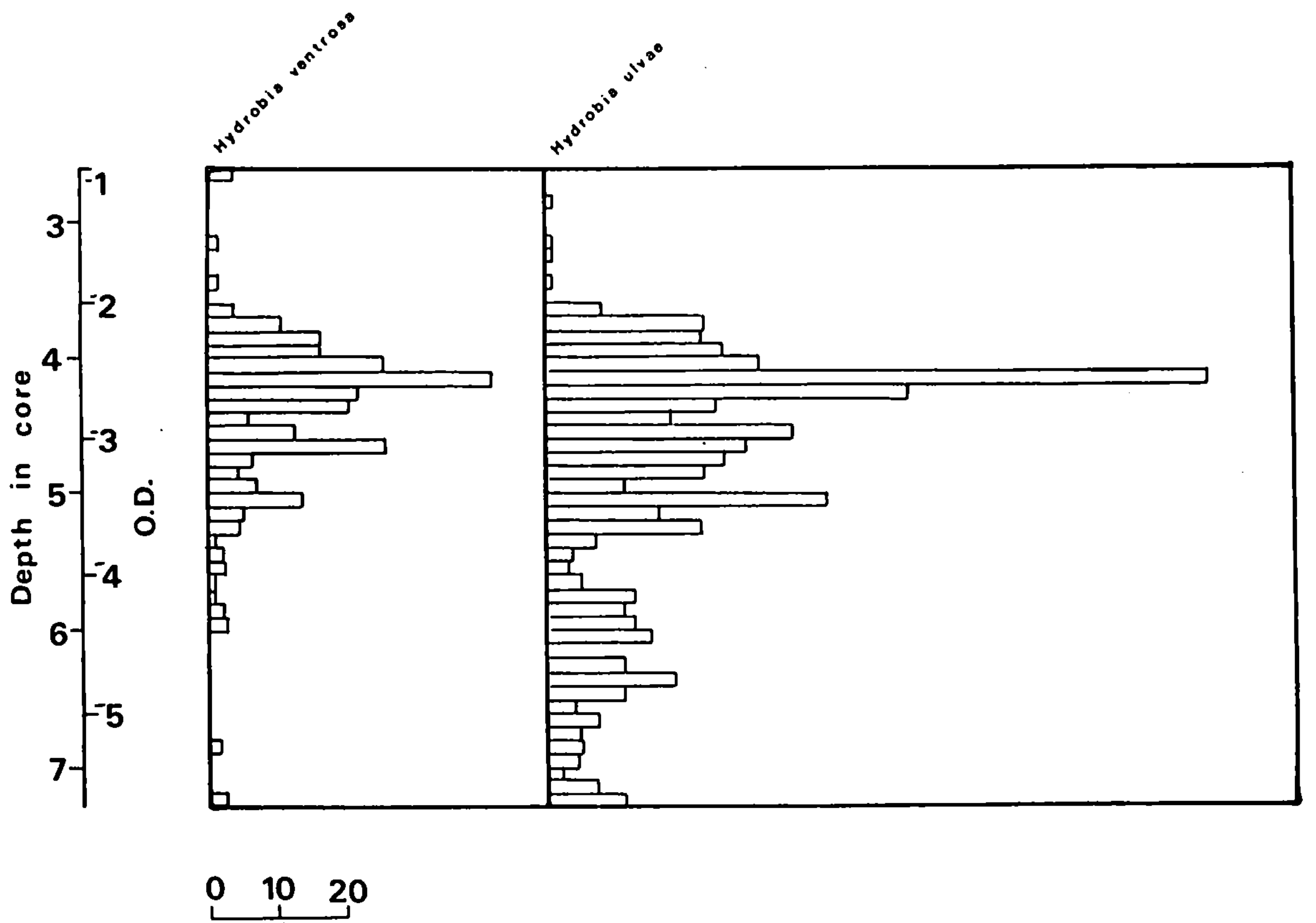


FIG 6.2b Borehole RM2 - Molluscan diagram

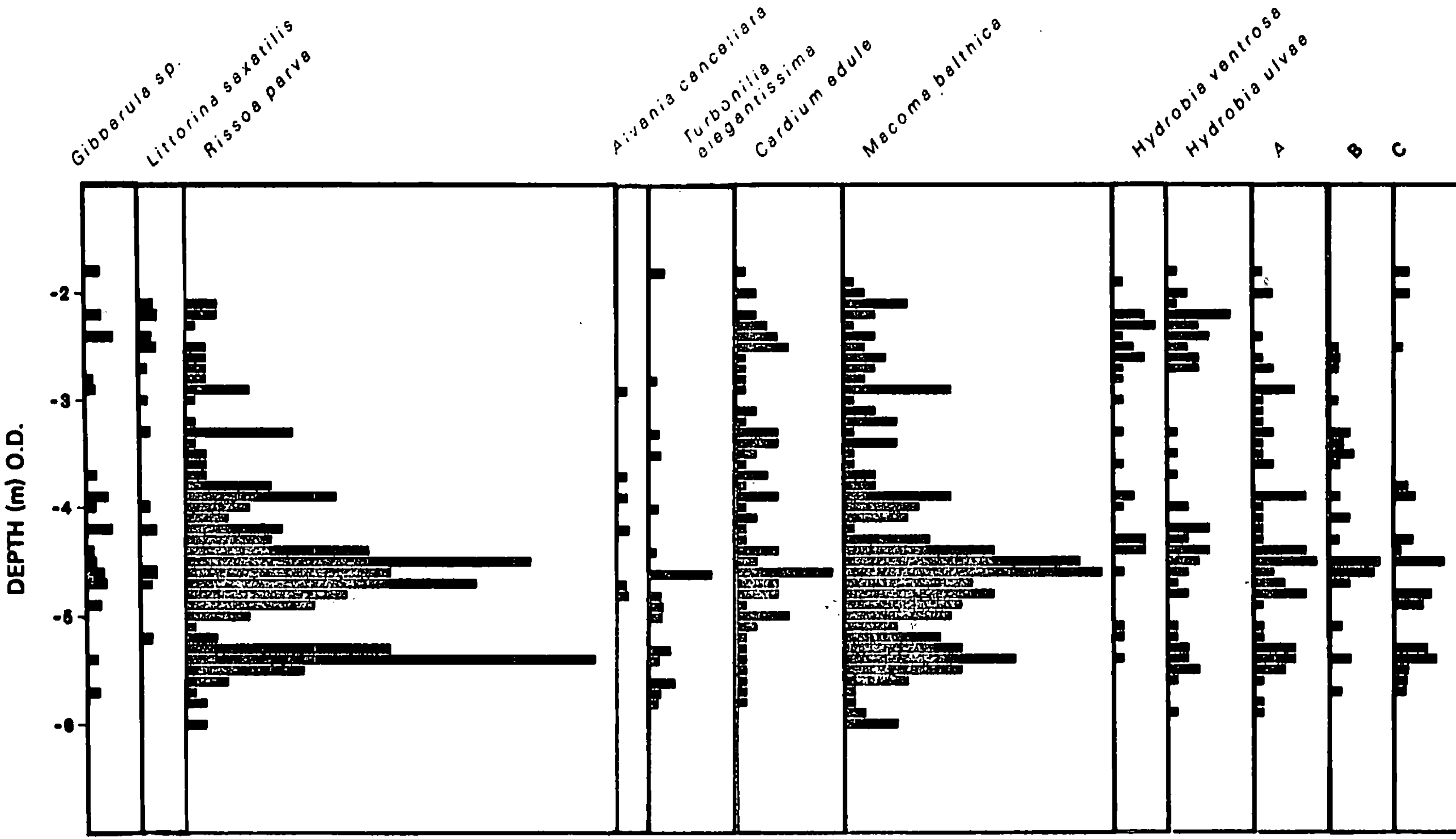


FIG 6.3 **BOREHOLE RM1 - MOLLUSCAN DIAGRAM**

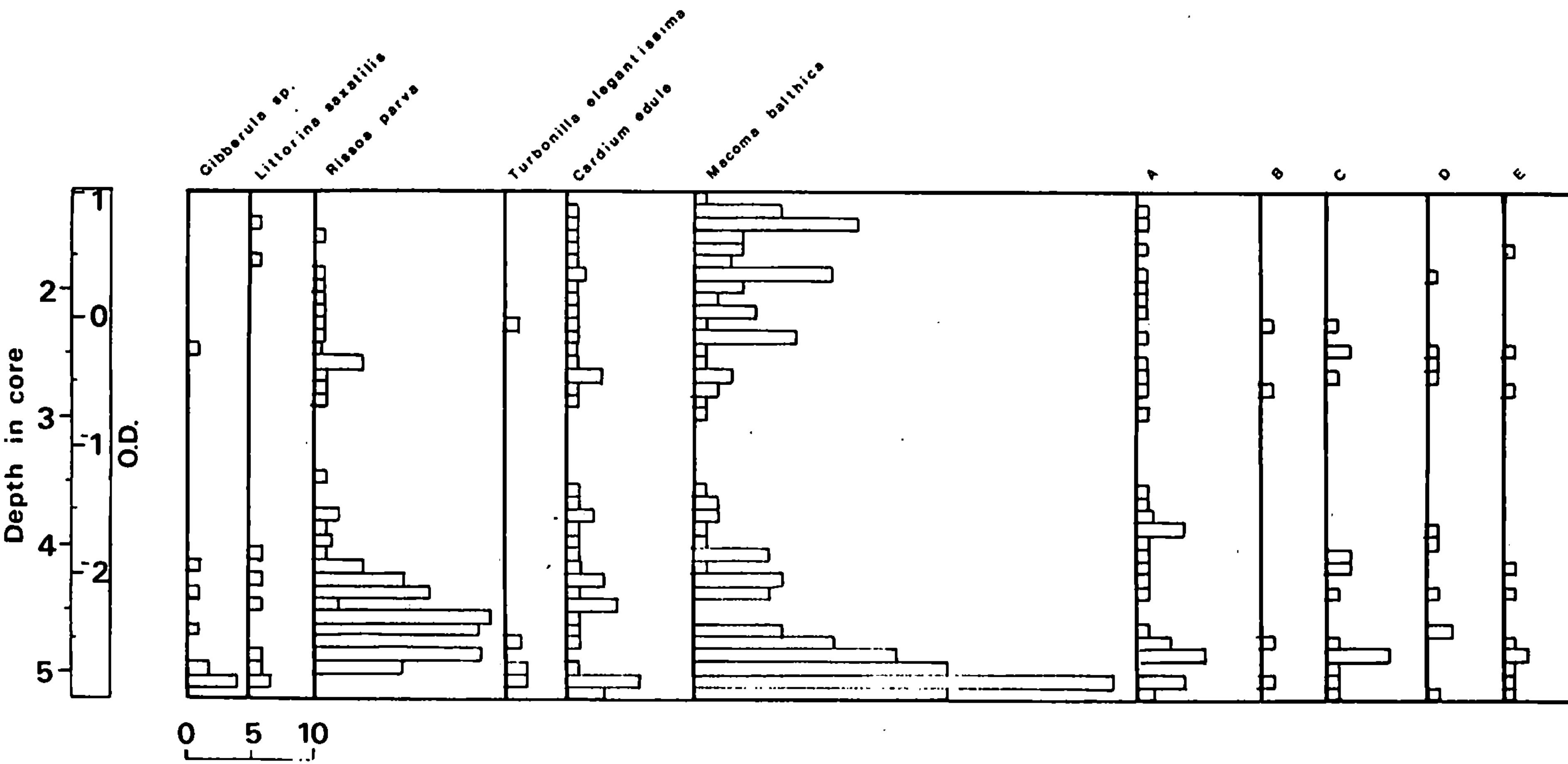


FIG 6.4a Borehole S2 - Molluscan diagram

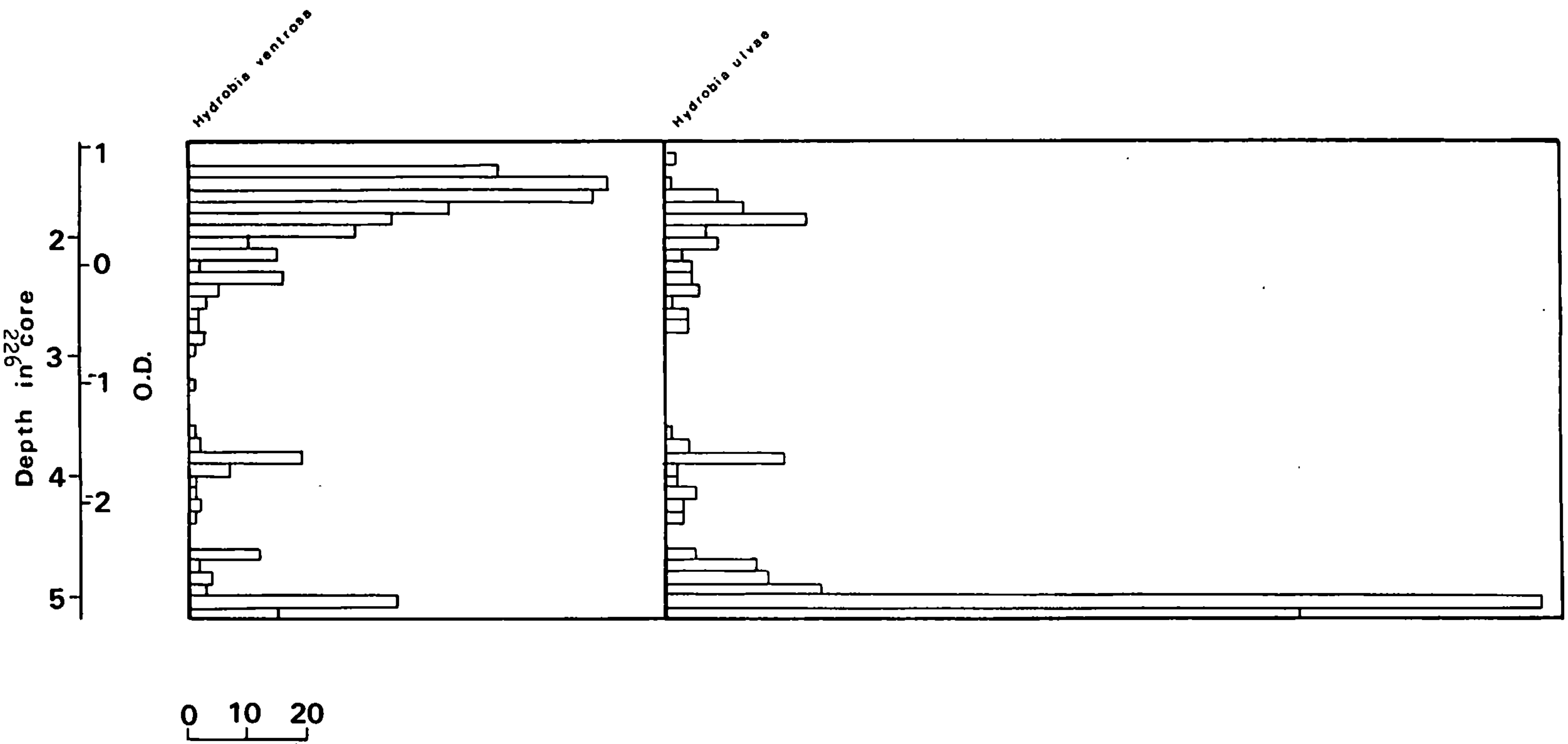


FIG 6.4b Borehole S2 - Molluscan diagram

Hydrobia ventrosa (Montagu) and *Hydrobia ulvae* (Pennant) are characteristic brackish water species. Although they appear somewhat similar they can be separated by their characteristic spire and whorl shape. *H. ulvae* is considered to be the more tolerant of saline conditions whilst *H. ventrosa* is associated with the less saline parts of the intertidal zones (Gilbertson and Hawkins 1978).

All the species present in the upper sediments of the buried channel of the River Erme indicate estuarine water temperatures not very different from today.

Mollusc shells are distributed throughout core BH12, (see figure 6.1) although they are in insufficient numbers to form definite comparisons with the other cores. The two *Hydrobia* and *M. balthica* are the most common species present, and occur in largest numbers between 0.5-2m depth in the core.

In RM2, (figures 6.2a and b) the peak distributions of most species occur between -2.5 to -3m OD, and at -4.5m OD. *Rissoa parva*, *Cardium edule*, *M. balthica* and the *Hydrobia* spp. are the most prevalent and changes in population numbers are consistent between the 5 species.

Rissoa parva and *Macoma balthica* are the most common species in sediments from RM1 (figure 6.3) with peak distributions at -4.5m and -5.5m OD. A number of interruptions to the sequence occur, the largest at -5m and -3m OD. *Cardium edule*, the *Hydrobia* spp. and species A occur in smaller numbers but peaks and troughs coincide with the *Macoma* and *Rissoa* distributions.

In the sediments from S2 (figures 6.4a and b), *Hydrobia ventrosa* and *Macoma balthica* show peak distributions between 1 and 0m OD, and *Hydrobia ulvae*, *M. balthica* and *Rissoa parva* between -2 and -3m OD. Smaller peaks occur at c. -1.5m OD. The other mollusc species present generally go along with these trends. There are two main breaks in the depositionary sequence at -1m OD and -2.2m OD, corresponding to a change in lithology to a coarse gravel unit.

In a study of marine interglacial sands and gravels at Kenn, Somerset, Gilbertson and Hawkins (1978) identified that a marine transgression had occurred by the changing ratios of *H. ulvae* and *H. ventrosa* with depth. As mentioned above *H. ventrosa* is the less saline of the two species. This technique was developed from the work of West and Sparks (1960) in a study of the marine Ipswichian interglacial deposits at Selsey, Sussex. As a large number of *Hydrobia* species were present in the Erme deposits it seemed worthwhile to apply the technique here and hence the distribution of the two brackish water species *Hydrobia ulvae* and *Hydrobia ventrosa* from all the cores are displayed in figure 6.5.

The expected distribution of *Hydrobia ulvae* and *Hydrobia ventrosa* with respect to water level is clearly seen in core S2 as *H. ventrosa* occurs between 1m and -0.5m OD in peak numbers, whilst *H. ulvae* is most abundant at -3m OD. At -1m OD and -2.3m OD a change in sediment type from silts to coarse gravel corresponds with a decrease in the total number of individuals at these levels. Core RM1 has fewer *Hydrobia* individuals with a total absence above -2m OD coinciding with coarser sandy gravels. The numbers of the two species in RM1 are near equal and there are no depth distinctions between them. Three small peaks in their numbers occur at c. -2.1m, -4.5m and -5.5m OD. In RM2 both species peak at between -2 and -3m OD, with *H. ulvae* having slightly greater numbers; this corresponds to the similar peak in S2 at -3m. Below about -4m OD most of the *Hydrobia* species present are *Hydrobia ulvae*. Cores BH11 and BH12 further upstream have fewer occurrences of the two species and there is no depth preference between them. In core BH12 most of the individuals are found at -0.3m to -2.5m OD and in core BH11 between -3.4 to -4m OD. The relationship found by Gilbertson and Hawkins (1978) is therefore seen only in core S2 and maybe to a limited extent in RM2 where towards the base of this core only *Hydrobia ulvae* is present.

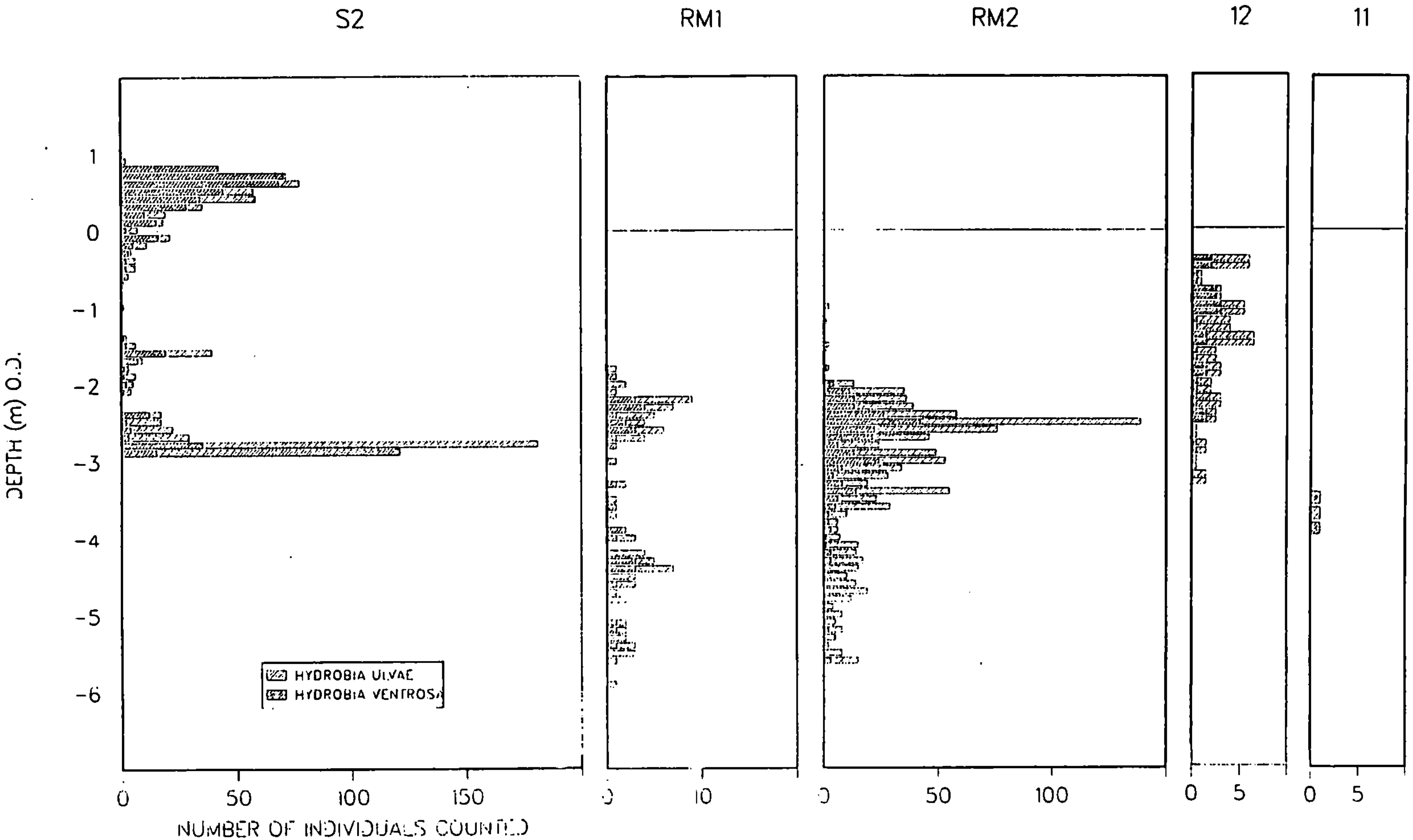


Fig 6.5 Distribution of Hydrobia sp. in S2, RMI, RM2, BHI2 and BHII

6.4 Discussion

The cores can be considered comparable in terms of the main peaks and troughs in species distribution and numbers of individuals. This is evidenced in the *Hydrobia* diagram (Figure 6.5), where S2, RM1 and RM2 peak between -2 and -3m OD and RM1 and RM2 have a lesser increase between -4 and -5m OD. The main breaks in the sedimentary sequence appear to be at levels of c. -5m, -3.7m, -2m and -1m OD and these are recognised to a greater or lesser extent between cores.

On the whole the molluscan shells occur in silts or fine sands. The breaks in the mollusc deposition sequence correspond to changes in lithology; where the sediment changes to a coarser sandy gravel few molluscan remains are found. These interruptions may be due to fluvial-inspired floods. The largest break is seen in S2 at -1m, but these gravels may also correspond with the highest coarse sand and gravel horizons of the cores on the reclaimed marsh (RM1-4). Other reasons for the abrupt changes must also be considered. For example, the River Erme may have reworked previous sediment layers to give the breaks in deposition as a result of lateral migration across the floodplain. Alternatively the surviving sediment may have resulted from erosional episodes leaving a long time span between various horizons. Similarly, storm surges and high tides may also have meant interruptions to the deposition sequence. It is likely that a combination of the above have influenced sediment deposition in this part of the study area.

A progression from more marine species to more brackish species with a decrease in depth OD can be seen in some of the cores. In S2, *Rissoa parva*, which tends to be found on the lower shore, *Macoma balthica* and *Hydrobia ulvae* all are present between -2 and -3m OD whilst the more brackish *Hydrobia ventrosa* is dominant between 1 and 0m OD. In RM1 *Macoma balthica* and *Rissoa parva* both peak around -4.5m and -5.5m OD, but both the *Hydrobia* spp. are more common between -2 and -3m OD. Similarly in RM2, *Rissoa parva* is more abundant at a lower level than *Macoma balthica* which in turn peaks at a slightly lower level than the *Hydrobia* spp. This may indicate a decrease in water salinity leading to more brackish conditions.

As S2 is the only core in which shells occur above Ordnance Datum (cores RM1-3 are lower in level and protected by a dyke) they are probably of fairly recent origin and represent current salt marsh conditions today. This most recent phase of deposition in S2 in which *Hydrobia ventrosa* is the dominant species is absent from the other cores; thus suggesting that conditions today are more brackish than when the lower sediments containing H. ulvae were deposited. In RM1 and RM2, the *H. ulvae* deposits are succeeded by fluvial gravels suggesting changes in the fluvial regimes of the river or a hiatus in the depositional sequence. If the land around the RM cores was protected after these gravelly units were deposited it would have been impossible for salt marsh conditions to redevelop.

Core S2 shows the differentiation of *Hydrobia* with depth, and it can be suggested that the sediments from RM2 are equivalent to those in S2 since both show a peak of *Hydrobia ulvae* at -3m OD. Below this depth in RM2, *Hydrobia ulvae* is the main species present and thus it can be argued that some differentiation with depth is also seen here. If the sediment sequences from RM2 and S2 are combined, a more complete picture of the increase in brackish conditions with time is seen.

In cores BH12 and BH11, *Hydrobia* spp. were not present in sufficient numbers to provide a representative sample. The low numbers of molluscan shells found in BH12 and BH11 make it hard to be confident about the results from these cores. In BH12, the molluscan remains do not correspond to any of the other cores, but as BH12 is some distance upstream of the salt marsh this may be due to tidal differences at the different locations. A period of higher tides may have swept these shells and shell fragments as far as coring site BH12, or they may have been deposited after the reclaimed area of land was protected by the embankment. In these cases it is difficult to identify which shells were deposited *in situ* and which are derived.

Very few of the shells or fragments extracted from the cores have signs of being water worn and in the case of the *Macoma* fragments the edges are sharp and the external surfaces do not show signs of wear. It is a possibility of course that the drilling procedure may have fractured some shells.

However, the very existence of molluscan shells at various horizons within these cores suggests that at one time conditions were of a more estuarine nature than today and that sea level was relatively lower than at present. Anderson *et al.* (1970) reported that in Morecambe Bay maximum densities of *Macoma balthica* and *Hydrobia ulvae* occur on a fine sand to silty substrate from lower shore levels to just above Mean High Water of Neap Tides (in Morecambe Bay 1.8m-2.7m OD). As the greatest depth from which these have been recovered is -6m OD it could be inferred that the sediments recovered from the Erme valley could have been deposited when sea level was some 7-9m lower than today; a more precise figure is dependent on knowledge of the former tidal range present in an old Erme channel. The dominance of *Macoma balthica* in some samples would suggest that the sands represent estuarine conditions with some nearshore sandbanks. Presence of *Hydrobia* species implies a slightly more brackish habitat and perhaps an environment marginal to the main river channel.

6.5 Conclusions

The results of the molluscan analysis from sites in the lower part of the Erme valley study area generally show a change to more brackish and marine conditions at lower horizons within the cores. Interruptions to the molluscan record may be due to flood events or storm surges, but these interruptions generally coincide with coarser sand and gravel sediment horizons and can be correlated between the sites investigated. All the molluscs present can be found as living or dead shells in intertidal zones of a typical muddy and sandy estuary in South West England today; their distribution in the cores to at least -6m OD would suggest lower sea levels of perhaps 7-9m lower than present.

This technique has served the purpose of allowing some correlation between cores from the lower part of the study area and has shown that the Erme once had more extensive estuarine conditions than today.

CHAPTER 7 EVIDENCE OF CHANGES IN HISTORIC TIME IN THE ERME VALLEY

7.1 Introduction

In recent years there has been a growing awareness that many of the physical features and associated sediments examined in various environments may have resulted from human impact upon the landscape, rather than simply natural processes. This together with a study of historical documentation and dating of deposits has led to a greater understanding of sedimentary sequences laid down in the more recent past and in particular the latter part of the Flandrian. Work of particular relevance here in relation to sedimentation in river valleys is that of Brown (1982, 1983), Brown and Barber (1985) and Macklin *et al.* (1985). These authors have identified the impact of human activity on river floodplain formation in the Late Flandrian and in particular the effect of forest clearance and mining activities in the upper catchments of the rivers under investigation.

We have already seen in Chapter 3 that the upper Erme catchment above Ivybridge was extensively cleared of vegetation during the Late Flandrian. In this chapter historical records of tin mining on Dartmoor will be reviewed with particular reference to the upper Erme catchment, upstream of Ivybridge. Tin deposits may have been mined by the same population that was responsible for forest clearance, as well as at a later stage when the moor was relatively deforested. It is believed that some of the sediments examined from the lower Erme valley may have been derived from these tin mining phases. The effect of tin mining and forest clearance may have affected the river channel position within its floodplain causing general valley floor changes and may thus be recorded in documentary sources. These changes will be examined using the old tithe maps of the local parishes and records of changes in the lower Erme valley. This will be followed by a discussion of the results of C-14 dating of some of the organic sediments in the cores retrieved from the buried channel of the River Erme. Dating of samples from the cores will be useful to demonstrate how the sediments relate to the historic timescale and human activities in the Erme catchment. The findings of this chapter will be discussed in relation to the sediments discovered in the channel of the Erme in chapter 8.

7.2 Mining Activities on the Moor

7.2.1 Introduction

Many of the river valleys in the granitic areas of south-west England have been exploited for tin, both in prehistoric times and especially in the tin boom years between the 15th and 18th centuries. The practices employed in extracting tin from granitic rocks often affected the river regimes by disturbance of valley bottom and valley side slope sediments, and even the bedrock.

The tin deposits of Dartmoor were formed from solutions which accompanied the gases and fluids of the granite as it intruded into the surrounding Devonian rocks at c.290 million years ago (Dearman 1964). The mineralized area emerged from the granite and separated into zones forming the metamorphic aureole. Tin solidified closest to the granite, followed by copper, lead/zinc and iron. Most of the Dartmoor mineralization occurs as shallow lode deposits on the western and south western corners of the moor, and in the Dart valley on the eastern moor. The tin ore takes the form of cassiterite, a tin oxide, and throughout south-west England occurs as fissures and veins. It occurs in granitic alluvial deposits derived from periglacial and later conditions that weathered the veins and deposited the tin bearing sediment in streams. In the vicinity of the Erme, variable tin lodes occur in quartz-tourmaline veins at greater depths than in the surrounding moorland.

Price (1979) noted that of the 250 square miles of Dartmoor approximately 130 square miles bear evidence of tin working, and Greeves (1981) stated that

> "Every stream which has its source on the granite has alluvial deposits of tin bearing sand and gravel. Some deposits extend well below the limits of the metamorphic aureole...";

He also considered that:

> "Probably every valley in the tin bearing zone has been worked at some time".

Thus it is extremely unlikely that the Erme valley will not have been prospected and mined for tin at some time in its past. There was also some limited early twentieth century china clay extraction in the upper Erme catchment which may have influenced sedimentation in the valley. The evidence will be considered here for both prehistoric and later mining of tin and china clay.

7.2.2 Evidence of Prehistoric Tin Mining

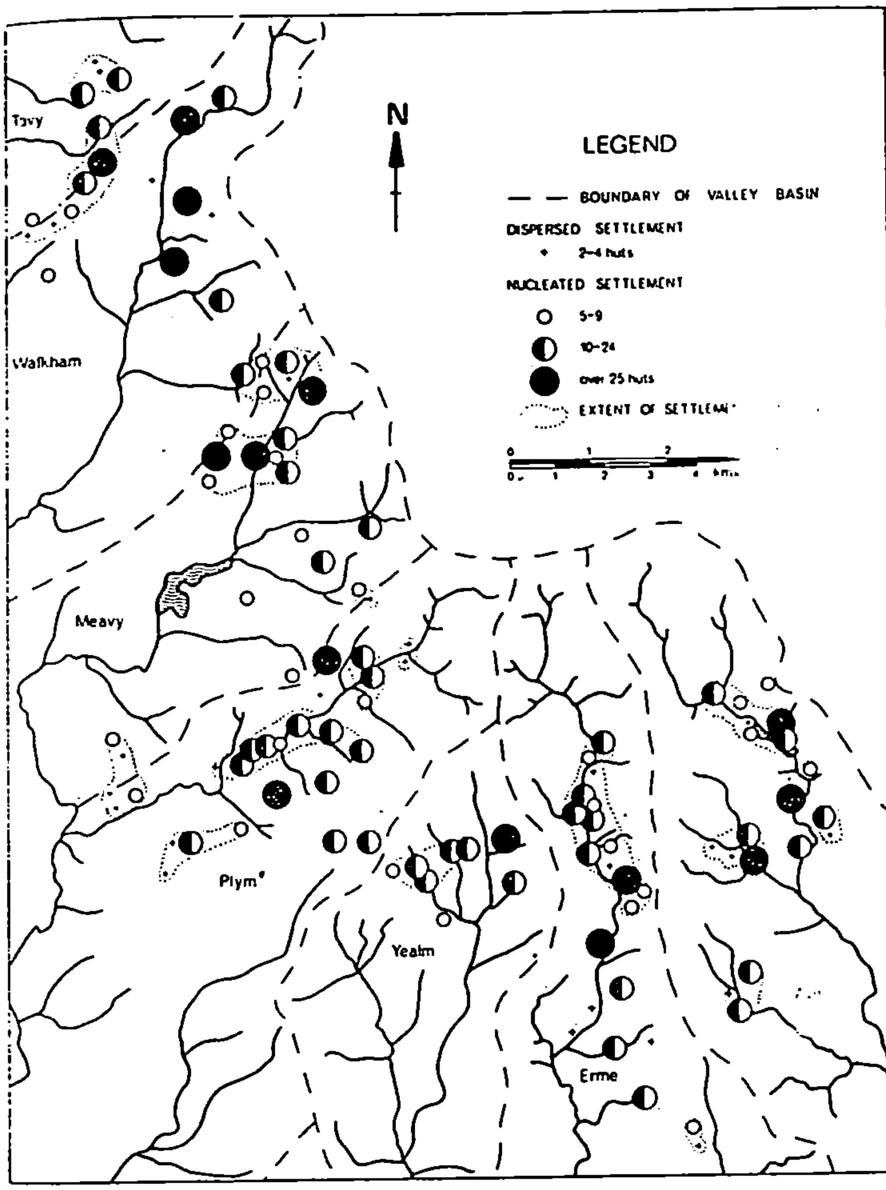
One of the problems in assessing the extent of any prehistoric tin mining or streaming is that the more recent phase of mining in Medieval times may have obscured the former land surface and thus evidence of any older mining phases. As a result of this Hoskins (1972) considered there to be no evidence of prehistoric mining on Dartmoor. In Cornwall, however, there is substantial evidence for prehistoric exploitation of tin (Greeves 1981) and it is unlikely that Dartmoor will not have been similarly affected. Pearce (1979) suggested that it is the alluvial gravel deposits that were most likely exploited in the prehistoric period. Bronze produced in the Bronze Age consisted of 90% copper and 10% tin and although copper was quite common, tin was not. Pearce (1979) thought it likely that Devon and Cornwall were the principal suppliers for British and Continental bronze workers, although she noted that there is evidence for tin mining in Brittany in the Bronze Age.

There is a little evidence to support early mining on Dartmoor. At the head of the River Avon there are extensive Bronze Age settlements, beneath which pebbles of tin ore and slag were discovered. Toulson (1984) considered that these groups were likely to have been the first 'tinners' on the moor. Similar evidence has also been found at Duck's Pool at the head of the Plym (Toulson 1984). Sims and Gomez (1983) provided two C-14 dates for organic deposits in the valley of the Narrator Brook in south-west Dartmoor. They related the formation of associated fluvial deposits to firstly, Bronze Age clearance (after 4040±60 BP) and secondly, to the work of tin streamers (after 630 BP). In the Erme valley evidence for the presence of Bronze Age communities is seen in the two mile long stone row crossing the river near Red Lake as described by Worth (1906). Crossing (1912) suggested that this stone row actually crossed some tin workings with the stones being set up on waste heaps although Greeves (1981) thought this evidence inconclusive.

Price (1981, 1982) has also tackled this subject by a study of the settlement pattern of the Bronze Age populations. His map in figure 7.1 shows the distribution of hut circles on the southern moor and in particular in the upper Erme valley around Harford Moor. He suggested (1981) that although there was little evidence for mining this explanation was more likely than that the hut circles represented an agricultural settlement. It seems that the hut circles are aligned along the valleys of the rivers between the Tavy and the Avon, and Price considered that this clustered pattern indicated a tin mining origin. However, Hammond (1979) thought the huts were aligned to the rivers because of a ready supply of water and because a more sheltered and wooded environment meant that construction material was at hand. From Price's work it can be seen that a number of settlements occur in the Erme catchment area and thus early tin mining on the moor is a likely possibility. Hammond (1979) counted there were 109 huts in the Erme catchment above 230m, making 15 huts/square mile in 7.2 square miles of catchment. In the Harford Moor area, Price (1981) counted nine settlements with 134 huts in a distance of 2.8km.

7.2.3 Later Tin Mining

The first mention of mining in Devon was in the Pipe Roll of 1156 A.D. (Hoskins 1972). Greeves (1981) and Hoskins (1972) found no evidence of earlier mining in Roman times on Dartmoor although there is evidence of tinning in Cornwall in the Roman Age. However, from 1156 A.D. to the end of the century the rich alluvial deposits of Dartmoor produced all the tin of Europe, whilst that from neighbouring Cornish mines was negligible. Cornish



(FROM PRICE 1982)

Fig 7.1 The distribution of Prehistoric settlement sites on South-West Dartmoor production overtook that of Devon in the early 13th century as the Dartmoor deposits had been quickly exhausted (Hoskins 1972). Production was reduced to one eighth of that in the 13th and 14th centuries and increased again during the 16th century, a period of increased exploitation of the mineral. Towards the end of the 16th century, production again decreased, with only a short lived 'boom' in the early eighteenth century. It is very possible that the increased production in the 16th century was due to the introduction of the new technology of shaft mining, whereas previously alluvial streaming had been the main extraction method. These various methods and sites of tin extraction will be discussed further in relation to their impact on river catchments.

7.2.4 Methods of Tin Extraction and their Resulting Effects on the Landscape

Various methods of extraction of tin have been practised on the moor, ranging from tin streaming and open cast mining to shaft mining. These methods will have altered the local drainage pattern and will have had a profound effect on the landscape. There is evidence of extensive stream workings on the moorland stretches of the Rivers Plym, Yealm, Erme and Avon in particular (Greeves 1981).

The streaming process involved separating pebbles containing tin from clods of loose earth by washing in running water. Stream tin is purer than lode tin, as during transport by rivers it has been separated from waste. The heavy tin bearing stones of crystals of cassiterite could therefore be dug or washed out. To extract the cassiterite pebbles the rivers and streams were diverted and trenches dug to remove gravels, as often the heavy tin stones occurred near the base of the valley bottom deposits. This practice of digging and washing of tin must have involved sending a vast amount of sand and waste products downstream thereby increasing the discharge of the river creating flood conditions. Between 1450-1750, Dartmoor was continually scarred by fresh diggings in the hillsides and valleys, and for much of this time the rivers and streams ran red with waste from the tin works (Greeves 1981). This was documented by several people and severe silting occurred at Plympton, Totnes and Dartmouth (Smith 1907). Although no records have been found for the Erme that suggest severe silting, it is highly probable that it did suffer but because there was no major port at the mouth of the river formal protests were not made. In 1637, the Plymouth Corporation reported to the Privvy Council that Plymouth harbour was still being silted up as a result of tin workings and mills on the Plym and Meavy. The extent of this silting led to the introduction of a bill in 1512 by Richard Strode to prevent tin working in the vicinity of sea ports and in 1531 it was amended specifically for the ports of Devon and Cornwall; it had however little effect (Greeves 1981).

The landscape was also scarred by the digging of peat and charcoal for the smelting of tin. Lode tin was best smelted with equal amounts of wood and peat charcoal. Tin was extracted from stones by subjection to intense heat by piling the stones in holes in the ground and lighting fires on top. Smelting was later carried out in Blowing Houses where a furnace was kept blazing by bellows operated by a small water wheel (Toulson 1984). The digging of peat and chopping of trees would itself have caused some erosion of the Dartmoor slopes and increased the discharge of water-borne sediment downstream.

As the deposits of stream tin became exhausted new methods were developed by extracting tin from the parent lodes. Strode tin, the concentration of larger tin stones in river banks nearer the parent lodes, and stream tin were used to find the parent lode. Open cast mining of parent lode material on the hillsides above the valleys was carried out in beamworks. Trees were needed for these mines which were up to 30m deep when being worked. Shaft mining was probably not used until the 16th century when the most easily accessed tin resources had already been exploited. These later methods probably had a reduced effect on the river discharge.

7.2.5 Sites of Tin Mining in the Erme Catchment

In this section, actual sites are identified in the Erme catchment to give an indication of the extent of the mining operations. Much of the evidence for these tin mining locations is taken from the work of Greeves (1981). He studied a number of public records for the whole of Dartmoor to identify sites of tinning, and attempted to match these to field evidence.

A list of the possible tinning sites in the Erme valley are given in tables 7.1, 7.2 and 7.3. This information has been extracted from the work of Greeves for the whole of Dartmoor, and is quoted here to show the full extent of mining in the Erme catchment. Table 7.1 shows sites of tin works, table 7.2 known tin mills and table 7.3 doubtful or unverified tin mills in the Erme catchment between 1450-1750. The dates do not refer to actual dates of operation but to dates of reference when the tin workings were noted. These sites have been marked on a location map and are shown in figure 7.2. A large number of probable mining sites between Ivybridge and the source of the Erme are seen. Some unlikely gaps exist in the upper Erme where later china clay workings may have destroyed sites (as in the case of the lower reaches of the Plym). At Red Lake, for example, 20th century china clay mining uncovered tinners gullies which were sunk through 6-7 feet of peat and then 10-12 feet of tin bearing clay.

There are many names for tinners mills, for example, 'knocking', 'stamping' and 'blowing', and always within a few metres of streamings in the tin-bearing zone, or outside in alluvial deposits. Blowing houses are seen today as ruins often sited by waters of leats or small channels that originally produced power to work the furnace (Toulson 1984). On the moor previous tinning sites can be recognised by haphazard heaps or heaps of parallel or concentric ridges of material with a retaining wall on one side. Some good examples can be seen at Lower Dry Lake and Left Lake and Knocking Mill (figure 7.2). Greeves thought that these are probably pre-1600 in age, although mining was practised on a very small scale into the 19th century on Dartmoor.

NAMES	GRID REF (approx.)	HEIGHT (m)	DATE
Adecombe	648582	244	early 17th
Armehead	621669	427	1531
Armed Pit	623668	411	1671
Blackland	?627594	191	early 17th
Blakpole	?620590	213	1530-1553
Brode Park, The	?649557	61	early 17th
Cater's Beam	635690	472	?
Combeshead Mead	642584	?	1583
Erme			??early 17th
Henlake Downe	631572	198	1581,82,96
Henlake Downe Combe	631572	198	1581,82,38
Hooke Lake	650650	427	1661
Hokelake, Little	640650	366	early 17th
Lukyslande	641578	183	early 17th
Marenahed	662590	335	1608, early17th
Munks Moore	674573	152	1639
Pethele Woode	636579	152	early 17th
	or 532607	61	
Pope Mede	635570	91	1581, 1582
Pyles Corner	648621	366	early 17th
Redelake, Little	640664	411	early 17th
Redelake, Riche	640664	411	early 17th
Shillalake	642592	244	early 17th
Shillalakehedd	650595	290	early 17th
Stoford	641570	137	1527
Stofordcombe	639570	122	1527,1538
Stoford Park	641570	137	1538
Verabrokehedd	655605	366	early 17th
Whelkers More	630585	183	early 17th
Wenfur Hill	620690	457	1601, 1625
Wollack	630675	427	1671

TABLE 7.1 LIST OF DEVON TIN WORKS (c.1450-1750)

(Compiled from Greeves 1980)

NAMES	GRID REF	HEIGHT	DATE	MILL TYPE
Butter Brook	64225920	236	?	B?/S
Duckspool stream Right bank	62936766	435	1532-3 1537-9	T
Hook Lake	63936509	366	?	T
Ivybridge/ Harford	63655665	76	Early 16th century	B/K/T
Left Lake, below	c.64135273	290	?	S

TABLE 7.2 KNOWN DEVON TIN MILLS c. 1450-1750

NAMES	GRID REF	HEIGHT	MILL TYPE
Blacklane Brook	62906690	412	T?
Dry Lake, Lower	64006337	305	T?
Dry Lake, Upper	63366636	389	T?
Duckspool Stream, Left bank	62966767	435	T?
Ivybridge, above	63555758	122	S?
Knackersmill Gulf	c.635652	397	K?
Knocking Mill	c.631661	412	K?
Stowford	c.641571	137	?

TABLE 7.3 UNVERIFIED OR DOUBTFUL TIN MILLS C. 1450-1750

B = Blowing S = Stamping K = Knocking T = Tin

Compiled from Greeves (1980)

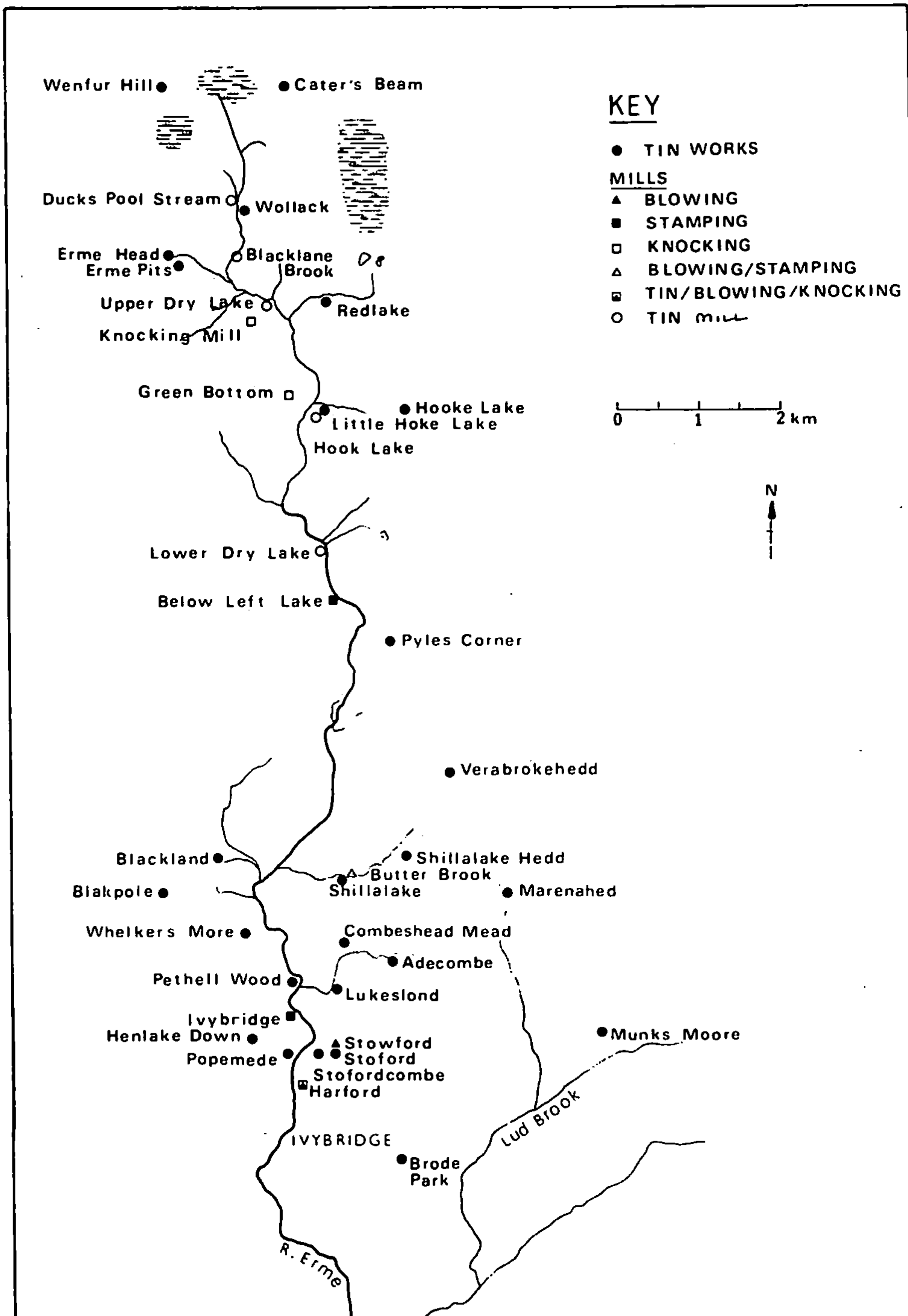


Fig 7.2 DEVON TIN WORKS c.1450-1750 in the upper Erme catchment

As already mentioned, Price (1981) suggested that the distribution of hut circles reflects a pattern of prehistoric tin mining. Toulson (1984) noted that at Stall Moor on the western side of the Erme valley there are remnants of hut circles and tinners dwellings. Several good exposures are found on the tributary streams of the Erme at Hartonsford Bottom, Knocking Mill and Red Dry Lake, each of which were extensively worked for tin. Beehive huts occur on the right bank of the Erme, and it is possible that sites of prehistoric hut circles were reoccupied and rebuilt by tinners. Greeves considered that there is evidence for this secondary occupation.

Whilst it is fairly easy to calculate the amount of tin extracted in historic times from the amount of tin collected at the four main stannaries, it is much harder to calculate tin production in prehistoric times. By attempting to correlate the various sequences of sediment in the Erme channel with known episodes of tin production, a relative sequence of events may be derived. This will determine how much tin mining on the moor has affected the Erme and allow some comparison with other studies in Britain in which human activities have been found to initiate and accelerate geomorphological processes.

7.2.6 China Clay Production

In the study area vast deposits of china clay are present between the Rivers Erme and Avon on the upper moor. The clay has been worked at Redlake and Left Lake on the banks of the Erme but no pit has yet bottomed the china clay deposits. This is mainly because of the distance from the main communication lines which make its exploitation uneconomic.

The only period of extraction was in the early twentieth century. In 1910, a three-foot gauge tramway was built from Bittaford to Redlake, a distance of 7.5 miles. The tramway was built to carry the workers, the clay being suspended in water and piped down to the main railway line where it was dried. Left Lake was worked from 1922-1932. Although the effect of these workings on the Erme is unknown it is possible that some of the china clay may have escaped into the channel directly affecting the sediment yield and siltation downstream. Richards (1979) looked at changes produced by china clay quarrying upstream of the River Fal and considered the large suspended sediment of kaolin to have influenced the channel shape.

An earlier venture onto the moor in 1846 to cut peat and peat charcoal was also unsuccessful. It is likely to have had only a limited effect on the river. These aspects will be considered further in the discussion, after a consideration of map evidence for changes along the course of the River Erme.

7.3 Documentary Evidence of Changes in the Lower Valley

Old records and maps are an important source of information for the study of changes in a floodplain environment over historic time. Tithe maps are some of the oldest documentary evidence of land use and were produced in the 1800's. Such historic records have been used for studies of rivers in East Devon (Hooke 1977) and Northumberland (Macklin 1986, Macklin and Aspinall 1986) and for the River Exe (Parkinson 1981).

The tithe maps for the parishes of Holbeton, Kingston and Modbury in the lower Erme valley were examined at the Devon Record Office. They are generally at a large scale and include details of buildings, field boundaries, field owners, field names, dates of ownership and plantation type or land use.

The position of the river and the field boundaries were traced from the tithe maps and information for each field looked up in the accompanying records of land-use. The river appears to have generally followed the same course since the map was surveyed, with major variations only at the mouth of the river at Mothecombe. The main exceptions to this are the short channels that join the western side of the Erme between Sequer's Bridge and Flete Mill; the tithe map shows a stream running down the side of the valley passing through Flete Mill before joining the Erme (see figure 7.3).

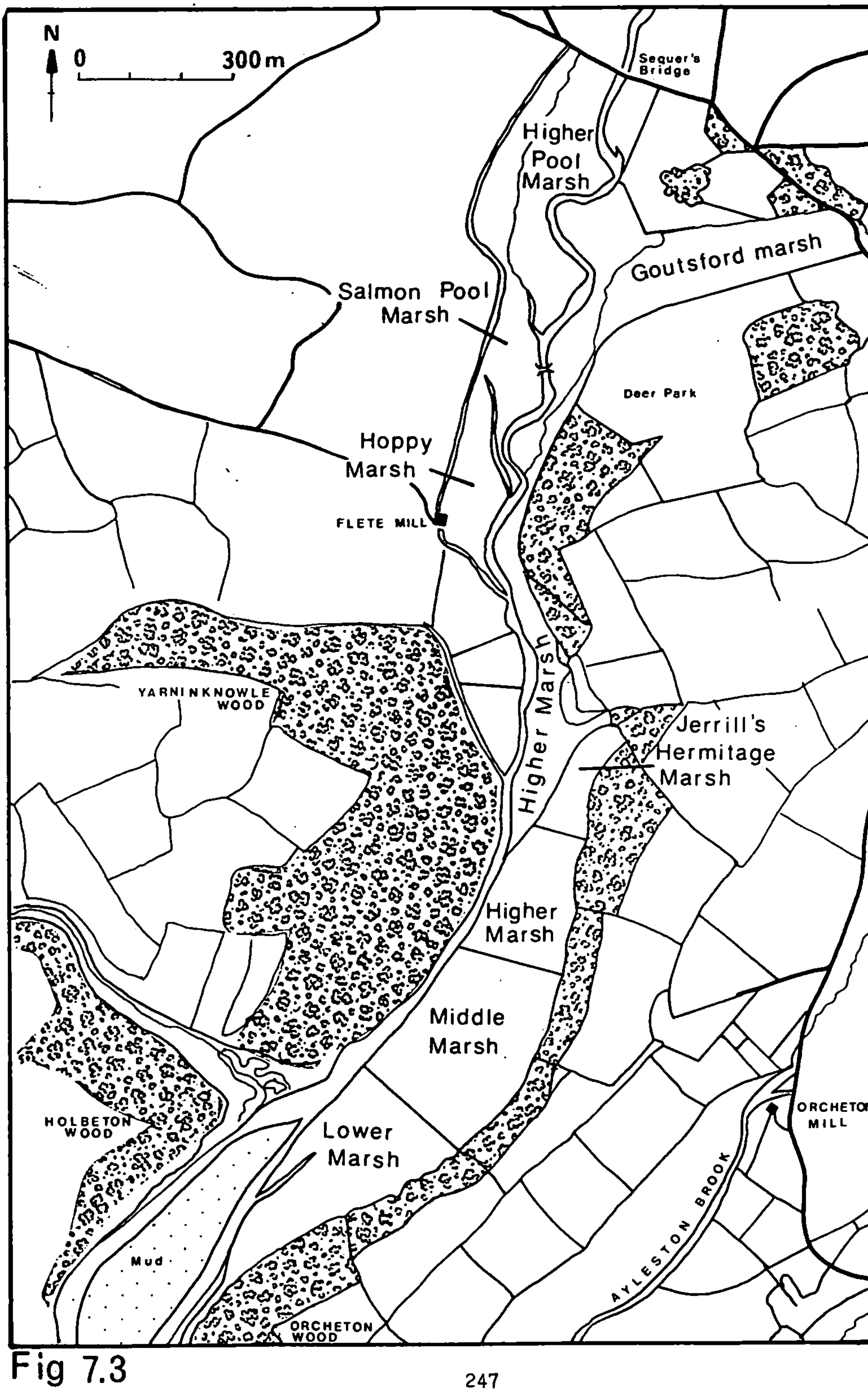


Fig 7.3

Former Field Names in the Erme Valley

The most important information arising from this study came from looking at details of the fields and in particular the field names. Figure 7.3 shows the names of the fields bordering the banks of the Erme at the time the tithe map was produced. Although the field usage was detailed as pasture, arable, orchard etc., the names bordering the river are indicative of a former marsh environment, for example in the Sequer's Bridge area there are field names of Salmon Pool Marsh and Hoppy Marsh. Thus boreholes SB2 and SB1 were from fields formerly known as Higher Pool Marsh, BH6, A1-4 and BH7 from Goutsford Marsh, BH1, BH4 and BH7 from Salmon Pool Marsh, BH9 and BH11 from Hoppy Marsh, RM4 and RM3 from Higher Marsh, RM2 from Middle Marsh and RM1 from Lower Marsh (see figure 4.3 in chapter 4 for the actual locations of the boreholes). The origin and age of these names is uncertain but the evidence suggests that at some time in the not too distant past the valley floodplain was considerably wetter than today.

Further downstream in the present salt marsh region there are records of changes in historic time. Evidence suggests that the estuary was previously more used and navigable than it is today. Oldaport Fort lies on a spur of land rising to 150' (46m), on either side of which runs a small creek, as illustrated in figure 7.4. At the tip of the spur, the two creeks join with a short arm of the Erme forming a natural harbour 1.5 miles from the sea. A plan of the fort is shown in figure 7.5. Worth (1933) quoted from Pole (c.1635) who had stated that Oldaport took its name from an old fort or gate and Cottrill (1935) considered it not unreasonable to associate the existing remains with a 'port'.

Hoskins (1954) thought the structure of the fort is largely of 16th century date but there is reference to it in 1310 and 1332 (Gover *et al.* 1931-32). Cottrill (1935) considered Oldaport to be assigned to between the Late Roman or the succeeding Dark Ages whilst more recent investigations by Farley and Little (1968) show the fort is of at least two periods with a possible Roman building of rectangular design and a later secondary walled enclosure incorporating the Roman port, of Roman, Dark or Medieval Age. It is possible that the fort may have originally been built in the Roman Age as there are signs of occupation

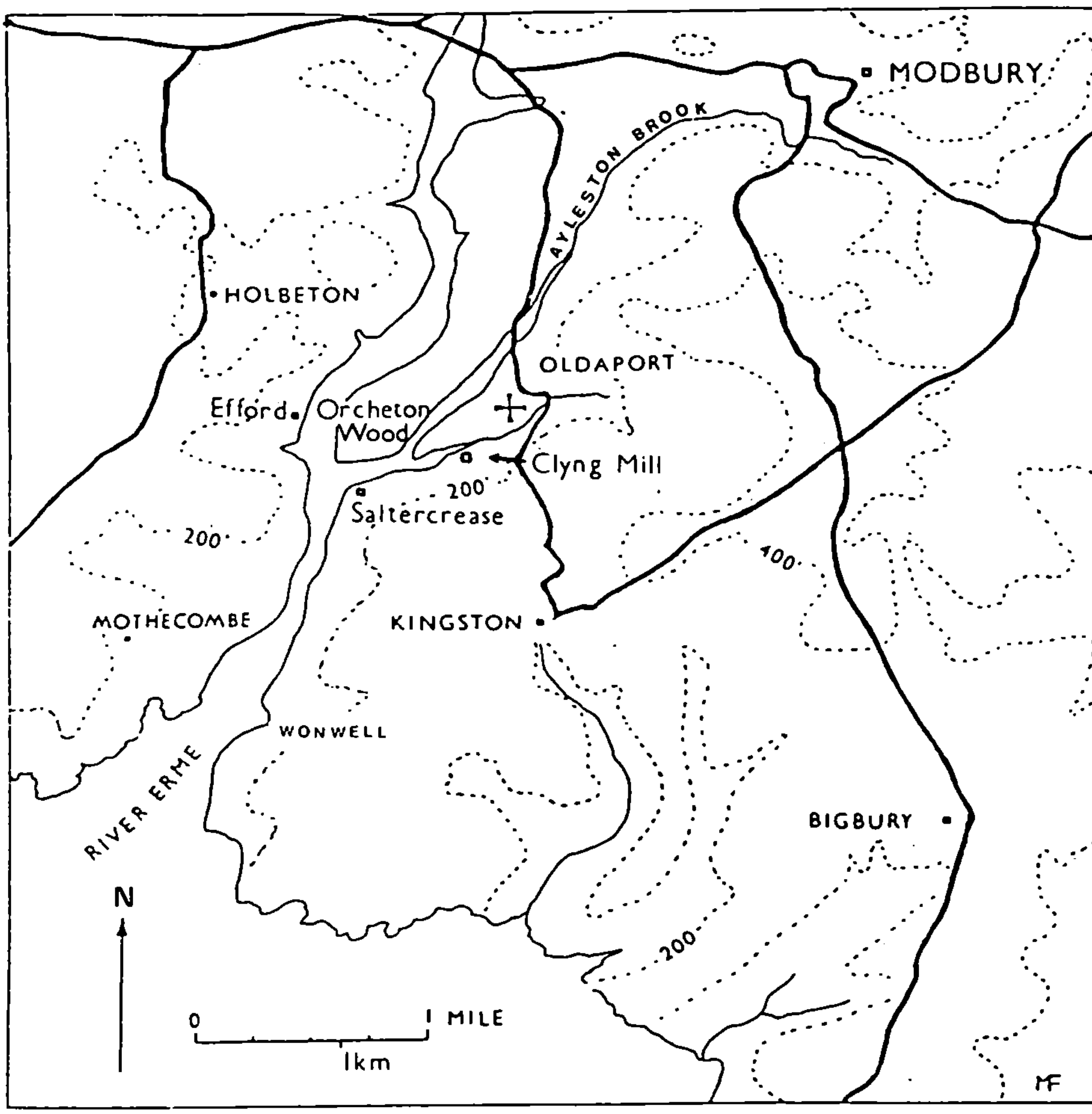


FIG 7.4 Location of Oldaport Fort in relation to the River Erme (from Farley and Little 1968)

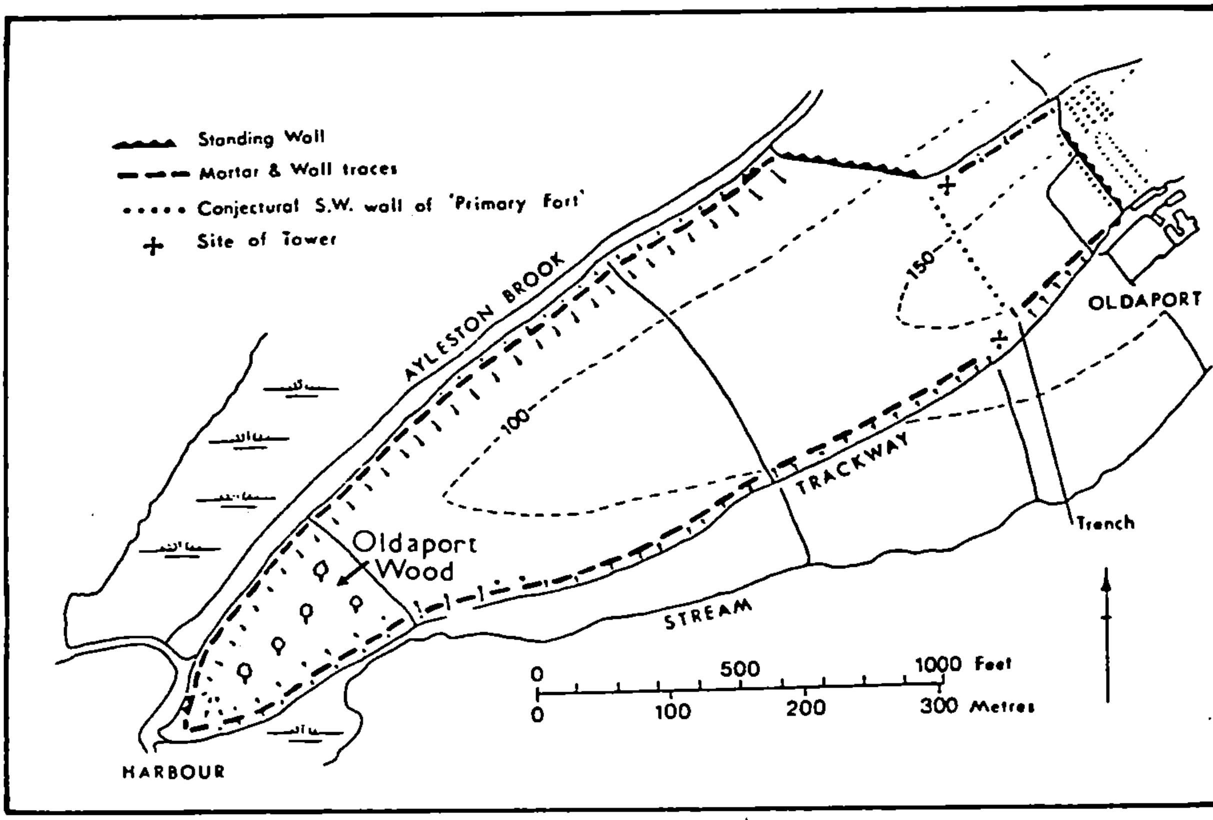


FIG 7.5 Plan of Oldaport Fort (from Farley and Little 1968)

at Mothecombe in the fifth and sixth centuries, Cottrill (1935) considered there to be no simple reason for the existence of a Roman port as he stated the

> "site stands in no obvious relation to the late Roman tin mines of Cornwall or Exeter",

although tin mining during the Roman Age may have been more extensive than generally believed.

Today the harbour at Oldaport is too heavily silted for use. A causeway was constructed in the late 19th century which crossed both creeks and touched the tip of the spur linking Clyng Mill and Orcheton Wood. As late as 1844 the western creek, Ayleston Brook, was navigable by barges for a further distance upstream towards Modbury (Lewis 1844). The estuary has silted to such a degree in recent years that the fords between Efford and Saltergrass and between the coastguard cottages at Mothecombe and Wonwell Beach (see figure 7.4 for the locations) are no longer passable even at low tide. Thus is seems there is confirmatory evidence that in recent years the lower part of the Erme valley has silted up.

Near the mouth of the Erme there are also records of dramatic swings in the river position. In the past 200 years or so the river channel has been recorded as changing position dramatically. In 1835 a large expanse of grass in front of the coastguards cottages existed, large enough for an annual fair to be held there (Britton and Bragley 1803). They documented that this grassed area nearly crossed the harbour, confining the Erme close to the eastern cliff. In 1798 a storm formed another such area across the harbour, as large and as firm as the old one, joining to the eastern cliff. Consequently the river was forced to flow across the harbour by the side of the new obstruction after clearing the old one. Several months later this obstruction was washed away in another storm leaving the ancient peninsula untouched (Mildmay-White 1985).

7.4 Radiocarbon Dating

Radiocarbon dating has become an established tool in methods of Late Quaternary reconstruction, and has been used to date sediments of at least 50,000 years old. There has been much discussion on the limits and accuracy of dating because of the natural variation in carbon dioxide over time, the random process of decay, hard water error, especially in areas of carbonate rocks, and contamination of samples by old carbon and carbon exchange. Actual years have been correlated to radiocarbon years by C-14 dating of tree rings.

C-14 dating of marine and freshwater sequences has been used to try and establish sea level curves for various locations around Britain. In particular The Wash and north-west England have been studied in some detail by Shennan (1980, 1982a) and Tooley (1978, 1982) respectively. There are a number of problems however in the derivation of sea level curves as discussed in chapter 2. C-14 dating has also been used in dating of Late Flandrian fluvial sequences, for example by Brown and Barber (1985).

In dating some of the deposits recovered in this study it is hoped to relate sediments from the buried channel of the Erme to documented events in historical time and to earlier prehistoric events on Dartmoor. The choice of samples for dating and their preparation before submitting to the radiocarbon laboratory are described, followed by an interpretation of the timing of events in the study area.

7.4.1 Choice of Samples for Radiocarbon Dating

The choice of samples submitted for analysis was limited by the quantity of organic material present in the sediment recovered and by the number of horizons that contained organic material. The nature of the organic deposits varied considerably; twigs, bark fragments and some seeds were present in some of the gravel horizons, whilst other horizons appeared to be predominantly 'organic silts', containing small plant fragments whilst some of the organic units were more fibrous. The gravels containing organic fragments did not yield enough organic material from any horizon to be considered for dating.

In order to extract the most useful and reliable information from C-14 dating samples were chosen from the organic sequence that could be traced between a number of cores in the floodplain area around Sequer's Bridge. The thickest organic layers occurred in cores SB1, A4 and BH6 (figure 4.3 in chapter 4) and samples were submitted from the top and bottom-most part of the organic horizon. Thus two samples were submitted from each core in an attempt to date the start and end of organic deposition at each location. Organic matter from the cores towards the lower part of the valley, at locations S1-2, RM1-4, BH11 and BH12, was not present in sufficient quantity for dating since it was mainly composed of fragmented twigs and bark and may have been contaminated. Thus the dating of the sediment will, on the whole, relate to the fluvial deposits from the Sequer's Bridge area rather than the more estuarine deposits at depth in the lower valley.

i) Samples from SB1

Material submitted for dating from core SB1 was from 4.3-4.4m (0.13-0.23m OD) and 4.1-4.2m (0.33-0.43m OD) depth in the core. (58g of sediment was submitted from the lower unit and 77g from the upper unit.) These samples occurred near the base of the total sediment column collected and were composed of a mixture of sand and organic material with some plant remains. They overlie the tough silt unit with large rounded granitic gravels found in the upper part of the study area and the tributary valley and underlay various horizons of silts, sands and gravels. Because of the method of collecting sediment in the field samples of 10cm thickness had to be submitted. Hence, if the sediment had accumulated over a long time period, any date will reflect an average for the sample and will not therefore mark the exact end or beginning of organic deposition.

ii) Samples from A4

Samples of 247g and 210g were submitted from core A4 from horizons at 2.4-2.5m depth (0.51-0.41m OD) and 2.7-2.8m depth (0.21-0.11m OD). These units had a higher organic content than those from SB1 because of a lower proportion of sand. They occurred above the tough silty-clay horizon as in SB1 and below mainly silty-clays or silt-fine sand horizons. A higher organic horizon at approximately 1.7m depth in the core did not contain sufficient organic material for dating.

iii) Samples from BH6

Core BH6 had by far the most organic material present out of all the cores, spread through a 1m thick horizon, at a depth of 2.05-3.05m. There was also some organic material in smaller quantities outside this horizon but in insufficient quantities for dating. Samples were chosen from the top and bottom layers at 2.05-2.25m depth (1.41-1.61m OD) and 2.85-3.05m depth (0.81-0.61m OD). The dry weight submitted was 195g and 141g from the top and bottom samples respectively. These samples span a 20cm thick layer which represents the smallest unit of sediment collection from BH6. Both the samples had a small amount of contamination by sand and also contained some plant remains.

Because of the proximity of the three coring locations it is likely that the organic layer is fairly continuous over the area and thus of the same general age. The C-14 dates obtained from each sample may differ considerably if erosion of some of the organic units has occurred or organic deposition continued for longer in one place than the others.

The samples were submitted for dating to the Groningen Radiocarbon Laboratory which requires information on the type of sample, the location of coring as well as an estimate of the age of the deposits.

7.4.2 Results of Radiocarbon Analysis

The dates received from the Groningen Radiocarbon Laboratory are listed in table 7.4 and include the Groningen Lab code number.

LAB CODE	SAMPLE NAME	CARBON DATE
GrN-13986	Erme A4 2.4-2.5	1175±30 BP
GrN-13987	Erme A4 2.7-2.8	1425±50 BP
GrN-13972	Erme BH6 2.05-2.25	1185±50 BP
GrN-13973	Erme BH6 2.85-3.05	2130±40 BP
GrN-13974	Erme SB1 4.1-4.2	1985±50 BP
GrN-13975	Erme SB2 4.3-4.4	2290±45 BP

TABLE 7.4 RADIOCARBON DATES OF SEDIMENTS FROM THE ERME CHANNEL

They are also shown as a schematic diagram in figure 7.6. The solid black lines indicate the sampling horizon and the cross hatches the rest of the organic unit. The diagram shows the dated units relative to Ordnance Datum.

In order to gain a better understanding of the way in which the samples relate to each other they have been plotted as altitude (metres OD) against age in radiocarbon years in figure 7.7. Because of the random process of decay of carbon atoms all dates are plotted as a band within one standard deviation of the mean. This graph is not meant to be a direct comparison with the work of Tooley and Shennan in producing a time altitude graph to predict sea level at various times but it is merely to show the relationship between the six samples dated and their sphere of overlap in time and space. One possibility arising from this graph is that there were two different periods of organic matter deposition since the dates from SB1 and A4 are separated by nearly 500 years. Alternatively, the same event may have been responsible for the organic units although it may not have been synchronous at locations A4 and

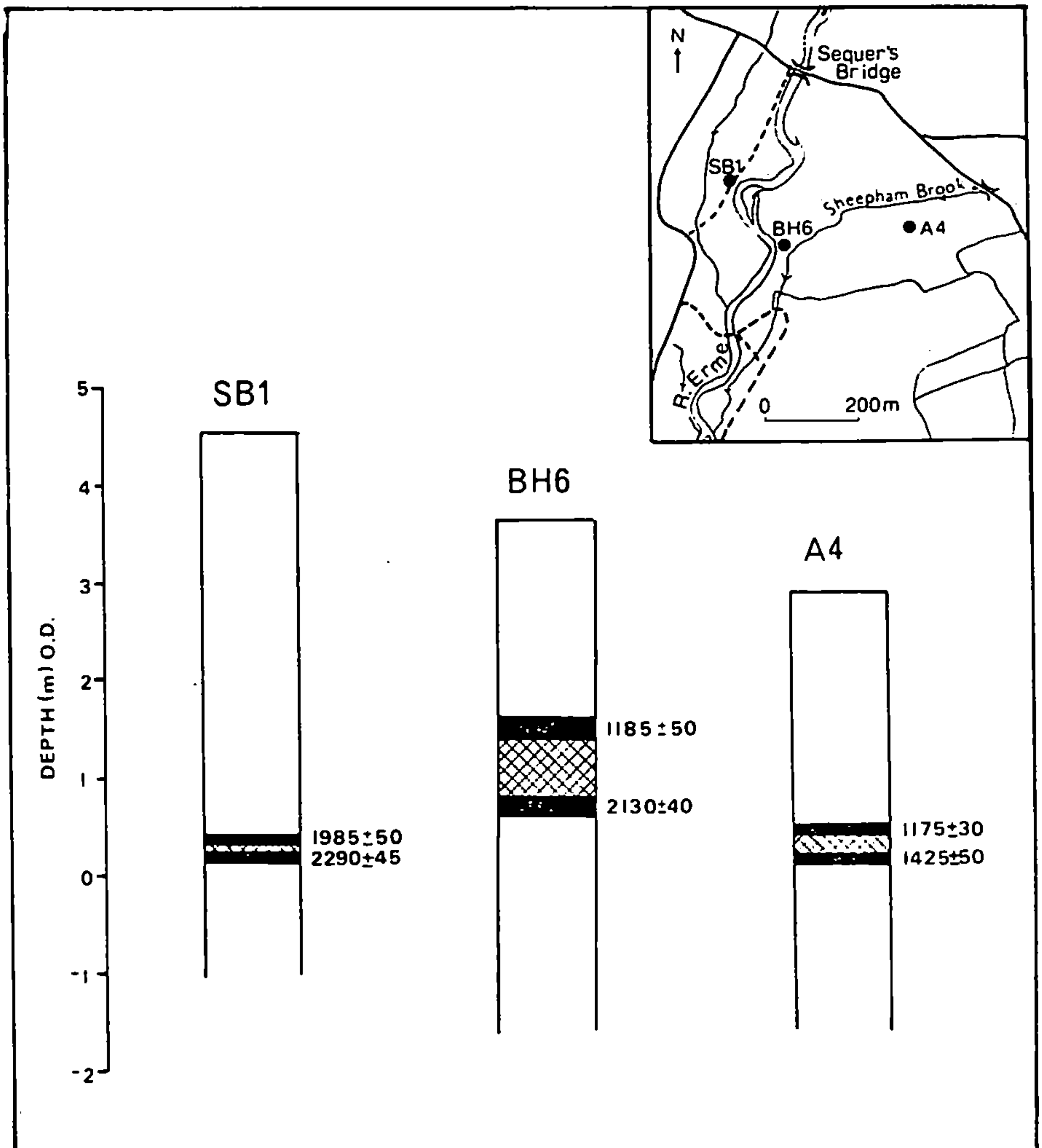


Fig 7.6 RADIOCARBON DATES

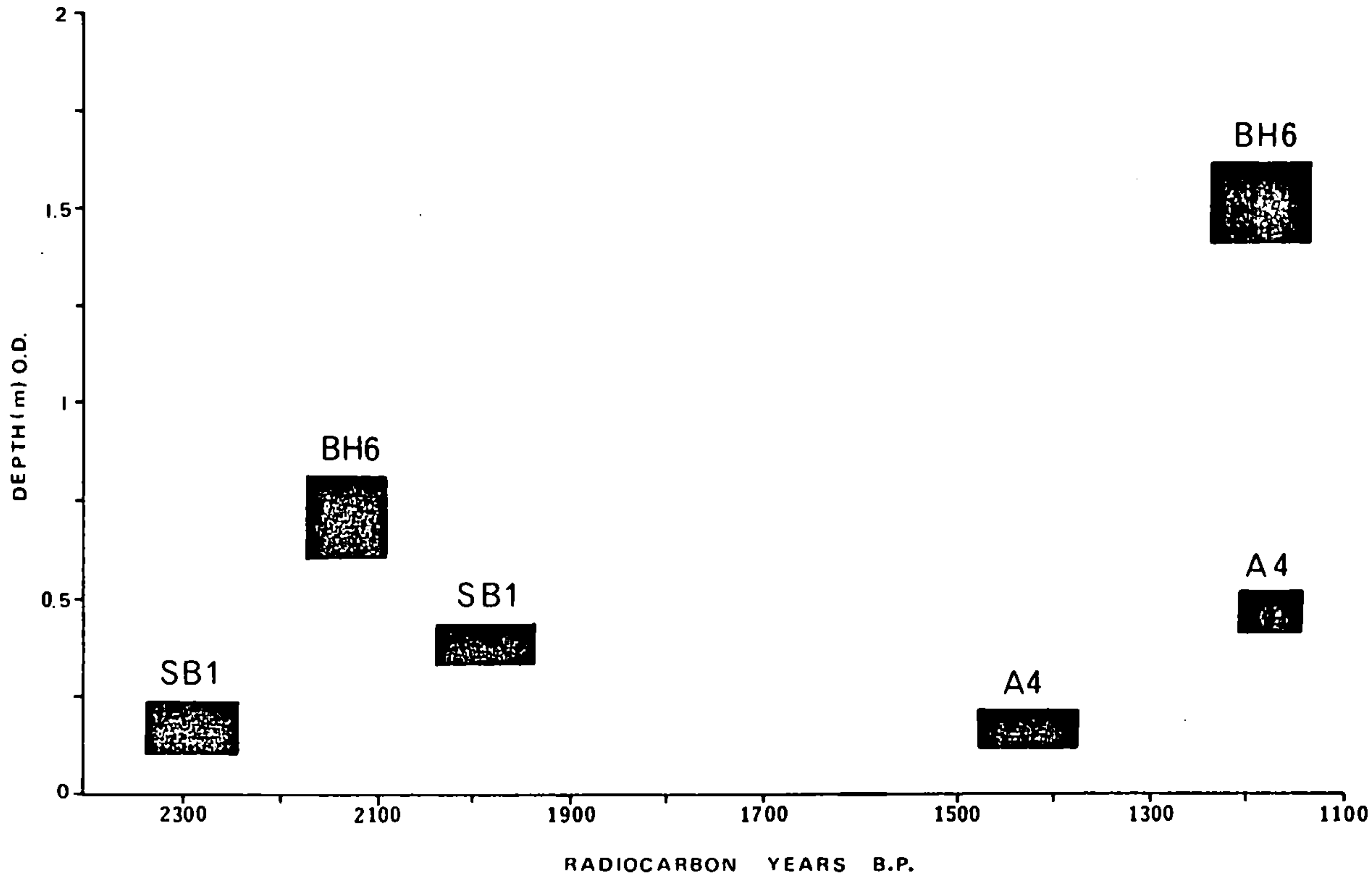


Fig 7.7 TIME ALTITUDE PLOT OF ^{14}C DATES

SB1. It seems that organic deposition occurred for almost all of the time at location BH6, so it is equally possible that erosion of organic material may have occurred at SB1, reducing the thickness of the organic layer. As A4 occurs in the tributary valley, it may not have experienced organic deposition conditions for the same length of time as those in the main valley.

Care must be taken in the interpretation of radiocarbon dates because of the limitations of the technique. Radiocarbon years are not equal to calendar years because of the natural variation in carbon production in the atmosphere over time; during the time period being considered however, there is little deviation between the two time scales. De Jong and Mook (1981) expressed concern that sea level rise curves may show false steps because of the fluctuations in the C-14 time scale; for example, a series of dates from a peat sequence with a constant sea level rise would give the impression of successively slow and fast rates of sea level rise. They also stated that it leads to a clustering of C-14 dates at certain intervals, one of which is 2400-2200 BP. Neither of those are considered a problem here as this study is not attempting to date a long sequence of closely spaced organic units, but rather to give an impression of the age of sediments and correlation between units.

Any date will be an average of the sample and since sediment was collected from 20cm and 10cm thick horizons, 20cm of organic deposition may represent a long time span and thus in reality the top of the organic units could be much younger than the dates suggest, and conversely those at the base may be older.

Some small scale contamination of samples may also have occurred in the field due to the collection of samples using a screw auger. Since all the samples were at least 2m below the floodplain, it is unlikely that the dates have been contaminated by young carbon from current soil formation processes. The possibility that some old organic material has been washed into the samples cannot be ruled out, though the organic deposits submitted for dating seemed to be a single unit. These points all suggest that care must be taken in interpreting these radiocarbon dates. However, the dates compare well with each other and they do tend to match the tithe map evidence which suggested a former marsh environment in the Park Driving Bridge Area and thus one can be confident that they are representative of the actual age of the deposits.

7.5 Discussion

The results from radiocarbon dating will be discussed further in Chapter 8, but brief mention will be made here as to their agreement with historical records. Core SB1 was extracted from the former Higher Pool Marsh and BH6 and A4 from Goutsford Marsh. Although the time of the marsh formation is not known the fields may have retained their names for a number of centuries and as all the dates lie between 2400-1100 years BP it is likely that the sediment deposited between these years corresponds with the records of marshland on the tithe maps.

Of importance also is the upper sediment overlying these units, which must have been deposited in the last 2000 years. At location BH6 2m of sediment must have been deposited in 1200 years, at A4 2.4m of sediment in 1200 years and at SB1 4m in 2000 years, that is at a rate of c. 0.2cm/year. Sedimentation is unlikely to have been at a steady rate and may have been affected partly by mining activities on the moor and partly by forest clearance in Roman, Saxon and Medieval times. As noted in chapter 3, official permission was given for clearance of the remaining Dartmoor forest in 1204 which may have led to an increase in sedimentation in the lower catchment. Since however, most of the Dartmoor forest clearance took place earlier than 2000 years ago, the upper sediment layers are probably a result of mining and forest clearance associated with the mining activities rather than widespread forest clearance. Greeves (1981) noted that the greatest period of tinning on the moor was in the second half of the 12th century when Devon tin production exceeded that of Cornwall. It is likely that streaming was the main extraction method since at this time the stream deposits would have been the most accessible. The main sedimentation in the Erme channel may have occurred during this time since streaming is the most likely of all the extraction methods to have altered river discharge, although tin mining undoubtedly continued to influence the development of the Erme throughout the Medieval mining phase. The effects of the china clay extraction early in the twentieth century are difficult to assess, as the period of extraction was relatively short and unsuccessful; thus the effects on the Erme are likely to be limited. The wood fragments and charcoal recovered from river gravels below the C-14 dated sediments, may be related to the earlier periods of forest clearance from the Neolithic onwards and possibly prehistoric mining activities on the moor.

CHAPTER 8 DISCUSSION

8.1 Introduction

This chapter aims to consider all aspects of the analyses undertaken in this study in order to derive conclusions as to the evolution of the Erme valley especially during the Flandrian. Firstly, the main points arising from the previous chapters are summarized. This is followed by identification of the various sediment layers and an attempt to date the various stages using the radiocarbon and historic data. This will lead to the presentation of a model of evolution for the Erme valley during the Late Quaternary.

8.2 A Summary Of Results From Earlier Chapters

Evidence presented in chapter 2 indicated that the age of the Erme river valley is uncertain. Some would suggest that the drainage pattern of the South West was formed in the Cretaceous, and shaped in the Tertiary by higher sea levels, whilst others have suggested the valleys were cut during the Pleistocene (e.g. Durrance 1971). Erosion surfaces related to higher Tertiary and Pleistocene sea levels have been identified on Dartmoor by some (e.g. Brunsden *et al.* 1964), whilst others would liken the features more to nivation terraces (e.g. Guilcher 1969). Since the study area is believed to be beyond former limits of glacial ice, periglacial conditions will have been more important in shaping the landscape. This is supported by the head deposits that flank the valley sides of the Erme. The buried channels of the Erme and other rivers of the South West were cut during a period or periods of lower sea level than today and the Flandrian rise in sea level has since drowned the mouths of these rivers with subsequent infilling of the channels with a mixture of marine and fluvial sediments. Sedimentation in the latter part of the Flandrian may have been aided by human activities in the catchment such as forest clearance, mining and agriculture. Previous to this research there has been little detailed study of the sediments occupying the uppermost horizons within these buried channels of south-west England.

Chapters 4,5 and 6 examined sediment from 20 locations in the lower Erme valley. A summary of the sites and the analyses undertaken is shown in figure 8.1. These analyses showed the sediments to be variable with horizons of sandy-gravels and estuarine silts occupying large parts of the cores, an organic layer, at approximately 2m below the current floodplain, traced around the Park Driving Bridge area, and in most cases an upper fine sand/silt layer. The sediments are derived from granitic and slate bedrock and diatom and molluscan analyses indicate deposition under a variety of fluvial, intertidal and marine conditions.

Questions arising from these studies concern the age of the sediment, under what environmental conditions the channel was in-filled, the relationship to sea level, whether the sediments have been reworked, the contribution of forest clearance and mining activities on Dartmoor to the sediment yield and the likelihood of any deposits older than Flandrian. These questions will be addressed in the following discussion while attempting an integrated explanation of events that have controlled the development of the Erme valley in the later stages of the Flandrian.

8.3 Correlation of Sediments

The similarities between the cores will be discussed here, thus aiming to identify horizons of sediment common to a number of cores. The cores will be examined starting with those from the upper part of the study area and tracing the marine influence downstream, that is from north to south. Wherever possible diagrams will be used to illustrate correlations found. The borehole locations in the study area are repeated here as figure 8.2. The main links between the cores are shown in figures 8.3-8.6. These diagrams have used all the evidence to equate sediment bands; symbols have been used to match sediments in terms of diatom, mollusc and radiocarbon evidence. Comparisons between some individual diatom species are shown in figures 8.7-8.14 and molluscan species in figures 8.15-8.17, these were used in the preparation of figures 8.3-8.6.

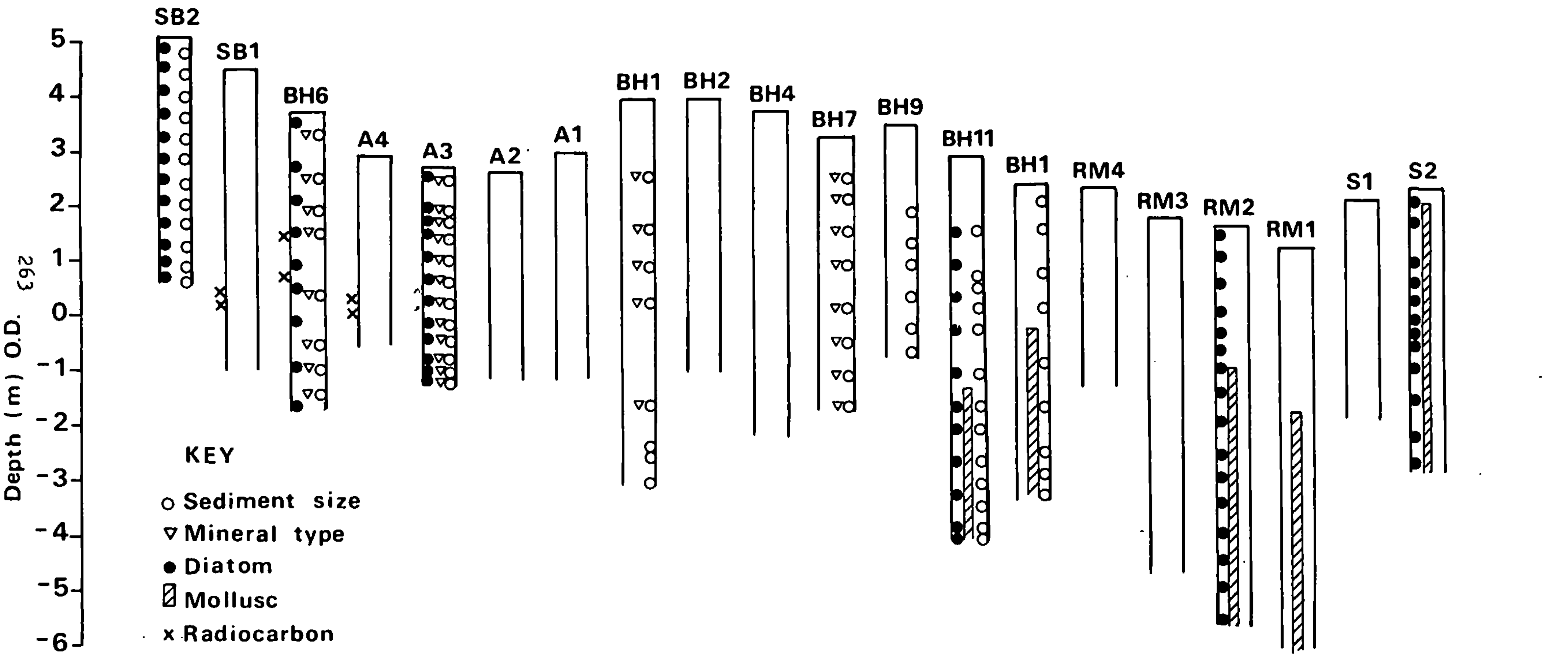


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FIG 8.1 Analysis techniques and sampling locations for all cores

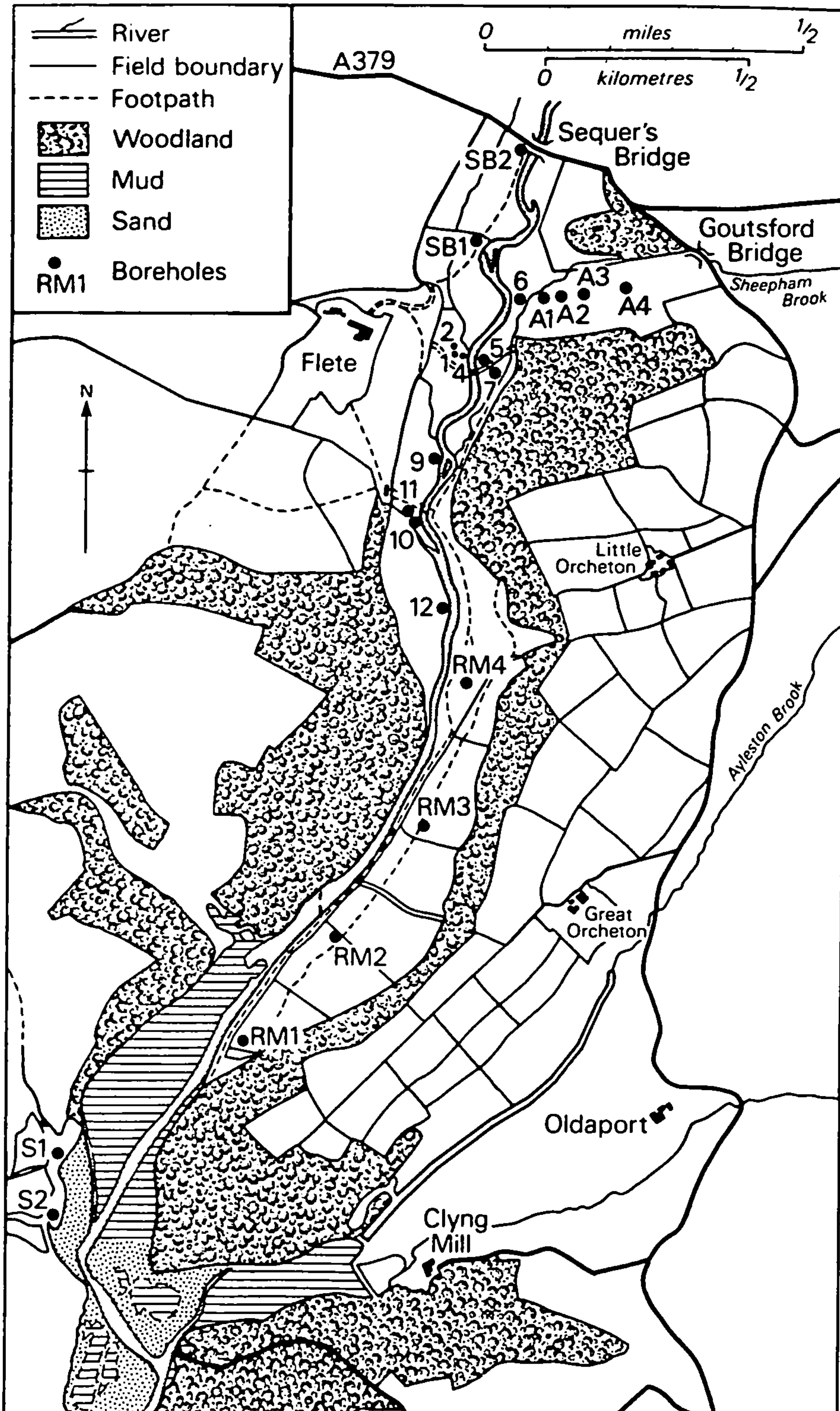

FIG 8.2 Location of all drilling sites

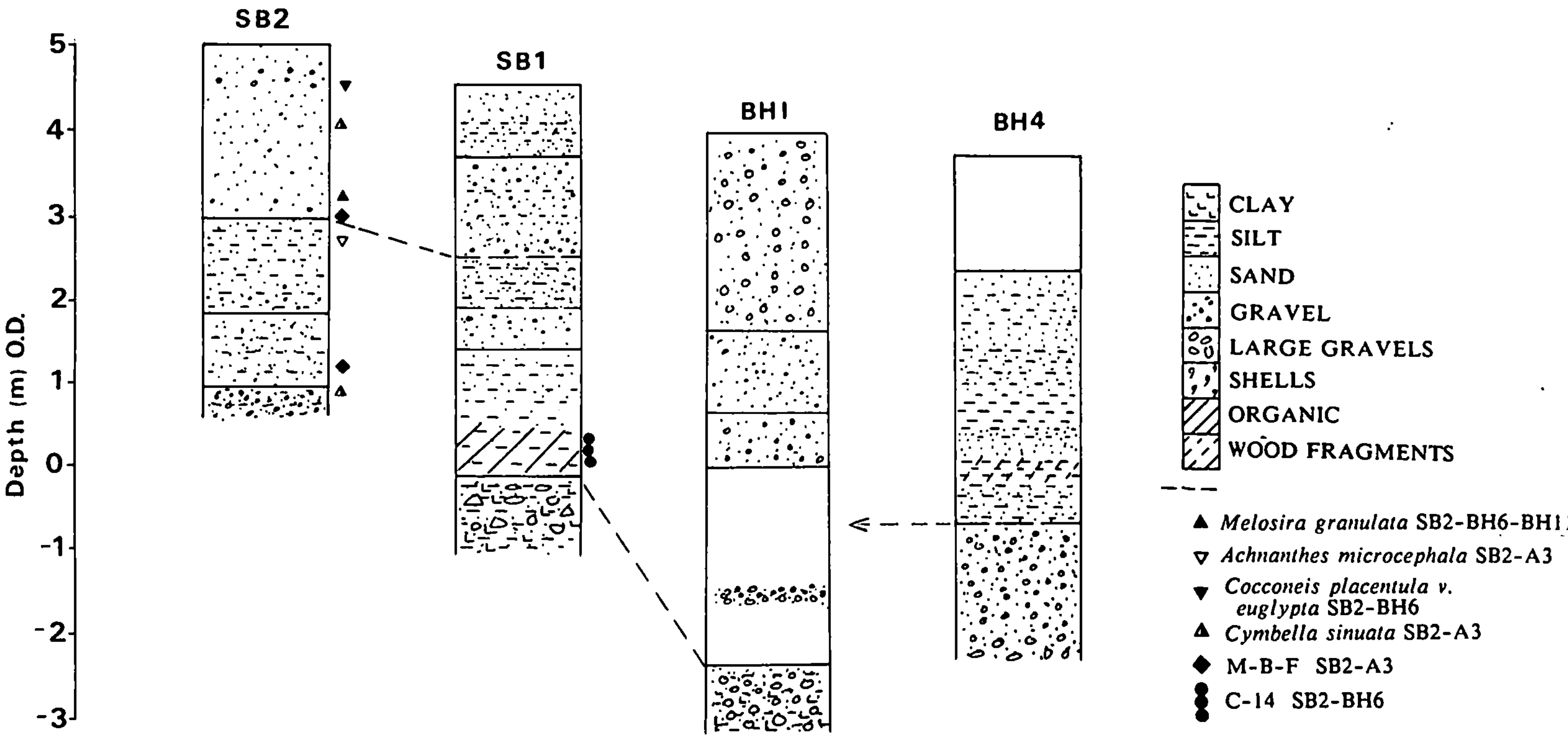

FIG 8.3 Sediment correlations between cores SB2,SB1,BH1 and BH4

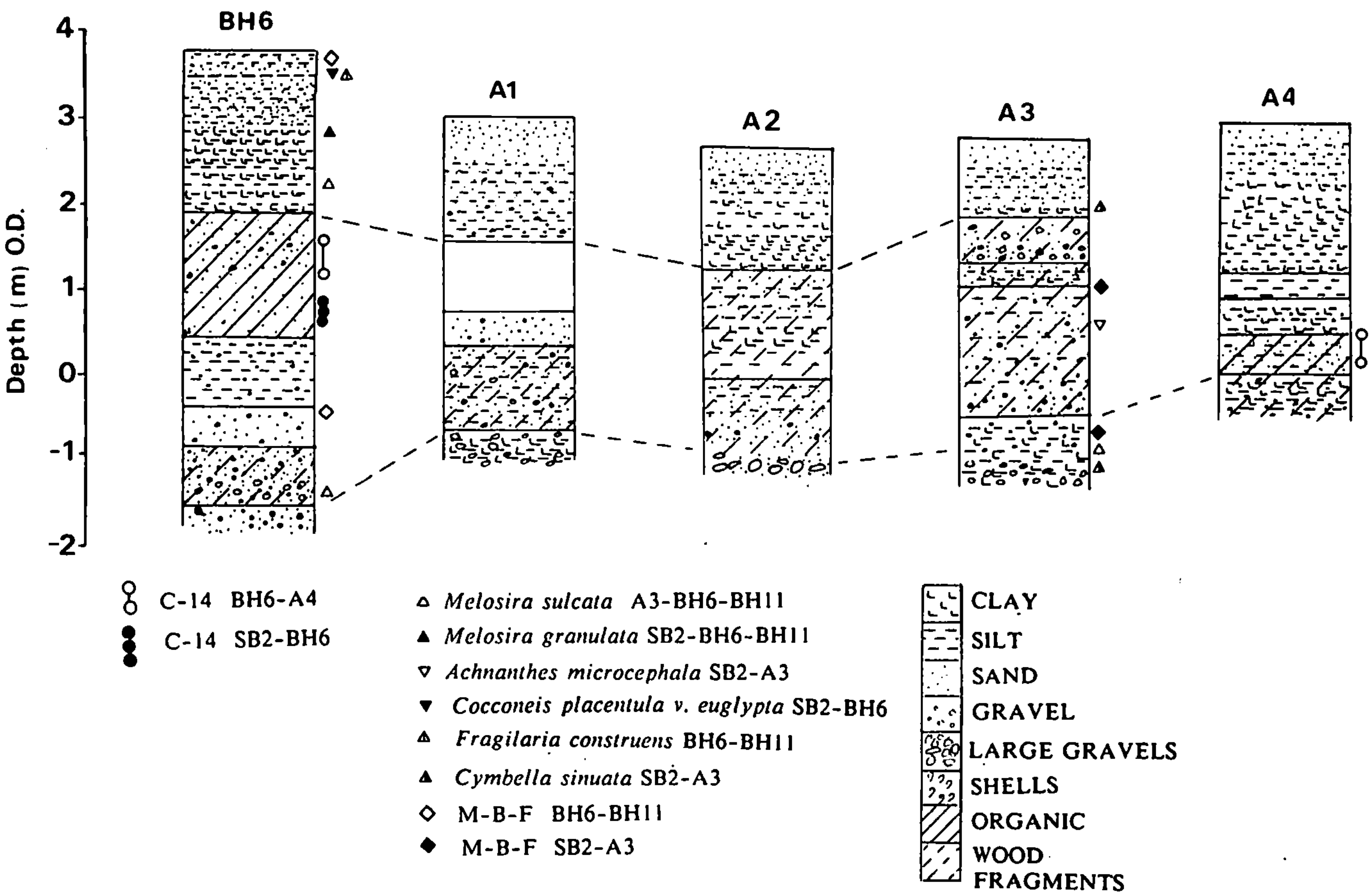

FIG 8.4 Sediment correlations between cores BH6,A1,A2,A3 and A4

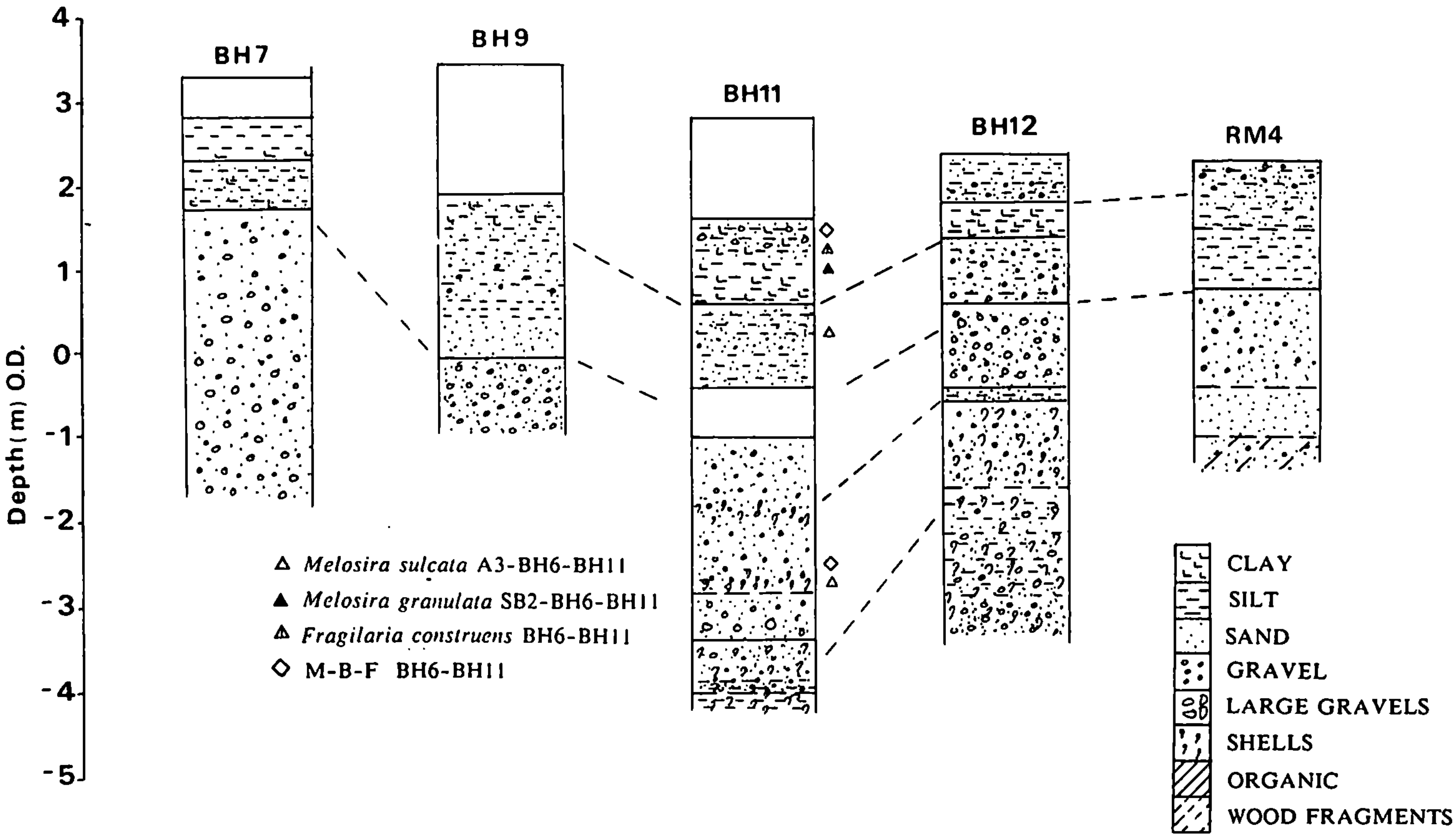

FIG 8.5 Sediment correlations between cores BH7,BH9,BH11,BH12 and RM4

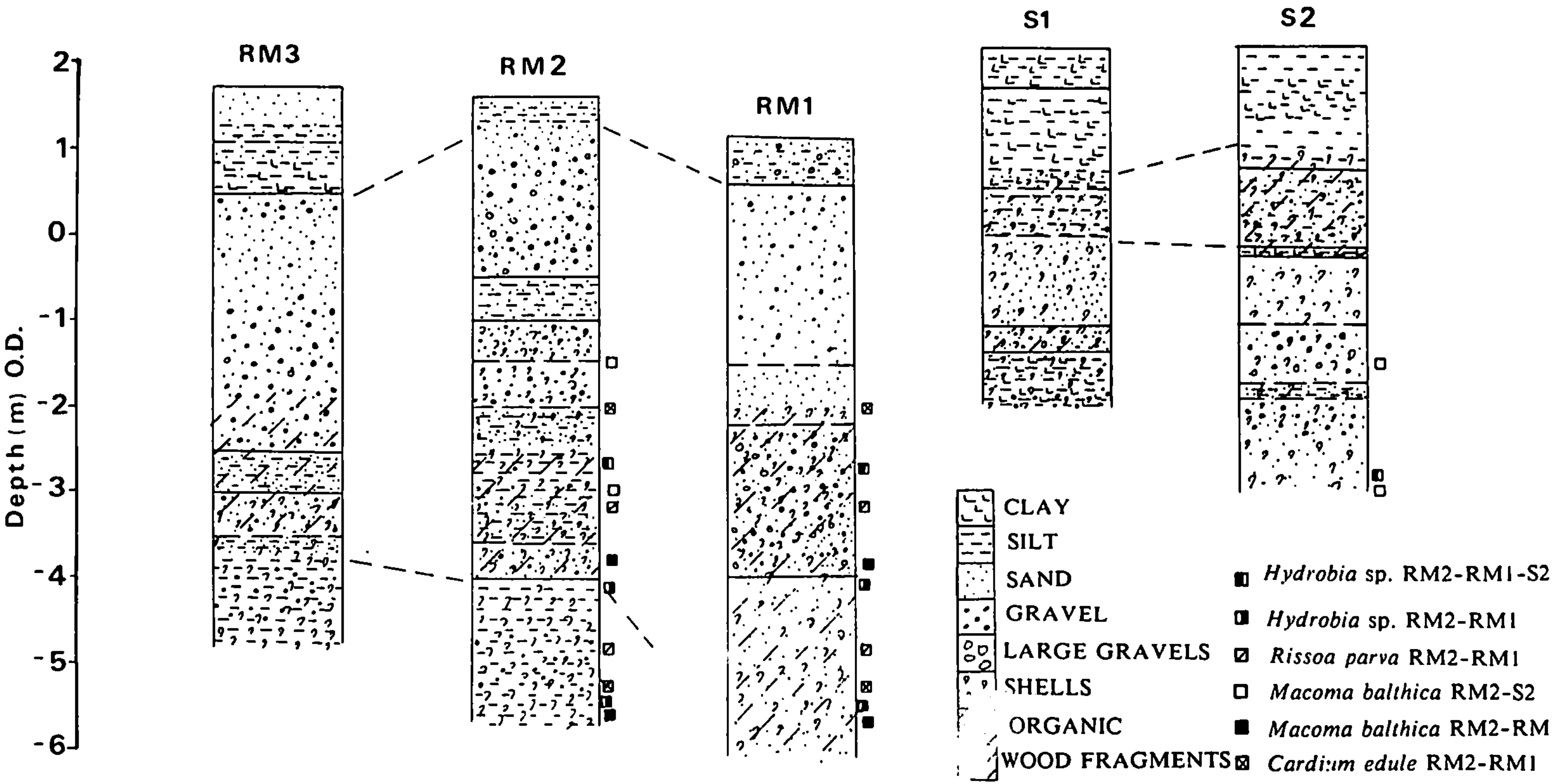

FIG 8.6 Sediment correlations between cores RM3,RM2,RM1,S1 and S2

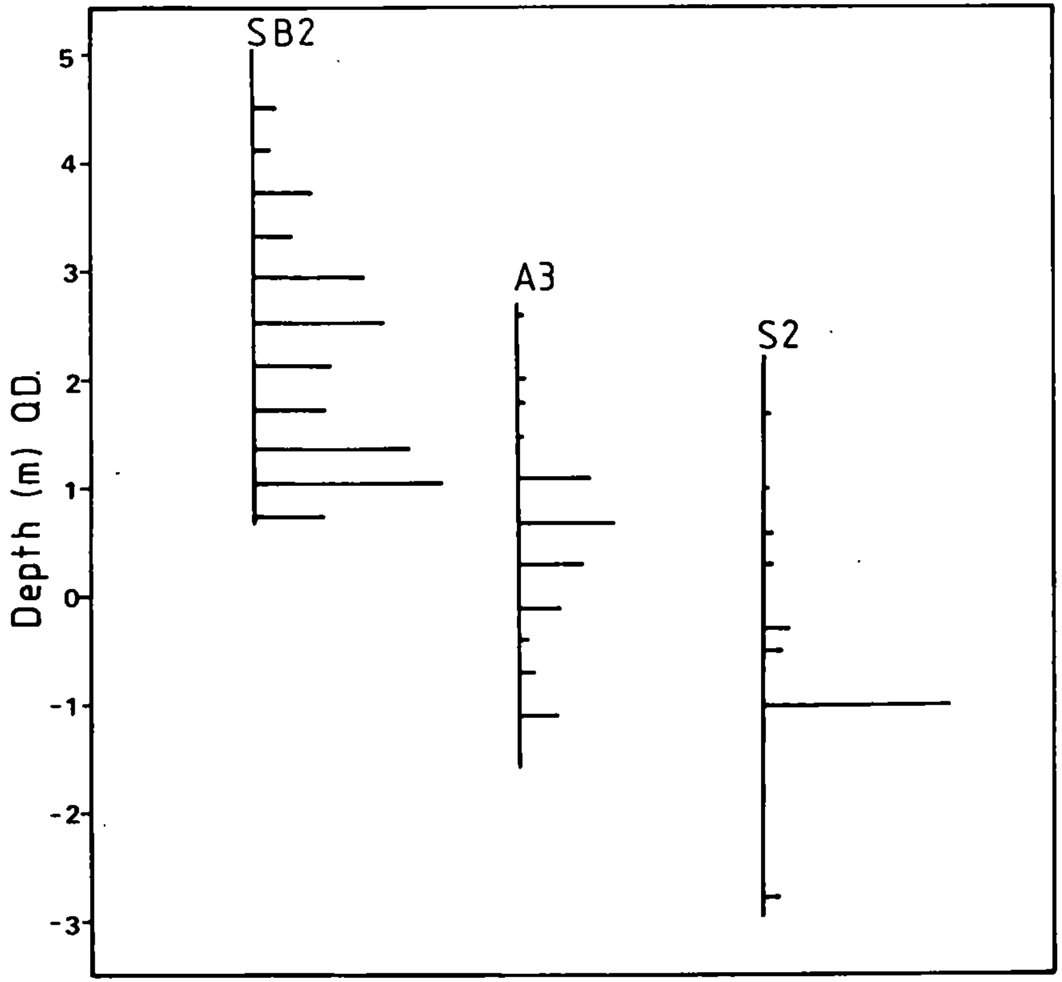

FIG 8.7 Distribution of Achnanthes microcephala in SB2, A3 and S2

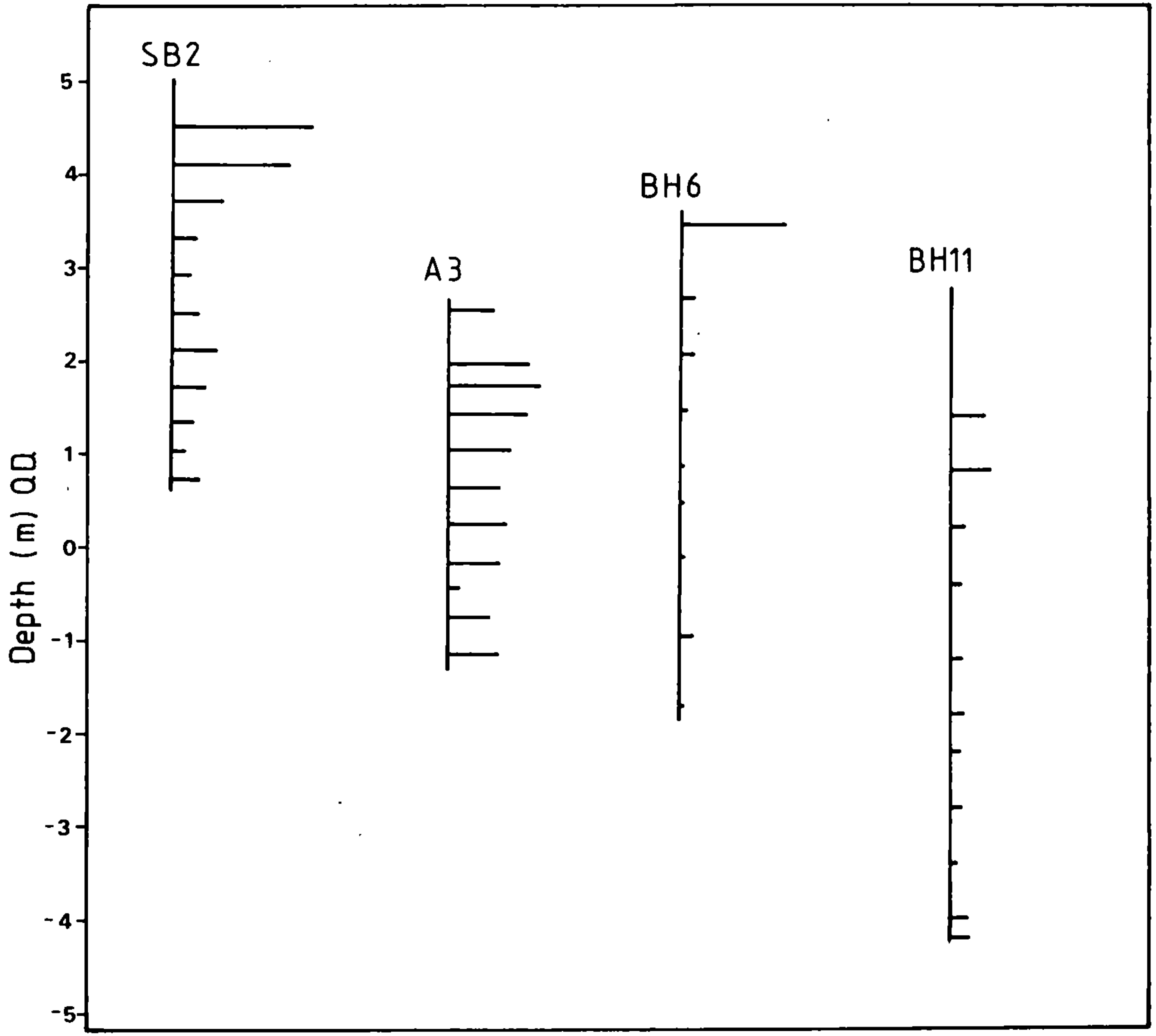

FIG 8.8 Distribution of <u>Cocconeis placentula v. euglypta</u> in SB2, A3, BH6 and BH11

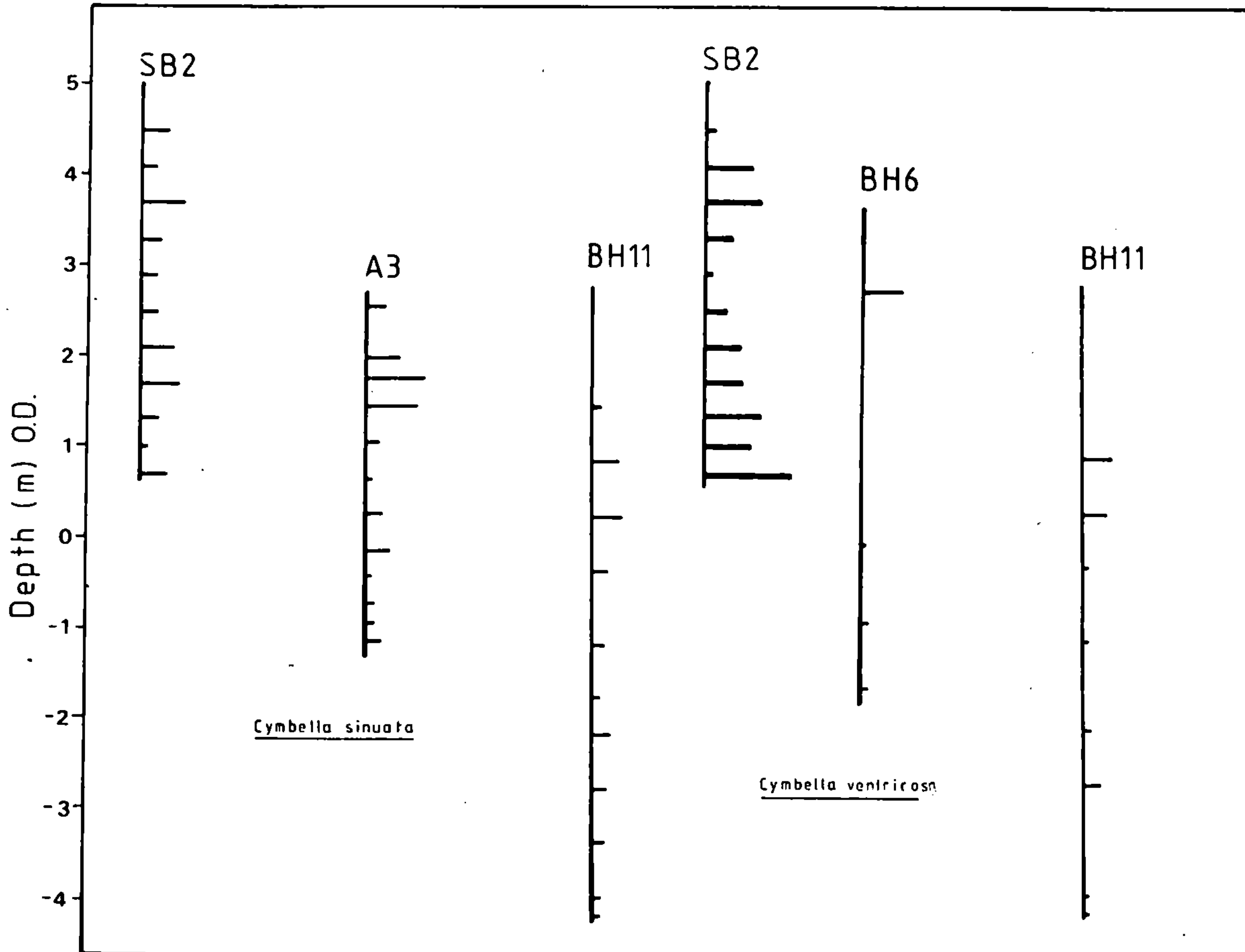

FIG 8.9 Distribution of Cymbella sp. in SB2, A3, BH11 and BH6

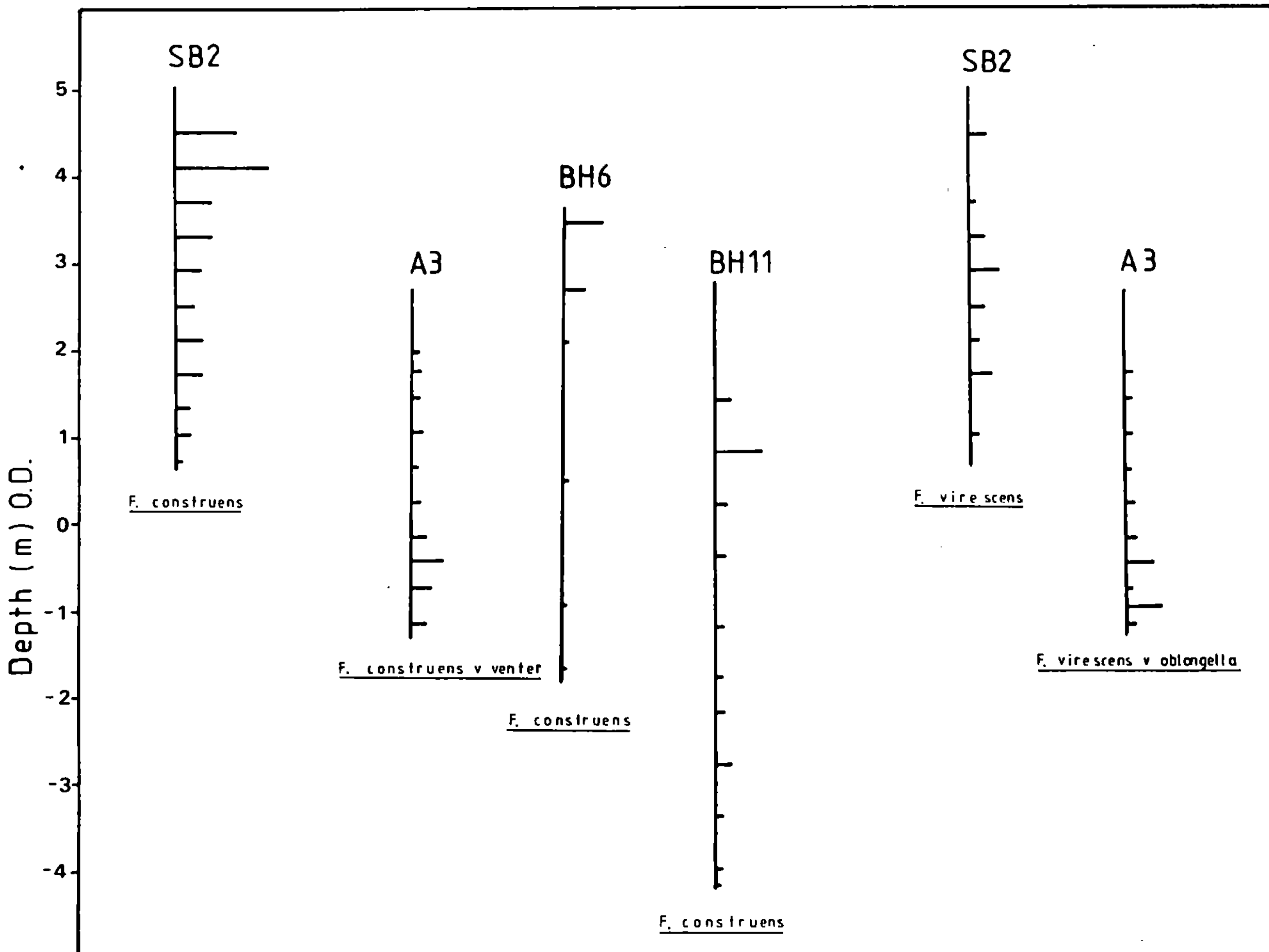

FIG 8.10 Distribution of <u>Fragilaria</u> sp. in SB2, A3, BH11 and BH6

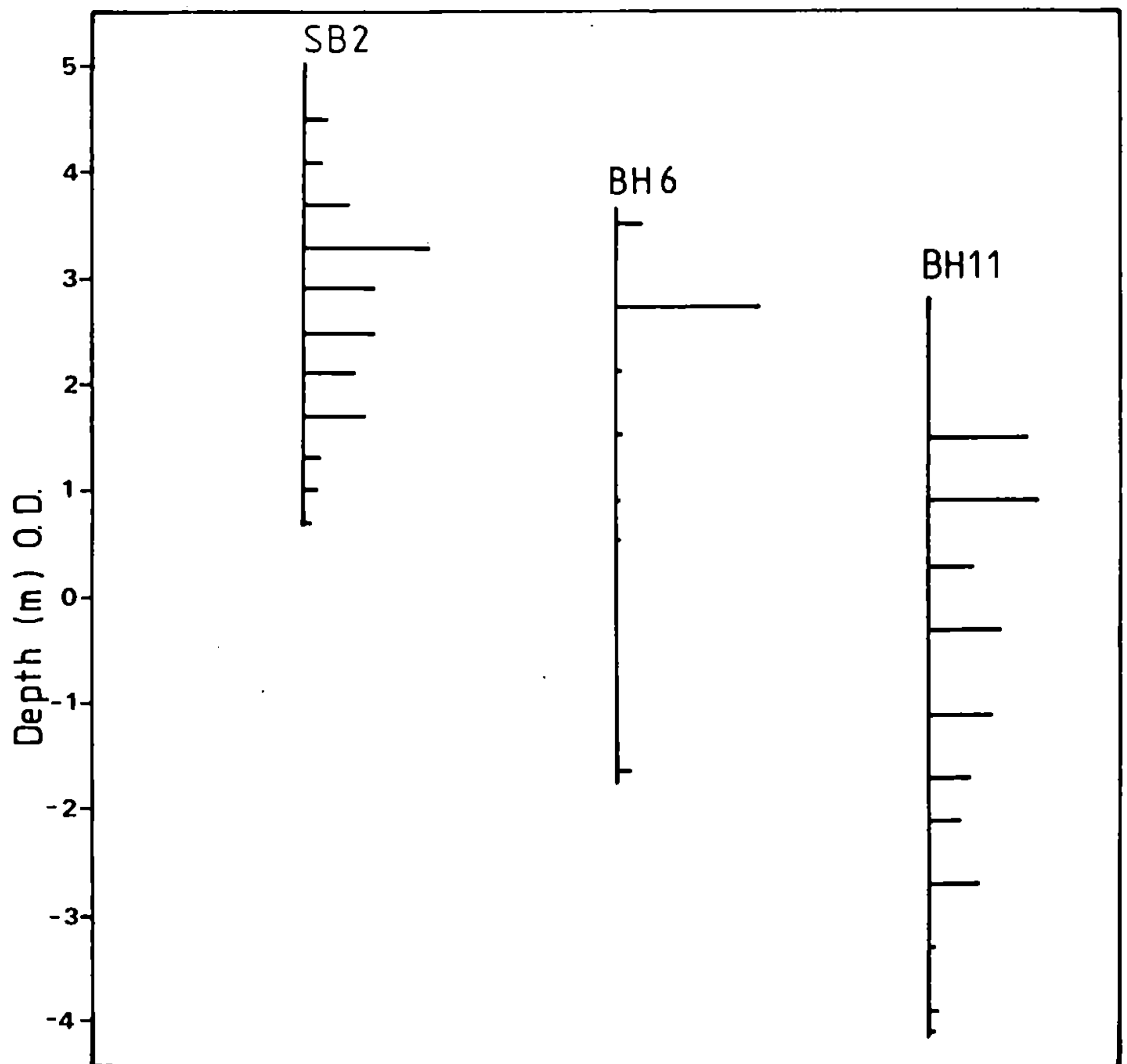

FIG 8.11 Distribution of Melosira granulata in SB2, BH6 and BH11

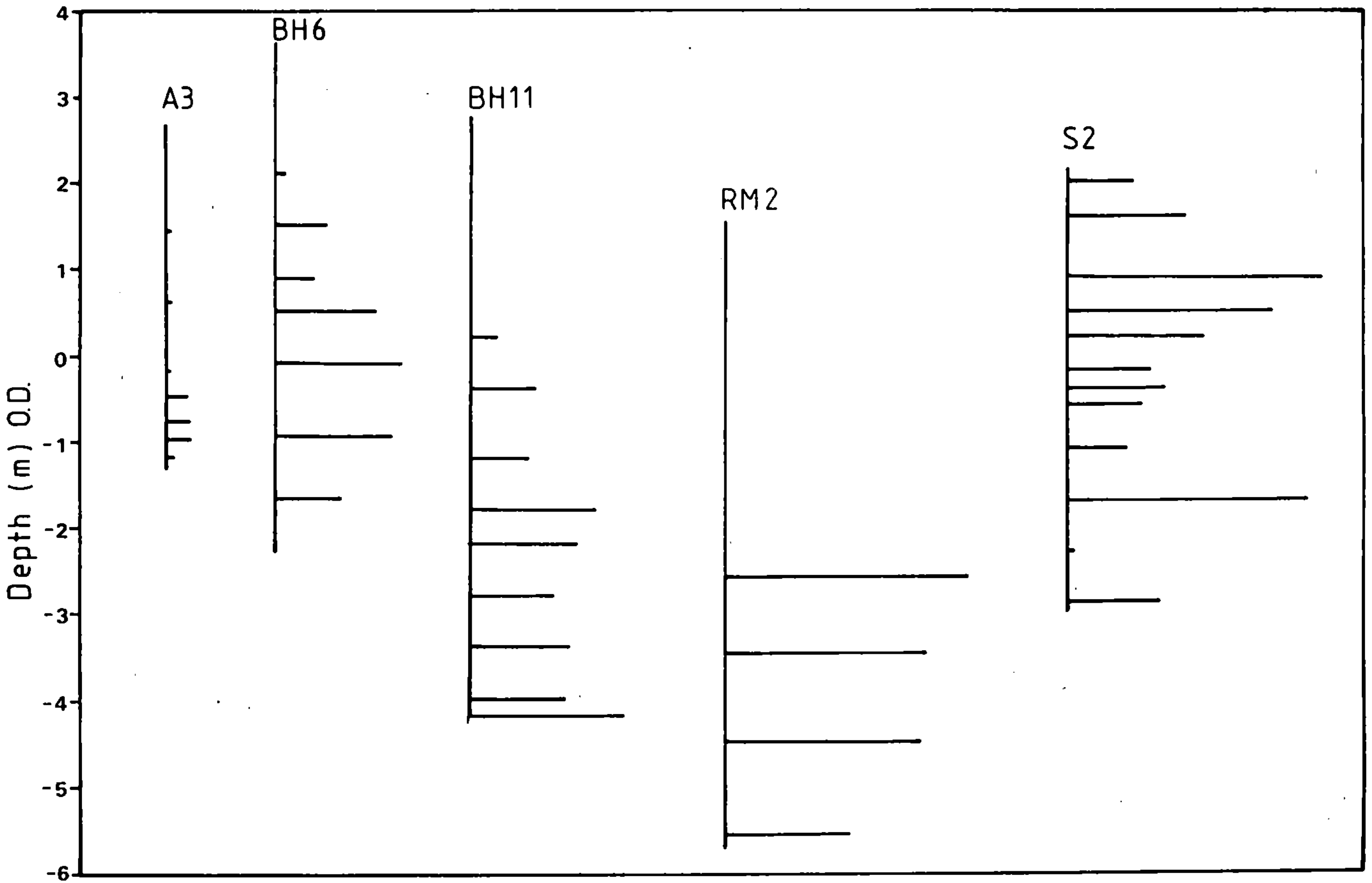

FIG 8.12 Distribution of Melosira sulcata in A3, BH6, BH11, RM2 and S2

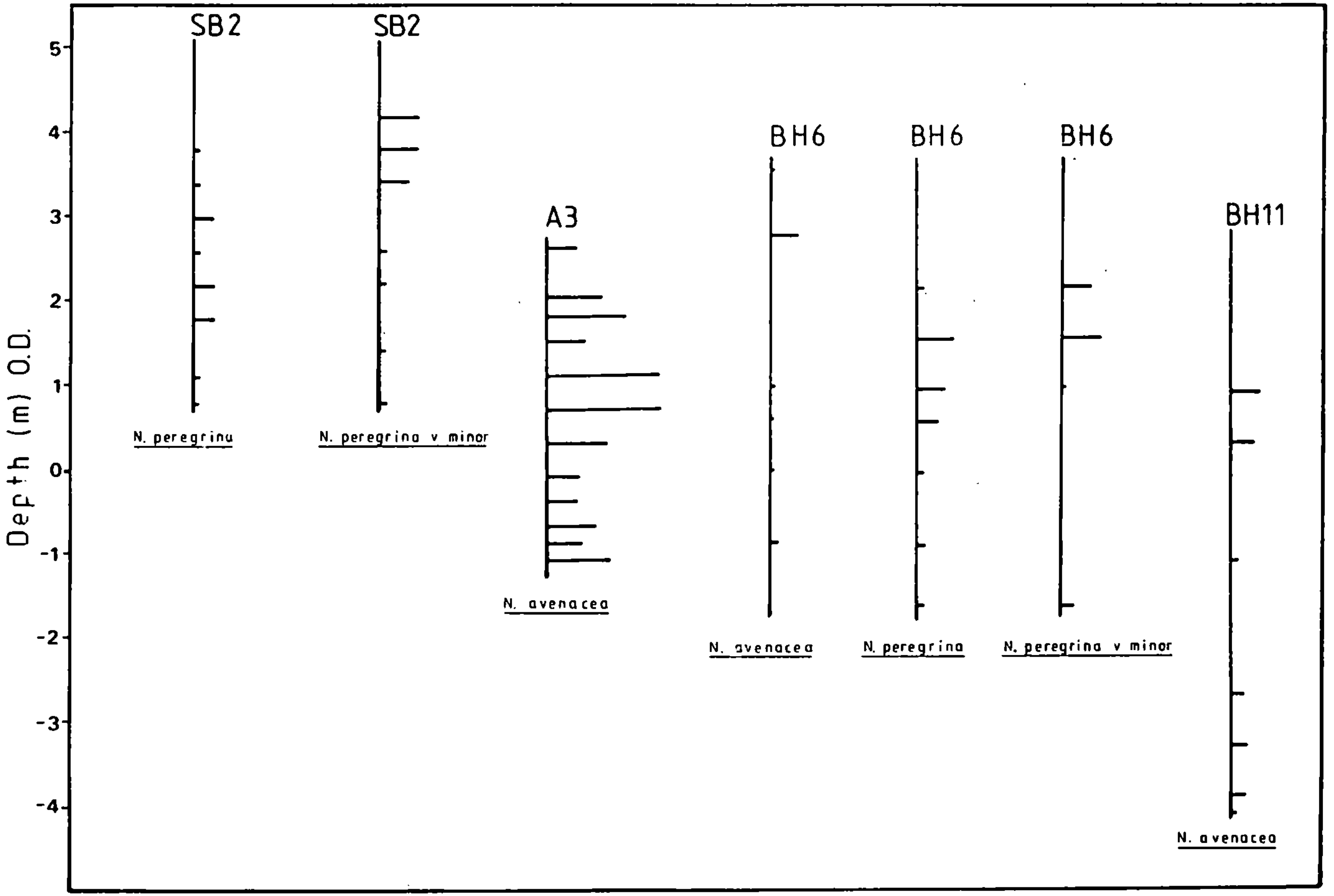

FIG 8.13 Distribution of Navicula sp. in SB2, A3, BH6 and BH11

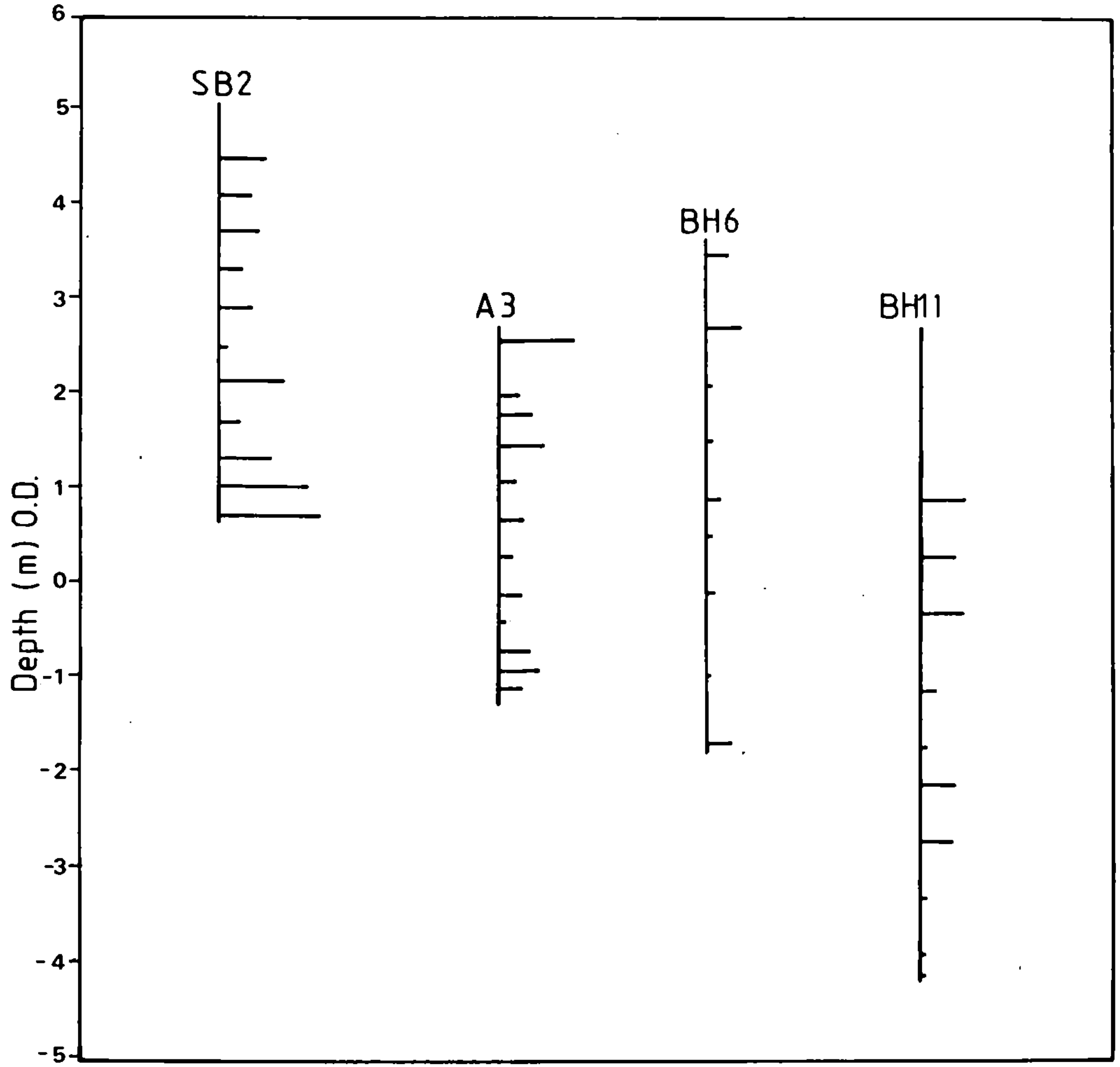

FIG 8.14 Distribution of Synedra pulchella in SB2, A3, BH6 and BH11

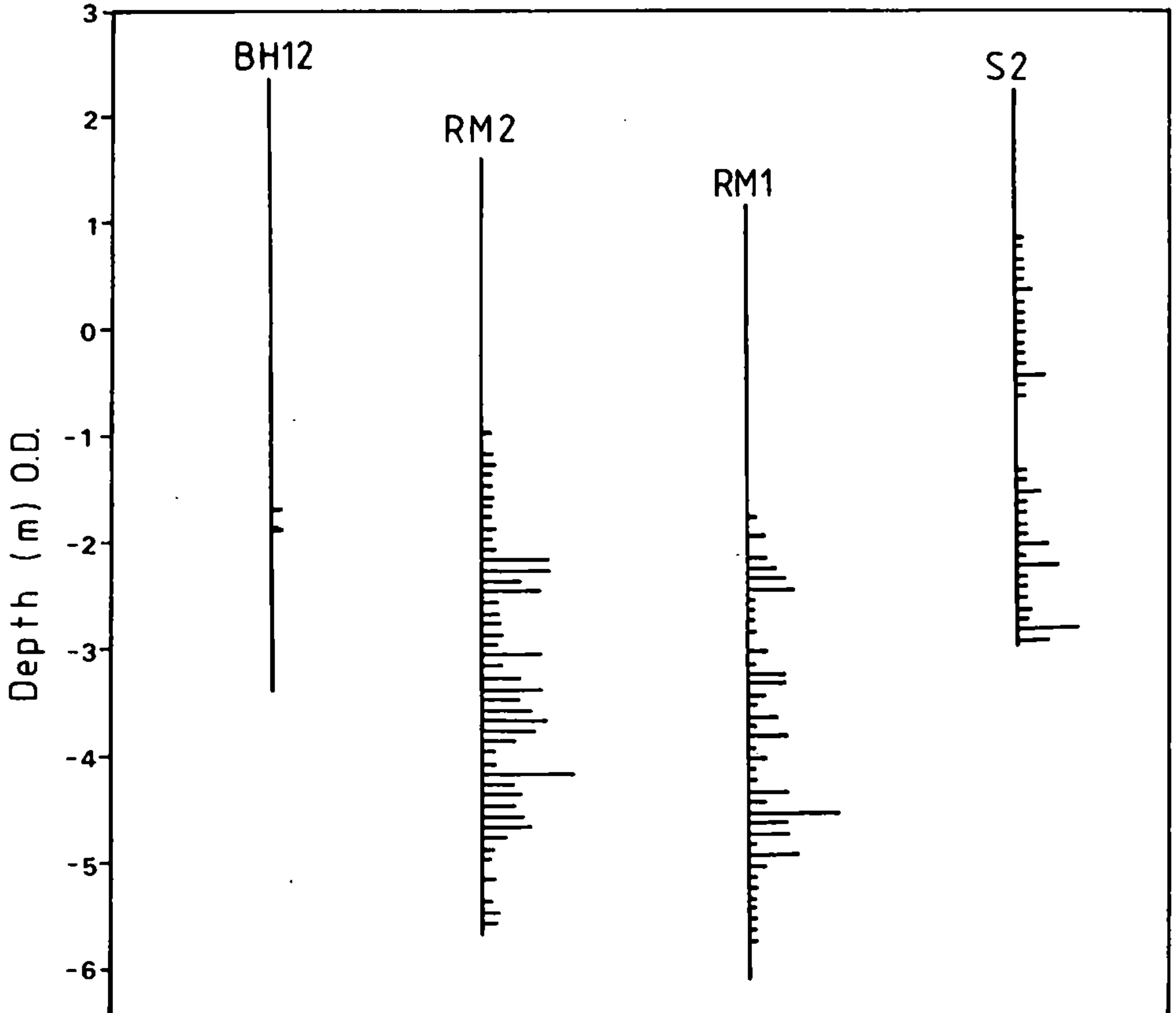

FIG 8.15 Distribution of Cardium edule in BH12, RM2, RM1 and S2

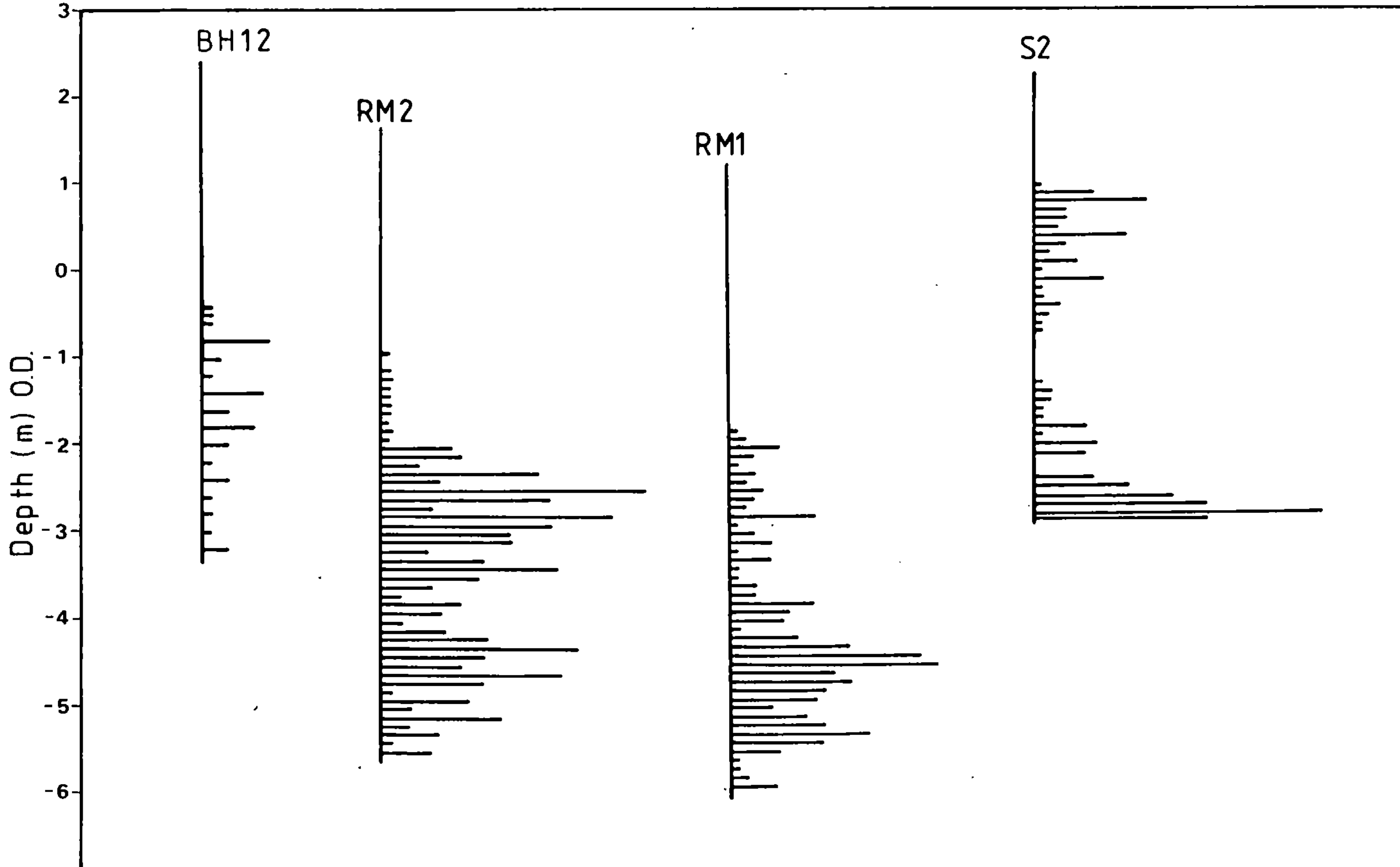

FIG 8.16 Distribution of <u>Macoma balthica</u> in BH12, RM2, RM1 and S2

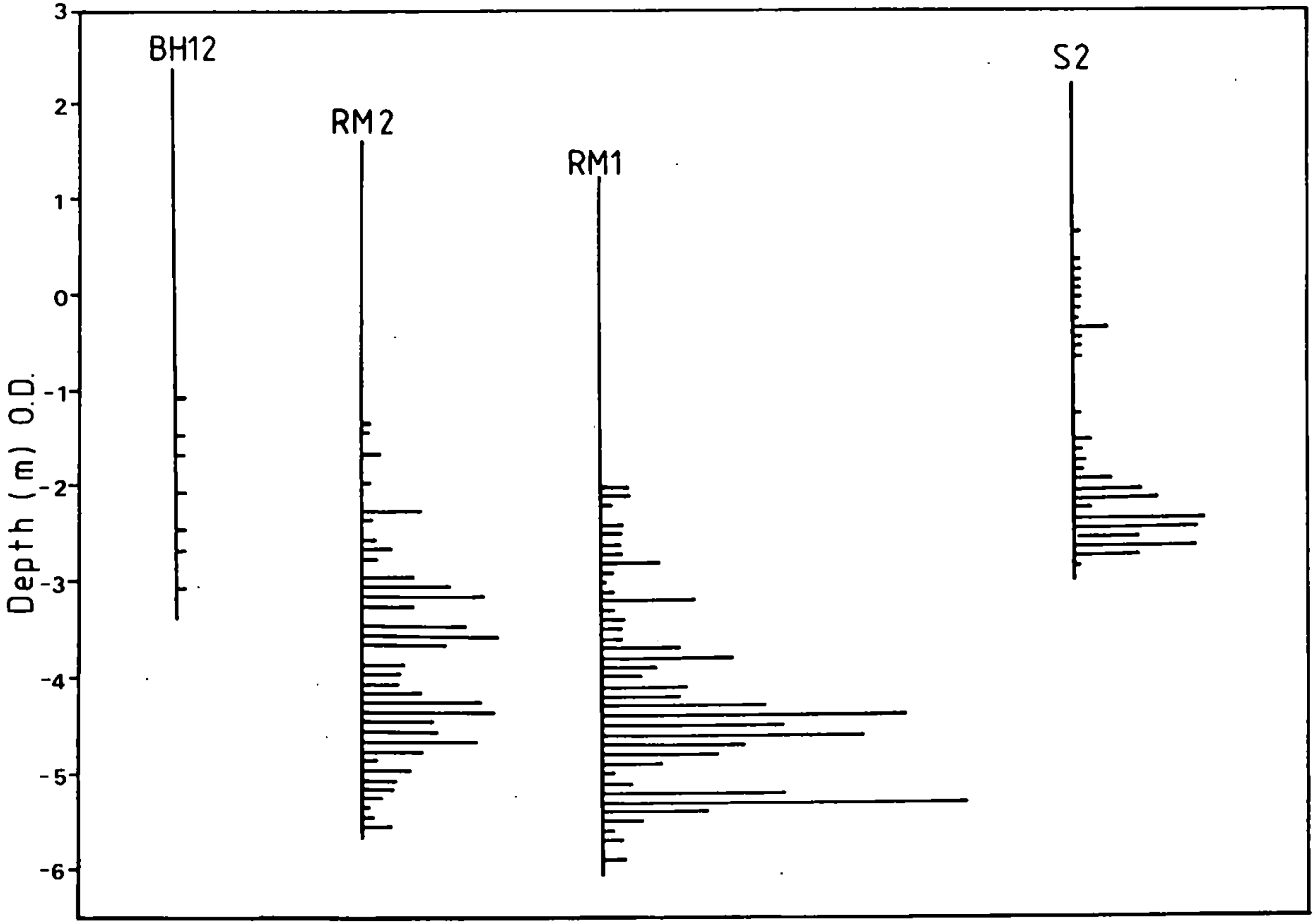

FIG 8.17 Distribution of Rissoa parva in BH12, RM2, RM1 and S2

Starting at the northern part of the study area, at Sequer's Bridge, matching sediments in SB2 appear to be about 0.5m higher than those from SB1 (see figure 8.3). They are predominantly sand in their upper horizons overlying layers of gravel and sand. SB1 has an organic unit overlying a tough gravel-silt unit at the base of the core whereas SB2 has a unit of sandy-gravel rather than the organic unit. The radiocarbon dating of the organic units near the base of the core at c. 0m OD in SB1 suggests that units in both these cores are mostly younger than 2000 years old. The sediments from SB2 and SB1 have some similarities with those recovered from BH6 (figure 8.4); the organic unit in SB1 occurs at c.0.5m lower than a much thicker organic layer in BH6. Diatoms in SB2 can be compared with those in BH6 at approximately 0.5m lower; in particular the diatoms *Cocconeis placentula* (Figure 8.8) and *Melosira granulata* (Figure 8.11) peak at c. 0.5m lower in BH6 then SB2. Below 2m OD in BH6, the diatoms obtained from organic units indicate more marine conditions (see figure 5.4 in Chapter 5); these units are absent in SB1 and SB2. Although the organic unit is present in SB2 it does not have a very large brackish or marine diatom population; this may be because it was on the edge of the organic-forming environment.

The sediments in SB2 and SB1 have fewer gravels than BH1 (figure 8.3) although they both have sand and gravel layers with low silt and clay content. There is no fine sand or silt-sand unit at the surface at BH1 as at many other sampling locations, but BH1 does have a tough gravel unit at the base, as seen in SB1. BH4 (figure 8.3) can be compared more to BH6 than to SB1 and SB2 as it has mainly fine sand and silt in the top 3m and a thin organic unit containing wood fragments between 3.6-3.8m depth (c. 0m OD). These overlie c. 1.5m of gravels that can be compared to those in BH1. The uppermost 1.5m of sediment from BH4 was lost during drilling but was mainly of gravels and thus comparable to the gravels throughout BH1.

The deposits from Sheepham valley (figure 8.4) are comparable to those from BH6 and a radiocarbon date from A4 is useful in correlating the sediments. Generally all the five cores have very fine sediments of sand and silt and clay overlying organic deposits and some gravels. A4 has the finest units of all. The very tough silt-sand-gravel unit at the base in the A1-4 cores is probably very close to bedrock as the drilling equipment could not penetrate this layer. It contained some large rounded and angular gravel (except at A4) in a silt matrix. It is comparable to that also recorded at sites SB1 and BH1 and may indicate the bottom of the channel. Diatoms were present in this horizon, as shown in the analysis of sediments from core A3, suggesting that it is not only bedrock or head but does include sediments that have been worked by fluvial action. A mainly fresh-brackish flora (including *Fragilaria* spp. and *Navicula rotaena*) is present with a slight marine influence shown by the presence of *Melosira sulcata*.

The sediments from A3 were mainly derived from the slate outcrops whereas those in the main channel have a higher granitic component. Diatom correlations can be seen between BH6 and A3 on the basis of the distribution of *Melosira sulcata* (Figure 8.12), the presence of this marine-intertidal diatom suggests an incursion of marine water in the lower sediments recovered from A3. There is some similarity between the distribution of *Synedra pulchella* in A3 and SB2 (figure 8.14). Correlations can also be drawn between SB2 and A3 based on the presence of the diatom *Cymbella sinuata* between 2m to -1m OD in A3 and c. 4m to 1m OD in SB2 (figure 8.9) and *Achnanthes microcephala* at 3m in SB2 and 0.5m in A3 (figure 8.7). Thus sediments from SB2 may be between 2-3m higher than equivalent units in A3. The species *Navicula peregrina* is present in SB2 and BH6 but in A3 is replaced by *Navicula avenacea* (figure 8.13). Both are brackish water species, and thus similar conditions occurred in the SB2-BH6-A3 area.

Ignoring core BH1 for the moment, cores BH6 and BH11 (figure 8.5) appear similar over a distance of 0.5km, with deposits occurring 2m higher at BH6 than BH11. Both have a fine silt-clay horizon at the surface although BH11 does not have an organic layer. Both have lower gravels although those in BH11 include some mollusc shell fragments. The shells may have been swept into this area as there are few whole individuals in comparison with the other cores that contained shells and fragments. Correlations are based on the presence of the diatoms *Fragilaria construens* (figure 8.10), *Melosira granulata* (figure 8.11) and *Melosira sulcata* (figure 8.12). The summary M-B-F diatom diagrams (see figures 5.4 and 5.5 in Chapter 5) also support this with very high percentages of fresh water diatoms in the top layers and a gradual increase in the brackish and marine influence in the lower sediments.

Core BH1 (figure 8.3) consists mainly of sand-gravels and is difficult to correlate with many of the other sediments discussed so far; however deposits in BH7 below 1.5m OD also contain more than 40% gravel (figure 8.5) and core BH4 (figure 8.3) has gravels below c. -1m OD. These coarser sediments may suggest that a different system was operating in the middle of the floodplain or that the deposits are of a different period of floodplain construction, and were deposited as localised flood or point-bar sediments. It is possible that the material in BH7, being near the valley sides, represents an old terrace deposit. The top 1m of sediment from BH7 is a fine silt-clay as seen in the cores towards Sequer's Bridge.

Moving downstream, an upper fine layer also occurs at locations BH9, BH11, BH12 and RM1-4 (figures 8.5 and 8.6); these all show high (12-17%) clay fractions. Further correlations are provided by the gravel units in BH7 which can be equated to sediments c. 1-2m lower in BH9 and in BH11.

Core BH9 has 2 metres of sand and silt overlying sandy-gravel horizons and is comparable to BH4. Like BH4 the surface sediments could not be retained because they were waterlogged gravels. Units in core BH9 appear similar to those in BH11 on the basis of sediment size (figure 8.5); sediments containing 25% gravel in BH9 match sediments 2m lower in BH11 but at the same level in BH12. Both BH11 and BH12 have high silt and clay percentages in their upper horizons grading into sand and sand-gravel layers followed by shelly sandy-gravels. Towards the base of BH11 the sediment is mainly a shelly silt whereas in BH12 the distribution of sand and silt is more even. It may be that the sediments from BH11 represent an old channel or deepening as BH11 occurs in the centre of the floodplain whereas BH12 is towards the side of the valley.

The upper layers from core BH12 are similar to those from RM4, RM3 and RM2 (figures 8.5 and 8.6) in that they all have sand and silt horizons overlying gravels with occasional organic material. These overlie shelly sands or silts with the exception of RM4 where sediment was not obtained from below -2m OD. The shell horizons in RM3 are about 1.5m lower than those in BH11; those in RM2 at approximately 1m higher than BH11 and in RM1 at about the same level, possibly because of local differences in the tidal range. At the time of deposition of these sediments, the area probably resembled a wide tidal flat environment as seen in the lower valley today.

Sediments from core BH12 would appear to be c. 1.5m higher than those from RM2 based on the presence and distribution of the molluscs *Hydrobia ulvae, H. ventrosa*, *Macoma balthica* and *Rissoa parva* (figures 8.16 and 8.17 and see also figure 6.5 in Chapter 6), although the actual numbers of individuals in RM2 are higher than BH12. Thus it appears there is a difference of 1.5-2m in altitude over a distance of c. 800 metres between the two drilling sites because of the tidal range and the gradient of the river. The sediments in core BH12 at these levels appear to have a higher percentage of gravel than those in RM2 which is composed of silty-sands. This may be because of a more fluvial environment at site BH12 and more estuarine conditions in the RM core area.

Cores RM2 and RM1 are similar due to the distribution of *Hydrobia ulvae, Hydrobia ventrosa*, *Cardium edule* (figure 8.15), *Macoma balthica* (figure 8.16) and *Rissoa parva* (figure 8.17) and also because the peaks in species and changes in sediment type appear at the same altitude relative to OD.

The cores obtained from S1 and S2 (figure 8.6) are very similar; shell fragments occur at the same level and both have a clay-silt horizon between 1-2m OD. These grade into silts and then silty gravels with only minor variations between them. With depth, S2 has more sand and S2 more silt. The peak in *Hydrobia ulvae* and *Hydrobia ventrosa* at c. -2.8m OD in cores RM1 and RM2 is probably equal to the peak in S2 at the same level (see figure 6.5 in chapter 6); and similarly for the peak in *Macoma balthica* (figure 8.16). The sediments from RM2-1 and S1-2 are comparable below c. -1m OD as they are mostly gravels and sands, with more silty-gravel units towards the base of RM2 and S1. Above this, S2 and S1 are different from the RM1-4 cores both in sediment type and molluscan fauna and indicate that sedimentation in S1 and S2 continued in a marine environment whereas RM1 and RM2 became predominantly fluvial. This may be connected with the draining and embanking of the land on the eastern side of the river changing the environmental status of the RM1-4 sites. Alternatively, cores S2 and S1 may once have had sediments equivalent to those of the RM cores, but which have been subsequently eroded and redeposited as newer horizons. The historical records show that the harbour at Oldaport has silted up in recent times thus suggesting the S1 and S2 units are fairly recent and represent contemporary deposition in the Erme channel.

8.4 The Main Sediment Types Recorded in the Lower Erme Valley

It can be suggested that many of the cores have common sediment bands and dip downstream in relation to the gradient of the river and the tidal influence. The sediments can be sorted into 11 basic groups on their differing properties. There are variations in these sediments between locations but generally the main units found are shown in figures 8.18-8.20 and can be described as follows:

1) The upper fine silts can be seen in all the cores except BH1 and RM1, which have a high gravel content, SB2 which consists of sand and BH4 and BH9 where the sediments could not be collected and were waterlogged gravels. Various amounts of silt, sand and clay are present, up to 17% clay in some samples. The diatom analysis indicates generally a freshwater flora, except in the salt marsh cores S1 and S2 which are predominantly marine.

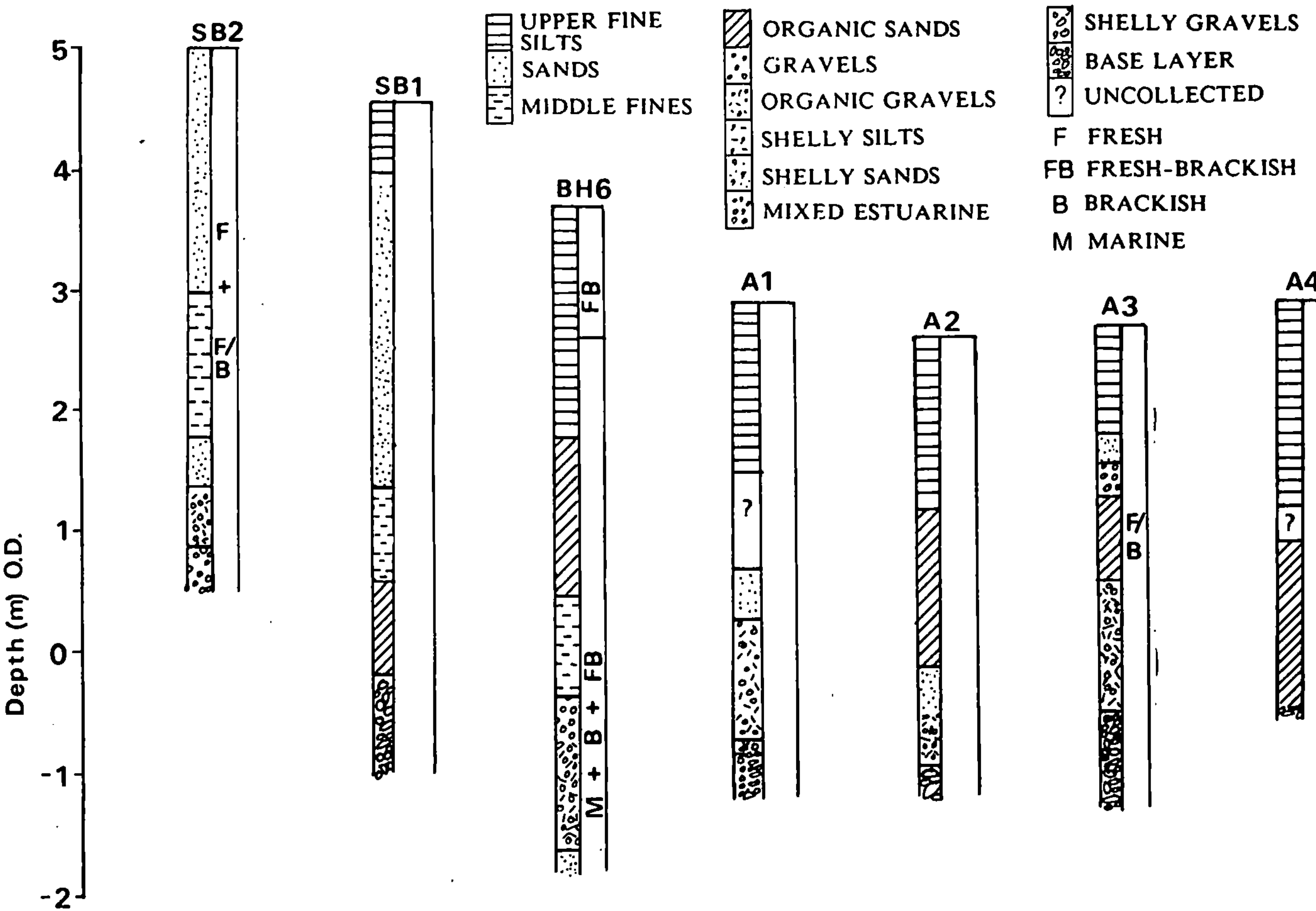

FIG 8.18 Summary of the main sediment types in SB1, SB2, BH6, A1-4

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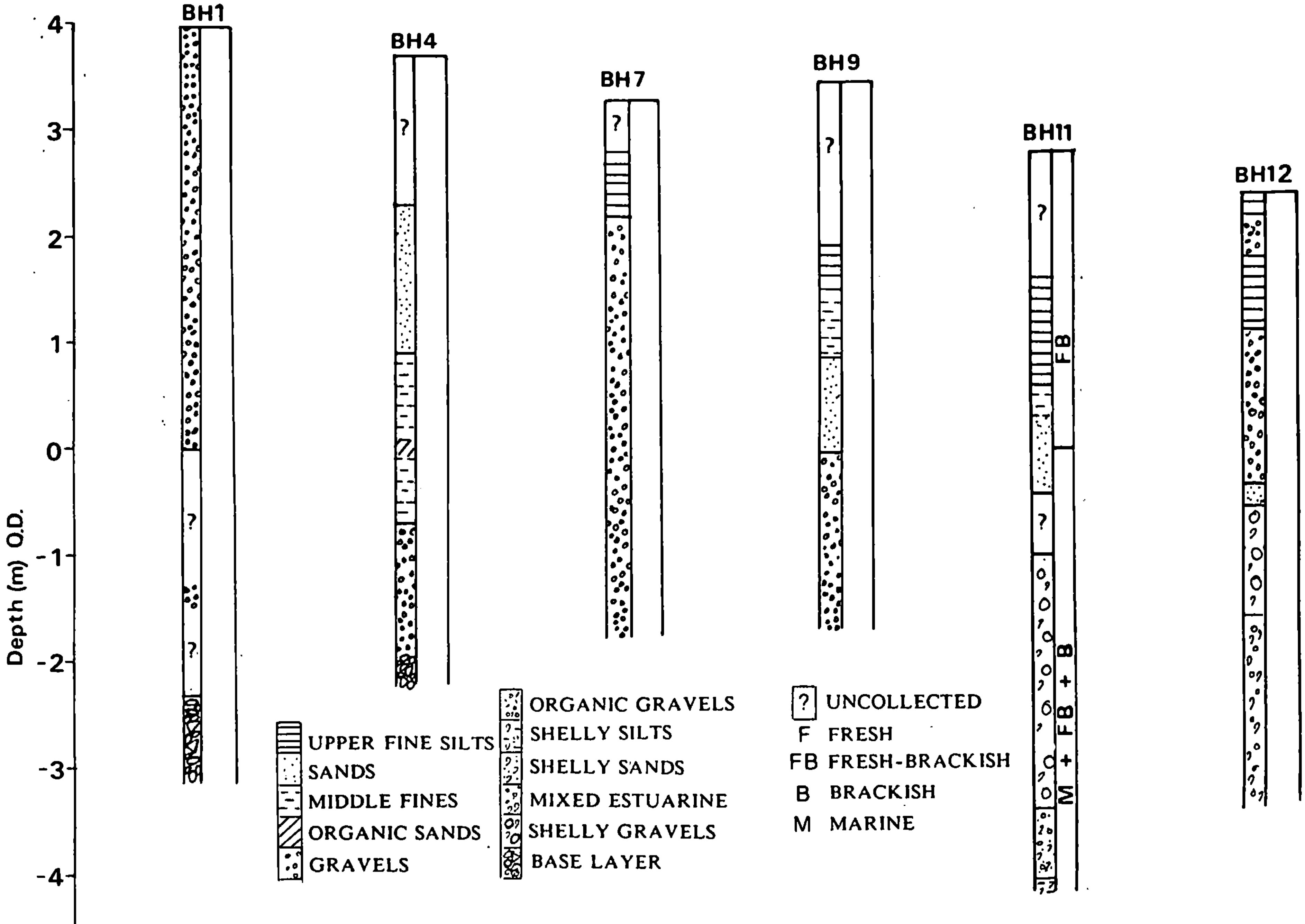

FIG 8.19 Summary of the main sediment types in BH1,4,7,9,11,12

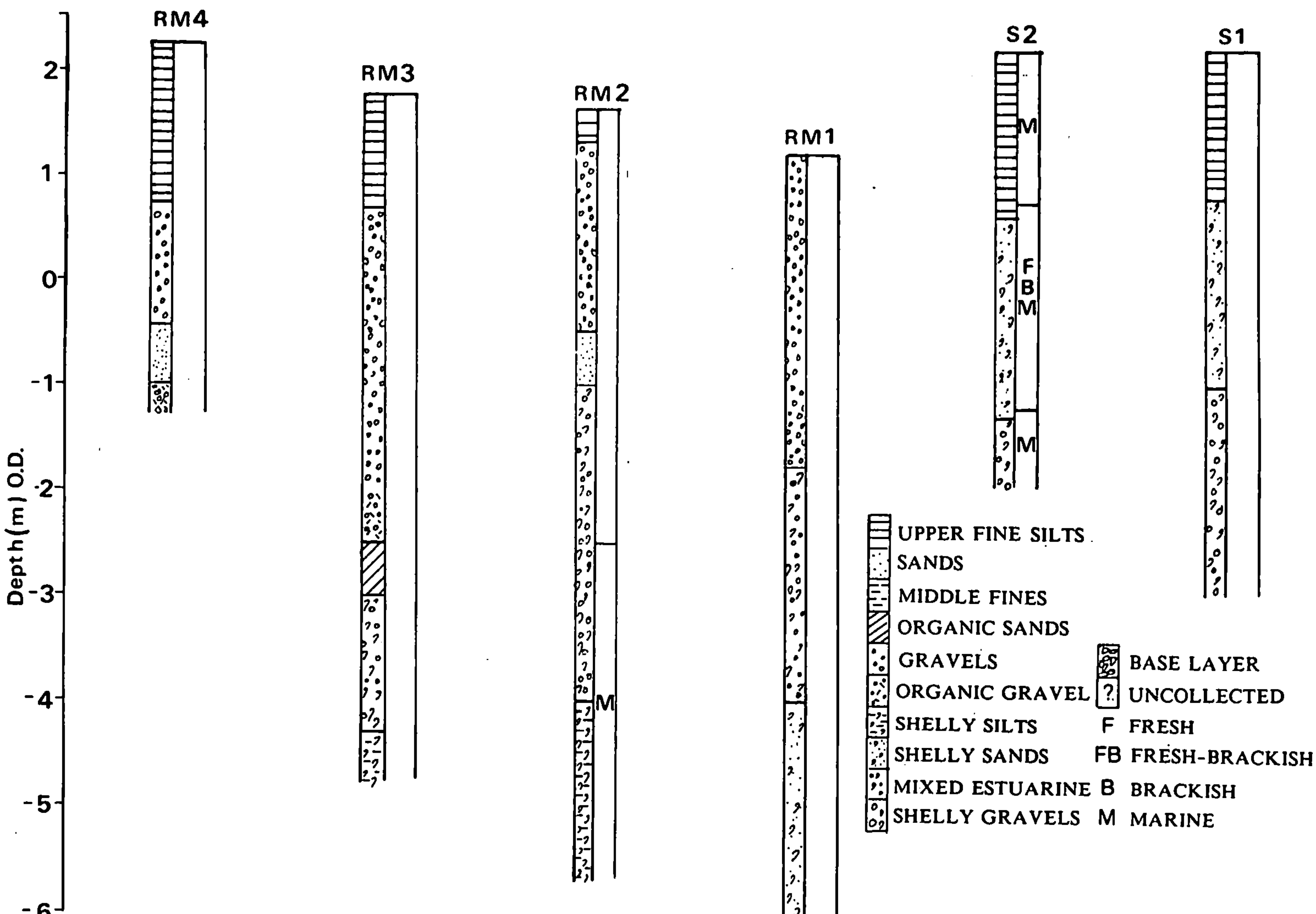

FIG 8.20 Summary of the main sediment types in RM1-4. S1. S2

The salt marsh sediments however are not considered to be a direct equivalent of the deposits upstream because of their more dynamic coastal situation.

2) The middle 'fine' units can be subdivided into **sands**, **organic sands** and **'middle fines'** which are generally of silt but include some sand layers. Some of the sites have more than one of these 'middle' units and because there is no definite order of deposition it is suggested that they are all broadly contemporaneous. The sands are present in SB2, SB1, BH4, BH9 and BH11, the organic sands in SB1, BH6, A2-A4 and to a limited extent in BH4, and the middle silty-sands in SB2, SB1, BH6, BH4, BH9, and BH11. These are probably equivalent in age as they occur at a similar location and depth OD. Diatoms indicate they were deposited in a brackish environment, becoming more freshwater towards Sequer's Bridge and more intertidal at the Park Driving Bridge. This may suggest a ponding and mixing environment where the salt water met the river.

3) Middle gravels are seen in varying thicknesses in many of the cores; they sometimes contain organic material in the form of wood fragments and twigs, and have therefore been sub-divided into **gravels** and **organic gravels**. The gravels are present in BH1, BH7, and RM4-1, to a lesser extent in BH4, BH9 and BH12 and in a limited amount in BH6. The organic gravels occur mainly in the upper part of the study area in cores SB2, BH6 and A1-A3 although some were found in RM4 and RM3. They are considered to be two distinct units as the gravels sometimes form thick deposits as in the case of BH1, whereas the organic gravels are more variable and occur below the middle sands, organic sands and fines. The gravels from RM2 were subject to diatom analysis but the diatom frustules were not well preserved and difficult to count. Diatom analysis of the organic gravels in BH6 and A3 showed brackish-marine and fresh-brackish environments respectively.

4) Base Units of large angular and rounded granite and slate clasts in a tough silt matrix were recovered from SB2, SB1, A1-3, BH1 and BH4 and a tough

silt horizon in A4. It is suggested that this layer may indicate proximity to bedrock since the drill could not penetrate the sediments any further. The layer may be a tough river gravel overlying bedrock or a mixture of old head deposits and river sediments and weathered bedrock. The presence of diatoms suggests there has been some fluvial working of these sediments.

5) Lower estuarine sediments were characterised by the inclusion of molluscan shell fragments. These sediments have been subdivided into **shelly silts, shelly sands, shelly gravels** and **mixed shelly deposits**. The shelly silts occur at the base of cores RM3, RM2 and BH11 and the shelly sands at the base of RM1 and higher in S1 and S2; these two units represent the deepest sediments recovered from the buried channel of the Erme. The shelly gravels are present only in BH11 and BH12 and may be a mixture of fluvial and marine sediments. The mixed shelly deposits occur below the shelly gravels of BH11 and BH12 and above the shelly silts and sands of RM3, RM2, RM1 and BH11. They also occur in S2 and S1 below the shelly sands. This suggests that the sands from S1 and S2 are not equivalent to those from RM1, especially in view of the altitudinal and site differences between the two locations. The shelly silts contain predominantly marine diatoms, the sands from S2 a mixture of fresh, brackish and marine diatoms, the gravels in BH11 had a mainly marine and brackish diatom flora and the mixed deposits were predominantly marine in S2 and RM2.

Deposits from the tributary valley seem to have a higher percentage of slate derived clasts whereas those in the main valley have a mixture of granitic and slate clasts. Since there is little correlation between changes in sediment size and mineral content, the sediments from the tributary valley are considered comparable to those from the main valley and have been placed in the same sediment groupings.

The depth of drilling was limited by the number of flights that could be extracted from the Erme channel infill and by resistant layers of sediment or bedrock. It is possible that granitic boulders as described around Ivybridge

(Gilbertson and Sims 1974) and Ermington (Perkins 1974) also occur in the channel infill in the area of study. Around the Sequer's Bridge area, the cores are shallower than those downstream and thus drilling may have been obstructed by large boulders. It is unlikely, however, that they are present in the smaller tributary valley.

8.5 Age of Sediment

Combining the results of the radiocarbon analysis and sediment correlations between cores, it is possible to tentatively assign dates for sediments from the sites in the lower valley. A correlation of the dated sediment from cores BH6, SB1 and A4 in terms of radiocarbon age is shown in figure 8.21.

Deposits in SB1 and BH6 at around 0.5m OD are approximately 2000 years old. Those in BH6 can be compared with those from BH11 at c. -1.3m and BH11 can be matched with those in BH9 at c. 0.7m. It is likely that similar aged deposits occur at approximately -0.6m in BH12, and by comparing BH12 with RM2 at about -1.3--1.6m in RM2 and -1.3m in RM1 and -1.3m in S2 (comparing RM1, RM2 with S2, and BH11 with S2). Links between SB1, BH6 and the A sequence can be made although corresponding dates are at a lower level (c.1m) in A4 than BH6. Most of the sediment in the Sheepham valley has been deposited in the last 1000 years or so.

It is more difficult to trace the date of 1185 BP in BH6 down valley. It is likely to be around 1-0.5m OD in BH11 and 1-1.5m OD in BH12, possibly 1m OD in RM2 and 0.8m in S2 (the latter is based on tentative links between S2 and BH6).

These correlations would suggest the gravel units found at depth in some of the cores are older than 2000 years ago, whereas upper fine sediments are less than 1000 years old. The middle fine units including the organic layer are of 1000-2000 years old, with the other fine sand units being slightly older or younger. The organic gravels must be older than 2000 years as they occur

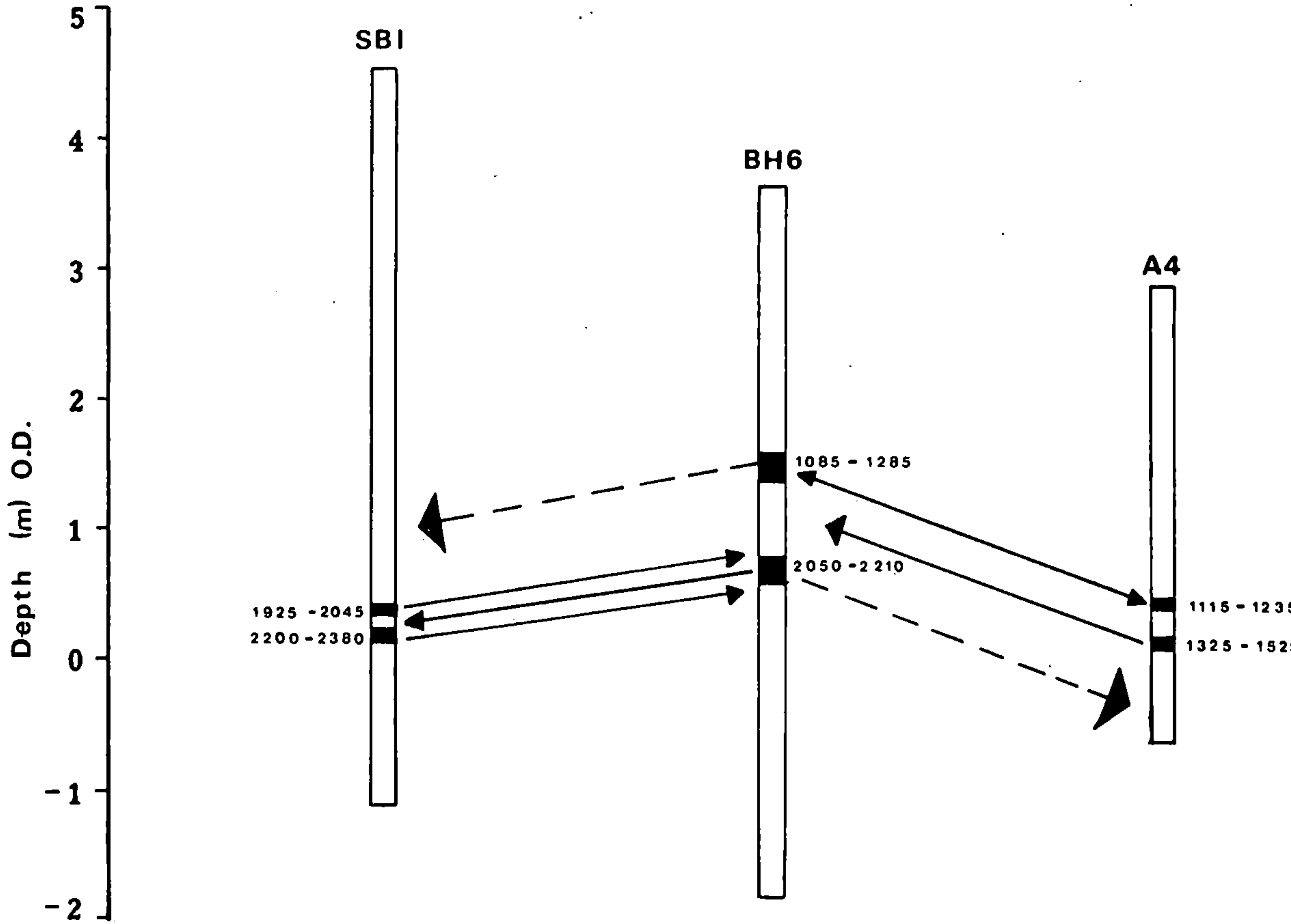

FIG 8.21 Correlation between SB1, BH6 and A4 based on radiocarbon analysis

below the organic deposits. The long gravel sequences in BH1 and BH7 are difficult to date and may represent deposition over a long time span. The evidence suggests that most of the estuarine deposits were deposited prior to 2000 years ago. No age can be suggested for the base unit.

8.6 A History of the Erme Valley

The development of the lower Erme valley in the Flandrian will now be discussed with some reference to its earlier evolution during the Quaternary.

It is difficult to relate the formation of the lower river valley to early events on the high moor, such as the creation of planation surfaces, and it is generally outside the scope of this study. The effect of periglacial action in shaping the Dartmoor landscape may be more important than planation, creating solifluction and cryoplanation terraces rather than shorelines. Evidence for the superimposition of a Tertiary drainage pattern determining the present day river course can be neither substantiated or disproved, neither can the views presented by Worth (1898) and Kellaway *et al.* (1975) that these buried rock channels were cut by glacial ice. It can be deduced, however, that the Erme actually has a buried channel grading to a lower level than at present, cut in the Pleistocene at a time of low sea level.

Durrance (1975) considered the buried channels of the Erme, Teign, the upper channels of the Exe and Taw-Torridge to probably have been cut during the Devensian. As the raised wave cut platform extends along the sides of the Erme, the channel must predate the last interglacial and is thus older than Durrance suggested. Similarly, Guilcher (1969) considered that river courses on the French side of the Channel were cut before the Normannian (≡Flandrian) transgression since in Brittany several beaches of Lower Normannian age (≡Eemian ≡Ipswichian) have been discovered inside them (Guilcher 1948).

This study is concerned rather with events affecting the Erme in more recent times; these events include the state of the river in the last cold stage, the following Flandrian rise in sea level and the most recent fluvial input to the channel. The data obtained from the Erme valley will be used to discuss the development of the Erme from the Devensian to the present day. A summary of events that have shaped the Erme valley is presented in table 8.1. This table relates the sediments recovered and geomorphological characteristics of the Erme valley to an approximate timescale, the vegetation and mining status of Dartmoor, sea level and other events in south-west England during the Late Quaternary.

8.6.1 The Devensian

At the time of the maximum extent of ice over Northern Europe, sea levels around the west coast of Britain were at least 50m lower than today (Heyworth *et al.* 1985). Even in Devensian interstadials, Harmon *et al.* (1983) suggested sea levels were probably not above -30--40m (Campbell and Shakesby 1986). During the initial exploration of the Erme valley augering reached a depth of c. -14m OD near the mouth of the Erme estuary opposite the lime kiln (see figure 4.2 in chapter 4). This was most probably a tough gravel or boulder layer rather than bedrock and it can be assumed that rock head in the estuary is actually deeper than this when compared to other studies of rivers in the South West and indeed, McFarlane (1955) detected the channel to be -29.2m near Owens Point (see Figure 2.4) and 21-27m (70-88ft) deep between Saltercrease and Mothecombe. McFarlane failed to find any evidence of the channel greater than one mile from the shore and he therefore suggested that at the time the flat bottomed channel formed the sea shore was not far off, whereas in North Devon, he considered the shoreline to be 8miles out into Bideford Bay. The age of the drowned shorelines around the coastline of south-west England is debatable and estimates have ranged from Miocene (Donovan and Stride 1975) to Late Quaternary (Sissons 1979).

During the Devensian, severe periglaciation on Dartmoor, frost shattering of the granite and lots of snow suggest that the Erme had a higher discharge and load than today. These conditions may have also formed the large

Period	Stage	Age	Pollen Zone	The Erme	South West	Sea Level	Stage	Vegetation of Dartmoor	Mining	Climate
				Little change in channel position		+2mm/year			China Clay	
		200 500	VIII	Deposition of fine alluvial sediments and some gravels	Siltation of river mouths due to tinning		Medi-eval	Total Clearance	Tin Mining	Mixed
		1000		Marshland in area of Park Driving Bridge	Sand dune formation on North Cornish coast		Saxon Roman	1204AD-legal permission for forest clearance 800-1000 AD cultivation		1-2 C > today
		2000	VIIb	Deposition of Lower organic gravels and sands	Sediment deposition in river channels of the South West Peninsula	Transgressive episode	Iron	Summer grazing		Wetter
							Mid - Late Bronze			Deterioration Continentle
		3000		Deposition of shelly units at sites BH12 RM1-4 and S1-2			Early Bronze	Tree clearance and spread of bracken	Tin Mining	2-3 C > today
	FLANDRIAN	4000				Sea near present levels	Neo-lithic	Bigger clearings		Slightly > today
		5000 6000	VIIa	Oldest sediments found ?	↑		Meso-lithic	Rowan, bracken and grasses Low activity		Warming
		7000 8000	VI	Sedimentation in lower part of buried channel	Inundation of coast ↕	Collapse of Laurentide Ice sheet	Palaeolithic	Establishment of vegetation Increase in woodland		Warming Bodmin - Elm
QUATERNARY		9000	V					Juniper, birch		
	LATE GLACIAL	10k	IV III II I			Rising seas c. 10mm/year		Open tundra		
	DEVENSIAN	13k		Head and Ivybridge Fan formation Channel incision	Loess and head, tor formation Fremington Deposits Ice Advance?	c.100m< today c.50m < today		Tundra		Periglacial
	5e	120k		Raised wave cut platform	River Taw I.G. deposits Raised platforms	c.8m > today		Interglacial		c.2-3 C>today
		128k		Channel incision in times of low sea level	Older ice advance ?	Oscillating				
TERTIARY	PLIOCENE	200k		Creation of Planation surfaces ?	Planation?	Calabrian sea c.300m >today Higher seas ?				

TABLE 8.1 Relation of Sediments from the Erme to Events in the South West During the Quaternary

boulder bed at Ivybridge, termed an 'alluvial fan' by Gilbertson and Sims (1974). This bed is predominantly of large granitic and calc-flinta boulders of up to 3m diameter. There is no dating evidence to suggest an age for this unit, although Gilbertson and Sims thought it could be 'Wolstonian'. It is best however to avoid assigning stage names when there is so much doubt about the validity of a Wolstonian glaciation, and the fact that the Quaternary record is more complex than once realised. There is no reason why the boulder bed could not be Devensian or even Early Flandrian in age. Similar boulder deposits were also described in the Teign gorge by Somervail (1901a,b) and it could be suggested that other rivers draining Dartmoor also have such features.

Downstream at Ermington, large rounded boulders of granite of c. 1m diameter can be seen in the walls of houses. It is possible that these were dragged up from the river bed rather than transported from Ivybridge. Since the village is built on the western side of the valley, the boulders may have been found whilst digging foundations into the terrace slopes. If this is the case then the discharge of the River Erme must have been far higher than today and a periglacial climate would seem most favourable.

During this periglacial episode head deposits formed in the valley. The best exposures of head are seen at the coast where they are derived from the Dartmouth Slates and form platy sediments to 3-4m thick. In cross section they are seen as the typical cliff profile of South Devon, that is of head forming a concave slope overlying a raised wave cut platform (as shown in figure 2.2). Some have suggested the head deposits of the South West have loess in their upper layers as described on the Lizard peninsula (Coombe *et al.* 1956) and West Cornwall (Scourse 1987). Roberts (1985) alternatively suggested that in some cases the finer head may be a weathering product derived *in situ*. The presence of loess in the Erme head deposits has not been proved, although it has not been excluded as a possibility. These head deposits overlie a raised wave cut platform which, around the south coast of England has been conventionally assigned to the last interglacial. Recent dating of raised beach deposits overlying wave cut platforms has suggested that beaches of different ages (stage 5e and 7 of the deep sea record) occur at similar altitudes along the south coast. No raised beach deposits have been found overlying this wave cut platform in the vicinity of the River Erme.

All the sediments examined from the channel of the Erme are younger than Devensian in age, although they may include reworked head deposits from Dartmoor and valley side slopes. All the sediments are derived from local bedrock, and do not include any erratic material that could be used as evidence for glaciation of the area.

8.6.2 The End of the Devensian (10,000) to 6,000 Years BP

Prior to 6000 years ago, the rising sea level is the most important event in the lower Erme valley. Between 18,000 and 6000 years ago, Pirazzoli (1985) suggested that sea levels were rising at rates often greater than 10mm per year. None of the sediments recovered from the channel have been positively identified as being of this age. By considering the environment in Start Bay it is possible to envisage the type of situation that would have been affecting the River Erme. Lees (1975) dated some sediments from Start Bay at -20m OD to 8,108±60 BP. At this time the shoreline was further out in the bay and bordered by lagoons, salt marshes and rivers. Thus the Erme would have been grading to a sea level lower than today although McFarlane considered the shoreline to be near the present coastline.

8.6.3 6000-2000 Years BP

Although most of the Flandrian sea level rise is assumed to have occurred by 6000 years ago there is evidence to suggest that since then sea level has still continued to rise slowly. At Newlyn sea level has been dated to -6m chart datum (where chart datum is the lowest astronomical tide) at 4000 years ago, -3.5m CD at 3000 years ago, and -2m 2000 years ago (Thomas 1985). Since sediment has been recovered from -6m OD it is likely to overlap with this date range, although there will be differences dependent on the tidal regime of the

Erme and depth of water. The lowest units recovered, such as from cores RM1, RM2, BH11 and BH12 may date back to 4000-5000 years BP on this evidence. These sediments are generally the lower estuarine units and possibly some of the middle gravels as described above. It is difficult to define the point of sea level at which these lower sediments from the Erme channel were deposited, and as Devoy (1979) stated all Flandrian sediments must now occur at lower heights than when they were formed because of compaction and compression, thus increasing the problem of defining former sea levels.

After sea level reached near the present day position the Erme was characterised by deposition of both estuarine and fluvial sediments in the study area. Oscillations of sea level as suggested by Mörner (1969) and Fairbridge (1971) may imply multiple layers of fluvial and estuarine units. However, the method used here of extracting sediment in 10 and 20cm layers from boreholes may have destroyed any fine layering. On the whole, for the Erme region, the sediments indicate a straight forward transgressive rise of sea level, becoming more fluvial towards the top of the cores. In the lower study area, cores contain a mixture of estuarine silts, sands and gravels which were probably deposited with rising sea levels. The diatom studies indicate deposition in marine tidal inlets, salt marsh and wide mud and sand flat environments. The molluscan analysis showed an increasing brackish fauna with time, with a change from *Macoma* and *Rissoa* species at depth to *Hydrobia* at higher levels in the estuarine sequences examined in cores RM1, RM2 and S2. In the upper part of the study area brackish-marine sediments overlie a more freshwater horizon as seen towards the base of cores BH6 and BH11, suggesting a transgressive episode.

The fluvial sediments underlying the organic layers, dated to around 2000 years ago, may be related to forest clearance on Dartmoor, which began on a small scale in the Mesolithic, increasing into the Neolithic and the Bronze Age. Forest clearance was not complete until Medieval times, so sediment erosion of the moor, aided by human activities, has acted for the past 5-6000 years. A number of horizons have organic fragments, (the organic gravels), thus supporting the evidence for erosion induced by land clearance. Bronze Age tin streaming may also have contributed to sedimentation in the lower Erme valley.

8.6.4 2000 years BP to the Present

From 2000 years ago the dating of the sediments is less tenuous because of the radiocarbon analysis of the organic layers. At this time a large marshy area existed in the Park Driving Bridge region, extending to the Sheepham Brook tributary valley. The records from study of the tithe maps suggest the marsh extended as far downstream as location RM1. This stagnant water or pond-like feature may represent a transgressive episode of the sea. Parkinson (1981) considered that tidal movements along the Exe were greater in previous centuries and in Roman times may have extended to Exeter. Thus the River Erme may have been meeting a rising sea where conditions were favourable for the 'ponding' of substantial quantities of water during high tides. Differences in freshwater diatom and brackish-marine species over this area may relate to differences in timing of deposition or proximity to the river entering the marsh land. The situation may be compared to the River Exe, studied by Parkinson (1981), where in the higher regions of the estuary, at Clyst St Mary, the present tidal rise is caused by holding back the river water rather than by actual salt water advance. Therefore the author inferred that any 'tidal' flooding of upper marshes in the past would have produced freshwater marsh rather than salt marsh. Similar conditions may have existed in the Erme thus explaining the variable diatom units within the organic deposit.

A regressive episode followed with a deposition of fluvial sediments. This may be because of an increase in siltation in the marsh area rather than an actual fall in sea level, as demonstrated by Ranwell (1974) in the case of the Fal estuary, Cornwall. In the Fal example, there is evidence of a transition from salt marsh to woodland within the last century and this is independent of isostatic and sea level adjustments; marsh formation has extended seawards by 800m in 100 years. Thus the change from marsh to fluvial conditions in the Erme valley may have occurred independently of any sea level changes.

At the time of this marsh phase, the lower valley may have been characterised by estuarine salt marsh and mud flats. Since brackish sediments overlie fluvial sediments at the base of BH11 and BH6 then the lower fluvial gravels from sites further seawards could be dated to before the marsh phase. Alternatively, since in the lower cores, estuarine sediments nowhere overlie any fluvial deposits, the lower fluvial gravels may be younger than 2000 years old and thus equivalent to the upper fine sediments from the current floodplain area. If so, most of the sediments extracted from the Erme will have been deposited in the last 2-3000 years. Erosion of some sediments may have removed evidence of estuarine sediments overlying fluvial deposits.

Fine alluvial sediments were deposited after the marshland episode, at a general rate of 0.2cm/year. Four metres of sediment were deposited in 2000 years at SB1, 2m in 1200 years at BH6 and 2.4m in 1200 years at A4. The upper catchment has been cleared of forest and mined for tin during this time, and thus it is likely that sedimentation was increased as a result. Whether a rate of 0.2cm/year could be attributed to natural erosion is debatable. The channel has been stable in the past 200 years and erosion is unlikely to have been acting at a continuous rate for 2000 years; thus annual rates of deposition will have been higher and lower than this. Current records of river discharge cannot be used to assess the former characteristics of the Erme because of the differences in land use, and as Burrin (1985) stated, contemporary hydrological records have little value in understanding former hydrological and sediment regimes and their relation to floodplain development.

Other studies have suggested that forest clearance and mining activities can influence fluvial processes. For example, Macklin *et al.* (1985) correlated concentrations of heavy metals in the alluvial sediments in the Lox Yeo valley, Somerset with documented 17th-19th century mining and earlier known mining periods. Scourse (1985b) considered the Amble valley, North Cornwall to have silted up because of higher discharge caused by alluvial tin mining. Hazledon and Jarvis (1979) described 0.5-1m of clay overlying sandy limestone gravels in the Windrush valley, Oxfordshire. Wood found between the two deposits was dated to 2660 BP which led the authors to ascribe clay deposition to a rapid increase in forest clearance.

It can be argued that sedimentation in the Erme has been similarly influenced by anthropogenic activities. Deposition of sand and gravel deposits followed the marshland development possibly as a result of further clearance on the moor and the beginning of Medieval tin extraction. As mentioned in chapter 7, legal permission for forest clearance on Dartmoor was given in 1204 (Roberts 1983) although by this stage much of the vegetation cover had already been removed by prehistoric groups. Greeves (1981) noted that the greatest tin production in Devon occurred in the second half of the twelfth century when production overtook that of Cornwall, and thus many of the sediments may be of this age. It is highly probable that later mining during Medieval times will have continued to contribute to sedimentation in the Erme channel and the fine silt units present in the upper horizons of the cores may be related to tinning as records suggest that widespread siltation of the estuaries in the area occurred in the 15th and 16th centuries.

The methods by which sedimentation occurred in the study area can also be discussed. Floodplain formation is generally attributed to lateral accretion by point bar construction and to a much lesser extent by overbank deposition as in the Leopald-Wolman model of 1957. However, in recent years there has been a general opinion that the processes are more complex. Brown (1985) attributed the fine alluvial deposits of many rivers as evidence of long term overbank deposition consequent on human induced accelerated erosion in the Late Flandrian. Burrin and Scaife (1984) and Burrin (1985) found the most important processes for the Rivers Ouse and Cuckmere were solifluction and colluviation transporting loess from the slopes to valley bottoms where it was reworked by rivers and deposited to form the floodplains. They considered that development of silty braided channels does away with the need for overbank deposition. In the case of the River Erme, the combined effects of forest clearance and tin mining on Dartmoor, the 'upland' nature of the catchment and the absence of thick loessic silts suggest that much of the upper sediment in the Erme will have accumulated more by overbank deposition rather than other processes. Lambert and Walling (1987) attempted to measure contemporary rates of floodplain sedimentation in the River Culm in Devon. They found that coarsest sediment is deposited more easily as overbank deposits, but high clay amounts in overbank sediments were attributed to clay deposited as aggregates. This may explain the high proportion of clay found at some sites, such as in the upper horizons of BH7.

There is no evidence of incorporation of loess in the fluvial sediments, in spite of descriptions of loess on Dartmoor and in the head of South Devon (for example Mottershead 1971). Burrin and Scaife (1984) noted that although there is a significant contribution of loess to valley sediments in south-east England, because the significance of loess decreases westwards (as described by Catt 1977) the proportion of locally derived material will increase in the same direction (Jones 1981). This is certainly true in the case of the Erme, where all the sediments are derived from local sources of bedrock.

Burrin (1985) showed there has been little floodplain reworking or valley development in the past 500 years in many of the lowland valleys in Britain, and in the case of the Wealden Ouse, the past 200 years. He therefore suggested that the Wealden floodplains had been formed during an earlier episode of Holocene alluviation. Although the rivers draining Dartmoor have different characteristics to the low lying catchments in south-east England, the position of the River Erme has changed little since the Ordnance Survey map of the early 1800's, suggesting that in the past 200 years at least, conditions have remained stable. This can be compared with East Devon where Hooke (1977) found that rivers have generally become more sinuous in the past 100-150 years.

Drainage of the land in historic time has meant considerable silting of the estuary towards Mothecombe. The salt marsh has continued to develop since the reclaimed marsh on the opposite bank of the river was drained and embanked, resulting in the former being at a lower level. The causeways at Clyng Mill and Mothecombe are no longer passable at low tide.

8.6.5 The Present Day

River activity today is generally much lower as indicated by the discharge records and Ordnance Survey maps. However, little is known about contemporary rates of deposition for rivers in Britain, as noted by Lambert and Walling (1987).

The effect of current farming and landuse practises on the supply of sediment to the Erme today are unknown. Embankment of the land and draining the farmland with ditches has confined the river flow. Flooding occurs in the lower valley in the salt marsh area and in the Park Driving Bridge region inundating some areas for a few months or so at a time in spite of the drainage ditches in the area. This is probably because of spring tides coinciding with higher rainfall, greater river discharge and storm surges. Active salt marsh growth is occurring, where generally plant species thrive to MHWST. As sea level is still believed to be rising at a rate of around 2.25mm/year (Thomas 1985) this is undoubtedly influencing the salt marsh growth. Thus the lower part of the Erme valley in the salt marsh region is less stable than the drained floodplain area where the channel position remains unchanged since the production of the tithe maps in the early nineteenth century. Sediment transported by the river may be deposited in the salt marsh areas or carried out to sea rather than deposited as overbank deposits in the upper floodplain area.

8.7 Correlations with Other Sites in the South-West of England

There is little investigation of sediments filling the channels of other rivers in the South West with which to compare the Erme. The 'stiff red clay with granitic boulders' recovered in the nineteenth century engineering works cannot be compared with sediments from the Erme since drilling did not reach bedrock in the main channel.

The buried channel fill in the upper estuarine reaches of the Exe and Teign as described by Durrance (1969, 1971) may be considered comparable to that in the Erme. The channels at both locations contained silty-clay or silt and fine sand overlying gravels. A thin peat horizon was found in the silt from the Teign channel although it has not been dated. Durrance found bedrock at -10m OD in the Exe at Exeter and in the Teign near Newton Abbott and since Codrington also reported rock at -9.5m in the channel of the Dart at Totnes, the depth to bedrock in the Erme channel may be about 10m in the Sequer's Bridge area. The initial drilling programme in the Erme valley reached depths of around 8m, although it is unclear whether the layer reached was bedrock or a resistant gravel horizon.

Durrance recognised other levels of channelling, at -14m and -22.5m OD, at the mouths of the Rivers Exe and Teign. He thus considered that the deeper channels of these two rivers are not as extensively developed as the younger channels since the deeper channels do not extend as far upstream. It is of course possible that the Erme has more than one level of channelling at the mouth, and it is tempting to correlate the -14m level found by Durrance with that reached at the lime kiln near the mouth of the Erme in the initial drilling programme. However, further study of the channel depth at the mouth of the Erme is needed before definite correlations with the Exe and Teign can be made.

Scourse (1985b) described a mixture of silts, clays and intercalated peats from 4.6m depth in the Amble valley in West Cornwall. Pollen analysis of the peat indicated deposition in temperate conditions of the Late Flandrian and the more intertidal nature of the sediment makes it comparable to the cores obtained from the lower Erme field area.

It can be suggested that the Erme is a fairly typical river of the south-west of England. The sediments analysed are of Late Flandrian age and consequent on human modification to the environment. Those larger and deeper channels of other rivers in the South West may contain more complex suites of sediments and those draining to the north coast may even contain sediments of glacial origin. Although the Erme is much smaller than the larger Rivers Tamar, Taw and Torridge, it can be regarded as a simple model against which to start comparing the development of river valleys in the South West during the Quaternary.

CHAPTER 9 <u>CONCLUSIONS</u>

In this chapter the main conclusions arising from the study of the sediments filling the buried channel of the River Erme will be presented.

Buried channel deposits from up to seven metres deep have been studied from 20 locations in the lower valley of the Erme and five basic groups of sediment have been recognised: upper fine silts, middle fine units, middle gravels, base units and lower estuarine sediments.

In the modern floodplain area, the **upper fine silts** of fine silt and sand are present in the upper horizons of the channel fill. These overlie a variety of fluvial sands and gravels, grouped as **middle fine units** and **middle gravels** and include a horizon of organic sands, traced between a number of cores in the area. This organic horizon has been radiocarbon dated to 1000-2000 years BP. **Base units** were recovered from the base of cores in the Sheepham Brook tributary valley. Seawards, the cores become more estuarine and much of the sediment recovered is of shelly silts, sands and gravels, grouped as **lower estuarine sediments**.

The radiocarbon dating of the organic horizon indicates that the overlying 2-4m of alluvial sediments have been laid down in the last 1000-2000 years at an average rate of deposition of 0.2cm/year. It is likely that siltation of the Erme's channel in the past 2000 years has been increased by forest clearance and Medieval tinning on Dartmoor. Records show that the Erme river system has been fairly stable in the past 200 years as there seems to be little difference in the channel position on the tithe maps produced in the early nineteenth century and the position of the channel today. At the mouth of the Erme, however, there have been swings in the position of river due to various storms.

The evidence from radiocarbon dating of the organic layer and the tithe maps suggests that around 1000-2000 years ago, an area of marshland was present over much of the study area. This may have been caused by a change of sea level and resulted in a ponding of fresh water against salt water.

Older granitic, sometimes organic, gravels underlying the organic layer and in the more seaward cores may have been deposited during earlier forest clearances of Dartmoor in the Iron Age and Bronze Age. The extent of tinning during these times is unknown, although it is considered that there was some tin streaming during the Bronze Age on Dartmoor.

Much of the estuarine and marine sediment from the lowest horizons, recovered from depths of -6m OD, was probably deposited with rising Flandrian sea levels. Diatom and molluscan analyses suggest deposition in a former mud flat and salt marsh environment and generally indicate increasing brackish conditions with time, showing a change from more intertidal or marine conditions, to a salt marsh environment with siltation in the channel. It is likely that all the sediments recovered from the buried channel have been deposited in the last 4000-6000 years of the Flandrian.

The maximum depth of the channel may have been found in the vicinity of Sequer's Bridge and in a small tributary valley, where a sediment resembling head or basal river gravels close to bedrock was found. Seawards though, the depth of the buried channel is still dependent on McFarlane's 1955 study.

The age of the river valley is uncertain; it was probably cut during the Pleistocene or Late Tertiary, but it is at least older than Devensian since raised wave cut platforms, conventionally dated to the Ipswichian interglacial, are present on the sides of the estuary.

This study is important in that it has implications for the nature of sediment filling other buried rock channels and their relationship to the surrounding landforms. As the South West had the richest tin deposits in Britain it is extremely likely that many of the valleys in Devon and Cornwall are filled with sediments arising from periods of tin mining. Indeed Scourse (1985b) also considered that tin mining, and streaming in particular, has contributed to the sediments filling the River Camel in North Cornwall. Forest clearance during the Bronze and Iron Ages will have also increased sediment deposition and may be responsible for some of the older fluvial units recovered from the Erme's buried channel.

This study is also important in that it substantiates the views that South Devon has not been affected by direct glacial action, but rather suffered a severe periglacial climate during the Devensian and earlier glacial periods. A glacial origin for these steep sided flat bottomed channels as described by Codrington cannot be either substantiated or disproved. The early workers described stiff clays with granitic boulders lying in the bottoms of the channels and the presence of such granitic boulders at Ivybridge (Gilbertson and Sims 1974) and in the Teign gorge (Somervail 1901a,b) suggest former periglacial conditions with high river discharge. The sediments extracted from the channel of the Erme are generally of slate and granitic origin and thus can be considered to be derived from local sources. In spite of the fact that many of the periglacial head deposits in the South West are said to contain loess deposits in the finer upper horizons, an initial examination of the fine river sediments did not reveal any inclusion of aeolian derived quartz grains. Like many recent studies of alluviation in lowland areas in England the effect of human activities appears to have greatly influenced the nature of erosion and deposition in the catchment.

In terms of wider implications for this study, there has been much debate on the derivation of sea level curves for wide areas and whether global or local factors have more influence on particular areas. In the region where organic brackish deposits have been found, it is difficult to assess whether they were formed because of widespread changes in sea level or more possibly because of local changes in sediment yield to the river, or localised 'ponding' of water. In addition, drainage and reclamation of marshland will have significantly altered the natural processes operating in the Erme valley.

This research reported in this study has highlighted the difficulties of cross correlating sediments from a range of environments even in a fairly small area. Using a number of different techniques however, it has been possible to correlate sediments of varying types using particle size, mollusc and diatom analyses. The main difficulties have been in the extraction of sediment from the channel at depths greater than 6-7m. This was because of the very tough granitic gravels that were found in the channel at depth and the pressure exerted by the water table, making extraction of cores difficult. At Ermington some rounded granitic boulders appear to have originated from the channel of the Erme; these may also have hampered exploration if they continued to fill the channel further downstream in the main study area. Attempts at geophysical profiling, using a hammer seismograph, also failed because of interferences caused by the water table. Far more powerful drilling equipment is needed in order to penetrate the sediments filling the channel to greater depths than those recovered in this study.

Future work can be suggested as a result of this study. Detailed probing of the sediment from Ivybridge to Mothecombe could be undertaken to assess the depth to bedrock, in order to calculate the approximate amount of sediment held in the channel of the Erme. More detail on sediment from different sites would aid in calculating the rates of erosion in the catchment at differing times. The sediments could be analysed for their heavy metal content (cf. Macklin *et al.* 1985) to look at variation in tin content through time. This may shed some light on amounts of tin production in the Bronze Age since little is known about prehistoric mining activities on Dartmoor at present. It may also be possible to correlate rates of sediment deposition with known changes in tin production during the Medieval Age. The calculation of the volume of the fine alluvial sediments infilling the Erme's channel below Ivybridge could possibly be related to tin production figures and the total rock removed from Dartmoor by the tin streamers.

Other buried channels in the South West could also be investigated for similar deposits. It may be that those on the north coast of the peninsula will have glacial as well as fluvial and estuarine deposits. The more extensively developed rivers of the South West, such as the Tamar, the Fal and the Taw-Torridge may include more complex sequences of sediments.

Thus this research can be regarded as a pioneer study of the valley sediments filling the buried rock channels of the south-west of England and in spite of obtaining fairly shallow cores compared to the depth of the valley, the Erme represents an important site for Late Quatemary studies of the region. It is believed that the Erme represents a typical river channel and the sediment sequences found may present a preliminary model against which other rivers of the region may be compared. Because of the size of the catchment area, and because the Erme is believed to lie outside the glacial limits, it can be considered to represent one of the simplest sets of deposits that one might encounter in the peninsula.

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APPENDICES

Appendix 1 Sediment Size Analysis Data

Appendix 2 Diatom Analysis Data

Appendix 3 Molluscan Analysis Data

APPENDIX 1 SEDIMENT SIZE ANALYSIS DATA

SEDIMENT SIZE DATA FROM BOREHOLE SB2

Depth (m)	Gravel	Sand	Silt and Clay
	(as a % of the total)		
0.1-0.2	3.8	63.8	32.4
0.5-0.6	0.5	60.2	39.3
0.9-1.0	0.1	68.9	31.0
1.3-1.4	2.7	62.4	34.9
1.7-1.8	0.0	65.2	34.8
2.1-2.2	0.1	42.5	57.4
2.5-2.6	0.4	49.1	50.5
2.9-3.0	3.4	46.9	49.7
3.3-3.4	0.6	59.2	40.2
3.7-3.8	0.5	75.2	24.3
4.0-4.1	3.5	63.7	32.8
4.3-4.4	12.7	58.1	29.2

SEDIMENT SIZE DATA FROM BOREHOLE 6

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
0.25-0.45	0.2	41.6	47.5	10.7
1.05-1.25	0.07	12.3	72.0	15.6
1.65-1.85	0.1	17.9	67.9	14.1
2.05-2.25	9.0	50.0	36.3	4.5
2.65-2.85	0.1	53.9	<---46.0--->	
3.25-3.45	1.7	25.7	64.8	7.8
4.05-4.25	7.1	47.1	36.4	9.4
4.45-4.75	17.6	38.2	36.9	7.3
5.05-5.25	41.2	33.1	21.8	3.9

SEDIMENT SIZE DATA FROM BOREHOLE A3

Depth (m)	Gravel	Sand	Silt and Clay
	(as a % of the total)		
0.1-0.2	0.1	43.0	56.9
0.7-0.8	0.2	28.1	71.7
0.9-1.0	0.4	51.5	48.1
1.2-1.3	30.6	45.4	24.0
1.6-1.7	1.7	38.3	60.0
2.0-2.1	9.2	32.2	58.6
2.4-2.5	15.6	43.9	40.5
2.8-2.9	24.6	40.7	34.7
3.1-3.2	23.2	30.9	45.9
3.4-3.5	9.5	25.4	68.6
3.6-3.7	36.0	27.0	37.0
3.8-3.9	32.0	37.5	30.5

SEDIMENT SIZE DATA FROM BOREHOLE 1

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
1.3-1.6	32.8	38.4	24.8	4.0
2.3-2.6	6.8	51.3	36.3	5.6
3.0-3.3	13.1	50.0	32.4	4.4
3.6-4.0	21.3	44.3	29.1	5.3
5.6	48.8	35.9	12.8	2.5
6.3-6.5	29.3	35.1	29.5	6.2
6.5-6.7	21.7	39.0	29.1	10.2
7.0-7.1	36.9	34.0	20.9	8.3

SEDIMENT SIZE DATA FROM BOREHOLE 7

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
0.6-0.8	0.2	16.7	65.8	17.3
1.0-1.2	15.1	24.6	48.5	11.8
1.6-1.8	34.5	36.1	23.7	5.7
2.2-2.4	26.0	38.9	28.8	6.3
3.0-3.2	36.3	38.5	18.8	6.5
3.6-3.8	37.8	42.1	13.9	6.2
4.2-4.4	42.4	37.3	<---20.3--->	
4.8-5.0	42.3	33.6	19.4	4.7

SEDIMENT SIZE DATA FROM BOREHOLE 9

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
1.5-1.7	2.3	40.6	44.9	12.1
2.1-2.3	0.9	43.0	47.4	8.7
2.5-2.7	2.1	49.5	42.1	6.3
3.1-3.3	0.4	55.2	39.1	5.3
3.7-3.9	25.7	56.1	13.4	4.9
4.1-4.3	38.2	44.1	12.9	4.8

SEDIMENT SIZE DATA FROM BOREHOLE 11

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
1.2-1.4	8.8	37.3	38.1	15.8
2.0-2.2	1.5	33.9	49.6	15.0
2.2-2.4	4.4	40.2	44.0	11.4
2.6-2.8	9.3	58.9	25.7	6.1
3.0-3.2	4.4	42.1	42.1	11.3
3.8-4.0	18.8	59.0	16.3	5.9
4.4-4.6	20.1	53.3	19.0	7.6
4.8-5.0	10.8	62.5	19.2	7.5
5.4-5.6	20.4	55.6	19.3	4.6
5.8-6.0	34.5	47.0	15.2	3.3
6.2-6.4	11.2	52.1	32.2	4.5
6.6-6.8	9.1	43.0	42.3	5.6
6.8-7.0	9.6	26.2	57.2	7.0

SEDIMENT SIZE DATA FROM BOREHOLE 12

Depth (m)	Gravel	Sand	Silt	Clay
	(as a % of the total)			
0.2-0.4	24.0	38.5	30.8	6.7
0.8-1.0	2.5	35.0	48.6	13.9
1.6-1.8	20.0	36.6	37.0	6.4
2.2-2.4	36.3	49.5	12.2	2.0
3.2-3.4	19.9	49.4	27.3	3.4
4.0-4.2	4.4	42.4	47.7	5.6
4.8-5.0	5.8	37.4	51.4	5.4
5.2-5.4	11.2	42.1	42.1	4.6
5.6-5.8	13.7	48.4	34.8	3.1

APPENDIX 2 DIATOM ANALYSIS DATA

DIATOM TAXA COUNTS FROM BOREHOLE SB2

	DEPTH IN CORE											
	0.1	0.5	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.7	4.0	4.3
SPECIES	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.1	4.4
ACHNANTHES												
A. brevipes					1			1				1
A. clevei							1					
A. delicatula						1						
A. hauckiana						1	11	1	3	3		1
A. hungarica					1							
A. lanceolata				3	1	3	6	3	6	2	3	2
v. rostrata						1	4	1		17	1	
v. ventricosa					1			1				
A. marginulata								1				
A. microcephala		2	6	41	29	81	103	57	53	119	141	54
AMPHORA												
A. ovalis								1				
v. libyca		1										
A. turgida						1						
ANOEMOENEIS												
A. follis v. homae		1		2	1	3	3	2			4	
A. serians v. irregularis						1	1		1			
CALONEIS												
C. formosa						2						
C. silicula v. ventricosa											1	
C. sp.						1					2	
COCCONEIS												
C. peltoides						2						
C. placentula v. euglypta		15	49	43	20	16	23	38	32	20	13	25
COSCINODISCUS												
C. apiculatus												
v. ambiguous								1		1		
CYCLOTELLA												
C. antiqua											1	
C. bodanica lemanensis						1						
C. meneghiani											1	
C. sp.								1				
CYMBELLA												
C. gracilis					3	7	8		2	9	3	5
C. sinuata		3	6	37	16	11	13	25	34	14	5	22
v. ovata					3							
C. ventricosa		1	21	49	24	3	19	32	34	49	40	76
DIDYMOSPHENIA												
D. geminata							1		1			

SB2 (cont.)

SPECIES	DEPTH IN CORE 0.1 0.2	0.5 0.6	0.9 1.0	1.3 1.4	1.7 1.8	2.1 2.2	2.5 2.6	2.9 3.0	3.3 3.4	3.7 3.8	4.0 4.1	4.3 4.4
DIPLONEIS												
D. ovalis			1	2	1	4		3		1	1	1
v. oblongella								2	1			
EUNOTIA												
E. diodon v. minor						2		4				
E. exigua			1		1	1		1		3	1	
E. faba			1	3	2	13		1				
E. major compacta									3			
E. pectinalis			7	20	19	19	37	6	25	5	4	2
f. elongata						2					1	
f. impressa											1	
E. robusta v. tetradon									2			
E. sp.					1			1			1	
FRAGILARIA												
F. breviastrata												5
F. capucina					3	3						
F. construens		7	44	34	32	23	18	23	26	13	13	4
v. venter				1								
F. pinnata		1		1	1							
F. virescens		2		3	11	28	14	7	20		5	
v. oblongella			1	1	3	7	14	5	11	13	2	8
F. sp.										3		
GOMPHOMNEMA												
G. acuminatum v. coronata			2	3		1		1				1
G. angustatum			4	2	1	4						
G. constrictum			3	4	2	1		5		7	1	5
G. gracile			2	5	4	3		1			1	
G. lanceolatum												4
G. parvulum			3	11	52	16	35	13	35	33	22	44
v. exillisium							6	1	4			1
GRAMMATOPHORA												
G. marina					2							
GYROSIGMA												
G. attenuatum					2	2			2			
HANTZSCHIA												
H. amphioxys		1										
f. capitata								1				
MELOSIRA												
M. granulata		2	7	32	93	51	55	39	47	13	10	4
M. sulcata											1	
MERIDION												
M. circulaire			3	3	3							
NAVICULA												
N. cincta				3	1	2	2			5	2	3
N. clementis								1				

SB2 (cont.)

SPECIES	DEPTH IN CORE											
	0.1	0.5	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.7	4.0	4.3
	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.1	4.4
N. digito-radiata		1		2	1							
N. elegans								3	1			1
N. flanatica						4		3			6	
N. hasta							2				1	
N. hungarica v. capitata			2							2		
N. mutica f. cohnii			1				1		1	1		
N. radiosa							3					
N. peregrina				1	3	18	5	22	21		2	1
v. minor			19	36	26		1	5		3		4
v. polaris					1			1			1	
N. pusilla												1
N. rhyncocephala										1		
N. rotaena											2	
N. sp.												1
NEIDIUM												
N. sp.				1			1	1				
NITZSCHIA												
N. linearis								2				
N. palea				1		6	9	3	2	1	2	3
OPEPHORA												
O. martyi									2		2	
O. pacifica					1							
PINNULARIA												
P. bilobata			1				3					
P. borealis		2		7	6	5	3	1	3		1	
P. major		2	1			3	1	3				
P. microstauron				1	4		2	1	2			
P. obscura				2	1	6						
P. viridis			1	4		5	7	1	4	1	1	2
P. sp.						1	1		4			
PLEUROSIGMA												
P. aestuarii							2			1		
RHABDONEMA												
R. minutum								2	1			3
SURRIRELLA												
S. fastuosa							1		3	1	1	
S. ovata				1		2		1				
SYNEDRA												
S. parasitica			1			5		12			2	
S. pulchella		5	13	34	18	27	6	55	19	42	74	89
v. lanceolata		1		2			2		3	14	3	5
S. tabulata							1					
S. ulna		3										
S. vaucheriae				1	1			5			21	
TABELLARIA												
T. fenestrata				2	4	1						1

DIATOM TAXA COUNTS FROM BOREHOLE BH6

SPECIES	DEPTH IN CORE (m) 0.0-0.25	0.85-1.05	1.45-1.65	2.05-2.25	2.65-2.85	3.05-3.25	3.65-3.85	4.45-4.75	5.25-5.45
ACHNANTHES									
A. brevipes			2	2	5	3	2		
v. parvula									1
A. delicatula			4		31	22	45	10	18
A. hauckiana	1				9	17	43	15	18
A. hungarica	2	1	14	14	5	8	4	4	11
A. lanceolata	1	1	1		19	8	5	5	
v. ventricosa			6		15	6			
A. marginulata			7	7	7	5		1	2
A. microcephala	4	2	3		2	1		1	5
A. septrionalis v. rhombica			2			7			
ACTINOPTYCHUS									
A. undulatus			2		1	3	1	1	2
AMPHORA									
A. ovalis			6		3	7			
v. libyca	3	1	8	9	7	23	10	13	6
A. turgida					2			1	
BIDDULPHIA									
B. rhombus								1	
CALONEIS									
C. formosa			6		10	4	4		
C. procera v. parallela		3	3						
COCCONEIS									
C. peltoides								3	
C. placentula v. euglypta	45	13	11	6	3	2	3	13	2
C. scutellum			7	2	3	3	5	12	4
COSCINODISCUS									
C. ambiguous v. apiculatus				1	1	2		1	6
C. sp.			2		2	1	2	4	
CYCLOTELLA									
C. antiqua	1		4	14	1	2	3	9	20
C. bodanica v. lemanensis		1							
C. meneghiani		1							
CYMATOSIRA									
C. belgica					1	2	1		1
CYMBELLA									
C. norvegica									2
C. sinuata	4	10		1	2	3		7	3
v. ovata	2	7							
C. turgida	1	1				1			
C. ventricosa		37					2	1	2

BH6 (cont.)

SPECIES	DEPTH IN CORE (m) 0.0-0.25	0.85 1.05	1.45 1.65	2.05 2.25	2.65 2.85	3.05 3.25	3.65 3.85	4.45 4.75	5.25 5.45
DIMEREGRAMMA									
D. minor							3		1
v. nana									4
DIPLONEIS									
D. aestuarii			2		3		2	4	2
D. didyma			1	5			1	1	
D. fusca v. subrectangularis		2							
D. interrupta			11	20	1	3	1		1
D. ovalis			2	6	4	4	1	1	13
v. oblongella	2	2	27	77	8	9	1	5	
D. smithii			12	20	3	1		1	3
D. stroemii	1		3	2	4		2	2	4
D. weissflogii						2		1	1
D. sp.						1			
EUNOTIA									
E. exigua							1	1	
E. faba		1							
E. major compacta									1
E. pectinalis	13	23	6	1	2		2	4	4
v. elongata	2	2							
FRAGILARIA									
F. breviastrata									5
F. capucina									1
F. construens	18	21	1			1		1	1
v. venter		1	2		8	2		2	
F. pinnata		1			3	1	8	7	
F. schulzi					4	3	1		
F. virescens	2	3	1	1		1		2	2
v. oblongella		3						1	3
GYROSIGMA									
G. attentuatum					1	2	1	4	1
GOMPHOMNEMA									
G. angustatum	1	9	9	1	1	1		2	1
G. constrictum		20	3	1					
G. acuminatum v. coronata		16							
G. gracile	2	10			1				10
G. lanceolatum				3				3	
G. parvulum		7	1	1	4	1		4	8
GRAMMATOPHORA									
G. marina					1		2		
G. oceanica v. macilenta		1	3		1			1	
HANTZSCHIA									
H. amphioxys	8	4		1					1
f. capitata			4	2					

BH6 (cont.)

SPECIES	DEPTH IN CORE (m) 0.0-0.25	0.85 1.05	1.45 1.65	2.05 2.25	2.65 2.85	3.05 3.25	3.65 3.85	4.45 4.75	5.25 5.45
MELOSIRA									
M. arenaria								1	
M. granulata	9	113	3	4	1	2			9
M. monoliformis							1		
M. sulcata	1		49	46	37	94	114	106	60
M. westii					4	1	1	4	
MERIDION									
M. circulaire	3	2	3			1		2	
NAVIULA									
N. avenacea	1	32			3	4	2	8	
N. cincta			2	1	12	6	2	4	6
N. clementis			2		7	2	1	3	1
N. digitoradiata	2		4	3	5	17	2	1	
N. elegans				1					3
N. flanatica					1	2			3
N. forcipata					3	5	28	4	4
N. grevillei					1				
N. jarnefetli		1							
N. lyra v. elliptica					3	1		1	
N. mutica			10	2					1
f. cohnii	1		4	2	1	2	1		7
N. palpebralis v. angulata			2	1	1	1	2	6	5
N. peregrina			6	34	28	19	4	8	8
v. minor			31	39	1				13
N. plicata									1
N. punctata v. marina					8				
N. pupula			2						
N. pusilla			15	35	15	4	2	2	8
N. radiosa			5						
N. rhyncocephala			1		3			1	
N. rotaena		1	34	16	2	2		2	15
N. sp.			1					1	
NEIDIUM									
N. sp.	1								
NITZSCHIA									
N. hungarica					7	3		4	2
N. linearis	3	3	7	2	11	7		4	11
N. navicularis					2	4	2		
N. palea	6				5		2	1	
N. panduriformis						1			2
N. punctata			1		1	2	1	2	
N. tryblionella					8	5	7	1	6
OPEPHORA									
O. martyi	1		3		7	19	7	13	14
O. pacifica				1	2	9	31	22	

BH6 (cont.)

SPECIES	DEPTH IN CORE (m) 0.0-0.25	0.85 1.05	1.45 1.65	2.05 2.25	2.65 2.85	3.05 3.25	3.65 3.85	4.45 4.75	5.25 5.45
PINNULARIA									
P. bilobata					1		1		
P. borealis	16	5							3
P. gibba									1
P. microstauron	12	2	1						3
P. obscura	14	1						2	1
P. viridis	4	5	1	2		1	1	1	1
P. sp.			8	2	1			1	
PODOSIRA									
P. stelliger			4	3	7	3	6	5	3
RHABDONEMA									
R. minutum								2	
RHAPHONEIS									
R. amphiceros				2			1		2
v. elongata									1
R. nitida					2	2		2	
R. surrirella			1	1	5	5	5	7	1
RHOICOSPHENIA									
R. curvata			6	3	8	4	6	20	
SCOLIOPLEURA									
S. tumida						1			
S. sp.							1		
STAURONEIS									
S. phoenicenteron		1							1
S. parvula v. producta					1	3		1	
S. sp.			1						
SURRIRELLA									
S. fastuosa							1		
S. ovata			2		2	1	1	1	1
S. smithii			1		1				
SYNEDRA									
S. parasitica	1	1	16						
S. pulchella	9	27	3	3	13	4	3	1	18
v. lanceolata	3								
S. vaucheriae		7				1			
TABELLARIA									
T. fenestrata		7			1			1	1
TRACHYNEIS									
T. aspera						1		1	3
TRACHYSPHAENIA									
T. australis							1	5	1
TRICERATIUM									
T. alternans									1

DIATOM TAXA COUNTS FROM BOREHOLE A3

	DEPTH IN CORE											
	0.1	0.7	0.9	1.2	1.6	2.0	2.4	2.8	3.1	3.4	3.6	3.8
SPECIES	0.2	0.8	1.0	1.3	1.7	2.1	2.5	2.9	3.2	3.5	3.7	3.9
ACHNANTHES												
A. brevipes									1		3	
A. clevei					1							
A. delicatula			1			3	7	4	1	1		4
A. hauckiana					1	5	4	18	2	2	9	
A. hungarica		2	1	2		1	1	5	16	9	6	7
A. lanceolata	25	28	13	24	21	11	17	25	16	10	1	5
v. rostrata			1		1	1				4		2
v. ventricosa	4			1			1	4	3	1		
A. marginulata			1			1	3	3				4
A. microcephala	1	3	2	1	57	73	45	28	3	8		25
ACTINOPTYCHUS												
A. undulatus									1			
AMPHORA												
A. ovalis						2			3		6	
v. libyca	3	2	8	7		3		1	9	12		11
A. turgida								3				2
CALONEIS												
C. formosa		1		1	1						1	
C. procera v. parallela	1							1	3	3		1
C. silicula												
v. ventricosa								1		3		
C. sp.		2		2	1	4	1					
COCCONEIS												
C. distans v. bahuensis											3	
C. peltoides											3	
C. placentula v. euglypta	38	70	80	66	57	47	49	46	8	32		41
C. scutellum										5		
COSCINODISCUS												
C. apiculatus v. ambiguous								1			1	1
CYCLOTELLA												
C. antiqua	1						2	1	8	1		1
C. meneghiana	3			1		13		2	1	1		3
CYMBELLA												
C. amphicephala								2				1
v. intermedia			2			2		1	1			
C. aspera	2	2								1		
C. gracilis					2	2		1				
C. sinuata	15	29	54	42	10	7	12	20	3	6	5	11
v. ovata	2	4	2	2			2	1	1	1		1
C. turgida	6	5	3	4	4			9	3	6	11	6
C. venticosa	1	2	1	2	14	8	10	4		7		5
DIMEREGRAMMA												
D. minor									1			1

A3 (cont.)

SPECIES	DEPTH IN CORE 0.1 0.2	0.7 0.8	0.9 1.0	1.2 1.3	1.6 1.7	2.0 2.1	2.4 2.5	2.8 2.9	3.1 3.2	3.4 3.5	3.6 3.7	3.8 3.9
DIPLONEIS												
D. didyma										1		
D. fusca												
v. subrectangularis	1	1					1					2
D. interrupta												1
D. ovalis		1	1		5	2	11	11	2	9	25	4
v. oblongella	7	16	4	12	1			2	13	6	1	5
D. smithii									1	2	1	
D. stroemii										2		
EUNOTIA												
E. antiqua					2							
E. diodon v. minor			2	1	3	2	2	4				4
E. faba		1				5	1			1		
E. grunowii f. subundulata								1				
E. major compacta	1							1			1	1
E. pectinalis	42	21	12	12	9	4	5	5	9	6	16	8
v. elongata	1	1	2	1		3	3					1
f. impressa						1		1				1
E. robusta v. tetradon									1			
E. sp.			1									
FRAGILARIA												
F. breviastrata			4				1		19	19	26	7
F. capucina	2	3			3	4	7	1	1	2		
F. construens	2			1	2	1		5		1		3
v. venter		1	6	6	9	3	6	13	30	16		11
F. lepostauron											3	
F. pinnata		3	6	3	6		5	13	3			13
F. virescens		3	2	1	4	1	1	10	2	6		6
v. oblongella			6	3	3	1	8	9	27	3	32	9
F. sp.											5	
GOMPHOMNEMA												
G. acuminatum v. coronata	7		2	1			2	1				
G. angustatum	39	19	7	17	7	3		4	7	9		8
G. constrictum	8	4	1	1				2		1	1	
G. gracile		4	7	1	2	2	13	6	1	1	2	4
G. lanceolatum											1	
G. parvulum	12	15	4	10	7	6	12	13		4	3	1
exillisium					6	2		5		1	5	
G. sp.	2	6			2	2						
GRAMMATOPHORA												
G. oceanica v. macilenta									1			
GYROSIGMA												
G. attentuatum		1	1	5	1	3	6	3		3		2
HANTZSCHIA												
H. amphioxys		1				2				3		4
f. capitata	7	5			1	3						

A3 (cont.)

SPECIES	0.1 0.2	0.7 0.8	0.9 1.0	1.2 1.3	1.6 1.7	2.0 2.1	2.4 2.5	2.8 2.9	3.1 3.2	3.4 3.5	3.6 3.7	3.8 3.9
	DEPTH IN CORE											
MELOSIRA												
M. granulata	3	1			1	1			7			1
M. sulcata				1		1		1	10	19	22	6
M. westii									2			
MERIDION												
M. circulaire		6										
f. constricta	17	3	6	9	4	2	5	2		4		1
NAVICULA												
N. avenacea	26	56	71	35	116	121	55	29	27	42	32	58
N. cincta	1		4	9	6	6	4	20	1	9	20	4
N. clementis							1					
N. digito-radiata									10			
N. elegans					2	5		1	2		3	1
N. forcipata									4			
N. grevillei					4			3				
N. hasta				1		1		1		4	2	3
N. humerosa								1			4	
N. hungarica v. capitata				1		1						2
N. Jarnefetli		2										
N. mutica		2						1	4			
f. cohnii				2		1	1	2	8	1		
N. palpebralis v. angulata												1
N. peregrina v. polaris	7	1	6	5		1	4	1	2	1		3
N. pupula	1	4				1			1			2
N. punctata v. marina										1		
N. pusilla	2			5			11		19	8	7	14
N. radiosa			2				1	3	10	4	7	
N. rhyncocephala					11	3	6					
N. rotaena		1	1	4	2	4	5	2	35	13	19	9
N. sp.							1			1	2	1
NEIDIUM												
N. sp.							2					
NITZSCHIA												
N. hungarica									1			
N. linearis	1	1	2	10	5	2	5	6	8	8	14	13
N. palea	2	2		1	9	17	4		5	2	7	4
N. punctata									1		1	
N. tryblionella		1		1								
N. sp.							3	2				
OPEPHORA												
O. martyi			1	1			3	1	4	3	8	
O. pacifica		1										

A3 (cont.)

SPECIES	0.1 0.2	0.7 0.8	0.9 1.0	1.2 1.3	1.6 1.7	2.0 2.1	2.4 2.5	2.8 2.9	3.1 3.2	3.4 3.5	3.6 3.7	3.8 3.9
	DEPTH IN CORE											
PINNULARIA												
P. bilobata			2	2				2	1		2	
P. borealis	1	5	1	4		1	4	2	2	1		
P. gibba		10	4		1	1			2	1		1
P. lata v. minor						1	1			1		2
P. major	5	2					1	1	2	1	3	
P. microstauron		3	6	3	2	1	3	1	2			3
v. ambigua	2	1										
P. nobilis											2	
P. obscura	15	4	9	5	2	3	5	2	1	3		2
P. viridis	3	2	2	14	1	1	6	2	6	11	10	4
P. sp.	6		5	4	1		13	2	5	3	5	3
PODOSIRA												
P. stelliger			1					1	1	3		1
RHAPHONEIS												
R. amphiceros									1		1	
R. belgica											2	
R. surrirella										3		
RHAPOLODIA												
R. gibberula v. producta		1	1					1				1
RHOICOSPHENIA												
R. curvata			1							5	3	
STAURONEIS												
S. anceps			1		1	1		1				
S. parvula v. producta		1			1			2	1			1
S. phoenicenteron	2	2	1	3				1				1
S. smithii				1	1	1			1			
S. sp.	1			1								1
SURRIRELLA												
S. ovata				1	2	1						
SYNEDRA												
S. parasitica	3	3	1	2	2		1	1	2	1		
v. lanceolata							1	1		1		1
S. pulchella	65	17	29	38	16	20	14	19	2	27	34	20
v. lanceolata			1		1			1				1
S. tabulata										10	1	
s. ulna									6			
S. vaucheriae	2	5	2	6		2		11	1			4
TABELLARIA												
T. fenestrata	2	1	1	1	1		3		2			
TRACHYNEIS												
T. aspera			1							1		
TRACHYSPHAENIA												
T. australis												

DIATOM TAXA COUNTS FROM BOREHOLE BH11

	DEPTH IN CORE (m)										
SPECIES	1.2 1.4	1.4 2.0	2.4 2.6	3.0 3.2	3.8 4.0	4.4 4.6	4.8 5.0	5.4 5.6	6.0 6.2	6.6 6.8	6.8 7.0
ACHNANTHES											
A. brevipes			4	2	3	1	2	1			
A. clevei				1							
A. delicatula			7	8	5	2	3	4	31	42	11
A. hauckiana			6	4	8	1	7	4	26	23	5
A. hungarica		6	5	4	1	2	1				1
A. lanceolata		3				1	3	1	8	4	10
v. rostrata			1								
v. ventricosa			1				1		1		
A. marginulata	1			1						2	
A. microcephala	1	6	17	8	4		3	3	2	8	4
A. septentrionalis v. rhombica			1		3				1		
A. sp.				11							
ACTINOPTYCHUS											
A. undulatus				1	2	2	3	1		1	3
AMPHORA											
A. ostraeria						2					1
A. ovalis			22		9	1				7	
v. libyca		4	4	30	14	8	17	7	8	5	20
A. turgida				1			2		1	1	1
ANOEMOENEIS											
A. follis v. homae			3	1							
CALONEIS											
C. amphisbaena v. subsalina			1					1			
C. formosa			2		1		1	1		2	
C. procera v. parallela										1	
C. sp.								1			
COCCONEIS											
C. peltoides						1	1			2	
C. placentula v. euglypta	4	36	11	10	13	6	7	5	5	16	18
C. pseudomarginata					1						
C. scutellum			3	2	3	3	4		12	10	5
v. stauroneiformis					2					2	
COSCINODISCUS											
C. apiculatus v. ambiguous			1	1	2			2	1	2	2
C. nitidus				1							
C. sp.				2		2		2	1	1	2
CYCLOTELLA											
C. antiqua		1	4	10	25	5		2	5	20	20
C. bodanica lemanensis			2	1	2	1			1		
C. meneghiana				2							
CYMATOSIRA											
C. belgica					1				3	1	

BH11 (cont.)

SPECIES	1.2–1.4	1.4–2.0	2.4–2.6	3.0–3.2	3.8–4.0	4.4–4.6	4.8–5.0	5.4–5.6	6.0–6.2	6.6–6.8	6.8–7.0
					DEPTH IN CORE (m)						
CYMBELLA											
C. amphicephala v. intermedia					1		1				
C. gracilis			2	1							
C. turgida		25	21	1	4		4	6		1	1
C. sinuata	1	25	26	15	11	2	13	5	7	2	4
v. ovata					2		1				
C. ventricosa			7	5	2		1		3		3
DIMEREGRAMMA											
D. minor			1						1		5
v. nana				4	1	3			6	3	1
DIPLONEIS											
D. aestuarii			1		2		2	1		2	2
D. crabo						1					
D. didyma			3	9	7	10	5	3	1	1	3
D. fusca										1	
v. subrectangularis									1		
D. interrupta					2	1	1	1			
D. ovalis			4	5	5		3	1	1		1
v. oblongella			1						2	1	
D. stroemi		1	11	24	23	11	17	8		4	1
D. weissflogii					1					1	
D. sp.									2	1	2
EUNOTIA											
E. diodon v. minor							1	1			
E. exigua											1
E. faba					2			1	1	1	1
E. major compacta											20
E. pectinalis	1	14	3	3	1	1	1	3	6	9	1
v. elongata		1						1			
E. robusta v. tetradon				1							
FRAGILARIA											
F. breviastrata							1				
F. construens	2	42	8	6	7	2	5	6	4	1	1
v. venter		2	3	3	1				1	1	
F. pinnata		1		2		1	1	1	1		
F. schultzi		1						1	1	4	8
F. virescens		1	4		2				1	2	1
v. oblongella		11	7	4	4		3			1	1
GOMPHOMNEMA											
G. acuminatum v. coronata			2							1	1
G. angustatum		1	3	2	1	1			1	3	
G. constrictum				1							
G. gracile	2				1						
G. lanceolatum											4
G. parvulum		5	12		2		3		2	2	1
G. sp.		1	6								

BH11 (cont.)	DEPTH IN CORE (m)										
	1.2	1.4	2.4	3.0	3.8	4.4	4.8	5.4	6.0	6.6	6.8
SPECIES	1.4	2.0	2.6	3.2	4.0	4.6	5.0	5.6	6.2	6.8	7.0
GRAMMATOPHORA											
G. macilenta			3		2					2	
G. marina								1	1		
G. oceanica v. macilenta			1		2	1			3		4
GYROSIGMA											
G. attentuatum	1		1		2				1	1	2
HANTZSCHIA											
H. amphioxys f. capitata	7		1					1			
MELOSIRA											
M. arenaria								1			
M. granulata	10	82	31	55	46	14	16	18	3	4	2
M. monoliformis			1				1				
M. sulcata			21	60	55	57	73	38	93	83	140
M. westii			1	1	4	10		2	12	6	16
MERIDION											
M. circulaire			1						1	5	
f. constricta		1	4	1			1		1	1	1
NAVIULA											
N. avenacea		28	19		7			5	16	11	5
N. cincta			16	6	5		6	11	1	3	2
N. clementis		3	3		1				1	1	
N. digito-radiata		1	4		3	3		2	1	2	2
N. flanatica			2							3	
N. forcipata					2	2			7	3	2
N. grevillei									1		
N. humerosa			1	3	2	1		2	1		1
N. Jarnefetli					1	1		1			
N. mutica		2	1		1		2				
f. cohnii		1					1		1	7	1
N. palpebralis v. angulata				3	2	1	2	1	1		1
N. peregrina			1		2		8	2	2		3
v. minor		5	5	8	8	2	12	4			
N. punctata v. marina				1							
N. pusilla		10		2	2	2	2	2	1		3
N. radiosa					1						
N. rotaena										1	
N. sp.		2									
NITZSCHIA											
N. hungarica				5	3		2	1	3	4	2
N. linearis	2		2	4	1		4	2	6	1	2
N. navicularis			3	3	3	1	2	1			1
N. palea	6	3	4			1			20	3	2
N. panduriformis				1		1	1		2		2
N. punctata				1	1			1			3
N. rhyncocephala			1								
N. tryblionella			1		1	1				2	1
N. sp.							2				

BH11 (cont.)

SPECIES	DEPTH IN CORE (m) 1.2 1.4	1.4 2.0	2.4 2.6	3.0 3.2	3.8 4.0	4.4 4.6	4.8 5.0	5.4 5.6	6.0 6.2	6.6 6.8	6.8 7.0
OPEPHORA											
O. martyi	1	2	2	6	10	4	1	4	8	16	13
O. pacifica											5
O. schwartzii			1	1	4	1		1	7	4	
PINNULARIA											
P. borealis	1	2	1		3	1					
P. lata			1	1							
P. major	1					1	1	1			
P. microstauron	3	1			1		1	3			
P. obscura	4	3			1						
P. viridis			1	1	3		1	1	1	1	1
P. sp.		7	2	3	3		1		3		
PODOSIRA											
P. stelliger	1		1	4	3	1	8	4	4	3	12
RHABDONEMA											
R. minutum						1					
RHAPHONEIS											
R. amphiceros						1	1			1	1
R. belgica							1				
R. nitida									1		1
R. surrirella		1	4	2	3	1	3	2	2	6	
RHOICOSPHENIA											
R. curvata		12	4		6	15	1		20	15	
SURRIRELLA											
S. fastuosa											1
S. ovata			1	1			1		4		2
SYNEDRA											
S. pulchella		35	25	34	13	2	22	12	7	1	3
v. lanceolata		1			1					1	
S. parasitica			4	1	1		1		1		1
v. subconstricta				1							
S. tabulata							1	1	2		
S. ulna		1			2	1		2			
S. vaucheriae		2	1		2						
TABELLARIA											
T. fenestrata	3	8	4	1	3		2	1	1		
TRACHYNEIS											
T. aspera				4	2	1		1	1	1	2
TRACHYSPHAENIA											
T. australis					2		1		1	5	2

DIATOM TAXA COUNTS FROM BOREHOLE RM2

SPECIES	DEPTH IN CORE (m) 4.1-4.2	5.0-5.1	6.0-6.1	7.1-7.2
ACHNANTHES				
A. delicatula	7	13	10	17
A. exigua		1		
A. hauckiana	18	7	6	9
A. lanceolata	1	9	2	8
A. marginulata	1			
A. microcephala	2	3	2	8
A. turgida		2	3	1
ACTINOPTYCUS				
A. undulatus		1	2	1
AMPHORA				
A. ovalis v. libyca	2	7	5	
ANOMOENEIS				
A. follis v. homae		1		
CALONEIS				
C. procera v. parallela			1	
C. sp.			1	
CAMPYLODISCUS				
C. adriaticus				1
COCCONEIS				
C. placentula v. euglypta	5	5	8	5
C. scutellum	15	28	23	16
v. stauroneiformis		2		2
COSCINODISCUS				
C. apiculatus	2	1	4	11
C. nitidus			1	
CYCLOTELLA				
C. antiqua		2	5	29
CYMATOSIRA				
C. belgica	5	2	2	8
CYMBELLA				
C. sinuata		1		
C. ventricosa		1	1	1
DIMEREGRAMMA				
D. minor	4	3	1	6
v. nana	3	4	6	10

RM2 (cont.)

SPECIES	DEPTH IN CORE (m) 4.1-4.2	5.0-5.1	6.0-6.1	7.1-7.2
DIPLONEIS				
D. aestuarii	5	6	6	5
D. didyma	3	2	1	2
D. ovalis				1
D. stroemi		3	2	
D. weissflogii	1	1		
EUNOTIA				
E. diodon v. minor				2
E. exigua	2			
E. faba		4		1
E: major compacta			3	
E. pectinalis	1	4	4	2
E. SP.			1	
FRAGILARIA				
F. breviastrata	1	1		4
F. construens		1		
v. venter			1	5
F. lepostauron		1	2	2
F. pinnata	3	2	2	1
F. schulzi		2		
F. virescens		3	3	1
v. oblongella	2			2
GOMPHOMNEMA				
G. parvulum		2	2	5
GRAMMATOPHORA				
G. marina	2	5		
G. oceanica v. macilenta	4			
GYROSIGMA				
G. attentuatum	3	2	1	7
MELOSIRA				
M. sulcata	225	190	185	114
M. westii	6	3	3	
MERIDION				
M. circulaire			1	
NAVICULA				
N. cincta	3	7	4	3
N. digitoradiata	2	7	6	
N. flanatica	2	1	3	7
N. forcipata	13	12	29	21
N. humerosa		2	1	3
N. lyra v. elliptica				1
N. palpebralis v. angulata	2			
N. peregrina				
v. minor		1	1	
v. polaris			2	

RM2 (cont.)

SPECIES	DEPTH IN CORE (m) 4.1-4.2	5.0-5.1	6.0-6.1	7.1-7.2
N. pusilla	2			
N. radiosa		1		
N. sp.	1			
NITZSCHIA				
N. hungarica		4	16	18
N. linearis		3	2	1
N. navicularis			1	
N. palea		1	3	6
N. panduriformis		1	1	3
N. punctata			1	
OPEPHORA				
O. martyi	24	10	4	4
O. pacifica	4	3	3	
PINNULARIA				
P. microstauron		1		1
P. sp.		1		
PLAGIOGRAMMA				
P. staurophonum			1	
PODOSIRA				
P. stelliger	6	7	1	6
RHAPHONEIS				
R. amphiceros	4	1	1	1
R. belgica	1	1		
R. nitida				5
R. surrirella	9	12	9	9
RHOICOSPHENIA				
R. Curvata			3	
SCOLIOPLEURA				
S. tumida				1
SURRIRELLA				
S. ovata			1	
SYNEDRA				
S. pulchella	1	1	1	7
S. vaucheriae			1	
TRACHYNEIS				
T. aspera	2		1	4
TRACHYSPHAENIA				
T. australis	1		1	
TRICERATIUM				
T. favus				4

DIATOM TAXA COUNTS FROM BOREHOLE S2

DEPTH IN CORE (m)

SPECIES	0.1	0.5	1.2	1.6	1.9	2.3	2.5	2.7	3.2	3.8	4.4	5.0
	0.2	0.6	1.3	1.7	2.0	2.4	2.6	2.8	3.3	3.9	4.5	5.1
ACHNANTHES												
A. brevipes	1					1				2		
v. parvula												2
A. clevei		4										
A. delicatula				8	4		9	10			4	8
A. hauckiana	12	10	12	14	34		43	41	1		33	62
A. lanceolata					9		4	14		1		4
v. rostrata								2				
v. ventricosa				2			1					
A. microcephala		1	1	5	5		18	13	17			9
ACTINOPTYCHUS												
A. undulatus	6	3	5	8	2	5	1	2		1		1
AMPHORA												
A. ovalis	4		2		2	1	3	1				
v. libyca									2	1		
A. turgida	3	3	1		2		2	4			15	
ANOMOENEIS												
A. follis v. homae											1	
A. serians												
v. irregularis				1								
CALONEIS												
C. formosa	48	16		1	2	51	8	10		5		
CAMPYLODISCUS												
C. balearicus								1				
COCCONEIS												
C. distans bahuensis								1				
C. peltoides		1			2		2	4			9	5
C. placentula v. euglypta	9	5	1	4	3		4	12		3	11	18
C. scutellum	3	10	8	28	6	3	9	8	3	4	5	4
v. stauroneiformis	4						3	1			2	3
COSCINODISCUS												
C. apiculatus												
v. ambiguous	11	8	22	21	12	3	7	9	1	2		7
C. nitidus	2						1	2				2
C. sp.		9										
CYCLOTELLA												
C. antiqua	5	17	15	14	25		22	32	3	3	1	17
C. meneghiana	5	2										
CYMATOSIRA												
C. belgica		3				1						

S2 (cont.)

SPECIES	0.1 0.2	0.5 0.6	1.2 1.3	1.6 1.7	1.9 2.0	2.3 2.4	2.5 2.6	2.7 2.8	3.2 3.3	3.8 3.9	4.4 4.5	5.0 5.1
	DEPTH IN CORE (m)											
CYMBELLA												
C. gracilis								1				
C. turgida					1			5	1	1		
C. norvegica	2	5				1						
C. sinuata							2		1			
DIMEREGRAMMA												
D. minor		1	1	3	1		1	2			1	2
v. nana	2	6		2	4		4	3		1	6	4
DIPLONEIS												
D. aestuarii	3	2	3	7	5		3		2	1		
D. didyma	5	24	3	11	4		8	2		5		
D. fusca												
v. subrectangularis			1				1			1		
D. interrupta						5	1					
D. ovalis			2	1		11	1	1			14	3
v. oblongella	2	7	1	2			16	2		1	27	
D. smithii											1	
D. stroemii	1		6	9	4	2	1					
D. weissflogii			3					5				1
EUNOTIA												
E. bidentula							1					
E. diodon v. minor								1				
E. exigua				1			2	1				
E. faba					1			6				2
E. major compacta					1	1						
E. pectinalis		1			3		3	2	1			5
E. robusta v. tetradon					1							
E. sp.		3					1					
FRAGILARIA												
F. breviastrata				1			1					
F. construens			1	1	1		3	1				1
v. venter										1		
F. pinnata												7
F. virescens								1				3
v. oblongella					1		2	5				3
F. sp.						1						
GOMPHOMNEMA												
G. gracile	2	3			1							1
G. parvulum	1	1			1	1	4					1
GYROSIGMA												
G. attentuatum		1					1					
HANTZSCHIA												
H. amphioxys												
f. capitata	16											

S2 (cont.)

SPECIES	DEPTH IN CORE (m)											
	0.1 0.2	0.5 0.6	1.2 1.3	1.6 1.7	1.9 2.0	2.3 2.4	2.5 2.6	2.7 2.8	3.2 3.3	3.8 3.9	4.4 4.5	5.0 5.1
MELOSIRA												
M. arenaria										1		
M. granulata									1	1		
M. sulcata	60	114	237	191	93	76	89	69	7	112	5	82
v. siberica		1		6			5					
M. westii												43
NAVICULA												
N. avenacea									1			
N. cincta	65	63	5		2	125	2	11		3	1	
N. digito-radiata	5	20							1			
N. elegans	2	5				1						
N. flanatica	3	3			3		4	2			31	4
N. forcipata		2									16	
N. gracilis	9											
N. grevillei		1		9	3		23	29			184	26
N. halophila	1	7										
N. humerosa	1		3		1		2	1			1	
N. Jarnefetli									1			
N. lyra v. elliptica	8	4	2	2	2	3	5	11			19	21
N. mutica f. cohnii					1			1				1
N. palpebralis v. angulata	1		3	2	3						3	
N. peregrina												
v. minor	2	6		1		3	2		1		1	4
v. polaris	1		1		1			1				2
N. plicata			6									
N. radiosa			1		5	5	1	1				
N. rhyncocephala											1	
N. rotaena						1						
N. sp.						8	2					1
NEIDIUM												
N. sp.							1					
NITZSCHIA												
N. hungarica	5	5	3	2	5		8	5				
N. linearis	1	1	1	1	2	2	2		1	1		
N. littoralis											1	
N. navicularis			2			1					1	18
N. palea	59	4	3		3	48	5	14			5	7
N. panduriformis			2				1	2				2
N. punctata	1	2	2	1		1	2					
N. tryblionella												1
N. sp.			1			5	1					
OPEPHORA												
O. martyi	7	1	4	8	5	4	10	8	1			5
O. pacifica	3	2		3	2						1	

S2 (cont.)

SPECIES	0.1–0.2	0.5–0.6	1.2–1.3	1.6–1.7	1.9–2.0	2.3–2.4	2.5–2.6	2.7–2.8	3.2–3.3	3.8–3.9	4.4–4.5	5.0–5.1
	DEPTH IN CORE (m)											
PINNULARIA												
P. borealis				2			2					
P. lata v. minor											9	1
P. microstauron			1					2				1
P. sublanceolata							1					
P. viridis							1					
P. sp.									1			
PLEUROSIGMA												
P. aestuarii	1					5	1					
PODOSIRA												
P. stelliger	3	8	25	15	9	1	14	4		6		5
RHAPHONEIS												
R. amphiceros	1					2		2			1	2
v. elongata							1					
R. nitida	4	10							2			
R. surrirella	4	1	4	2	5	19	7	3			4	4
RHABDONEMA												
R. minutum					1							
RHOICOSPHENIA												
R. curvata							1	1				
SCOLIOPLEURA												
S. tunmida							2	5				
S. sp.	1											
SURRIRELLA												
S. fastuosa	2		1				1	1				1
S. ovata								3				2
SYNEDRA												
S. pulchella	2		2	5	6	2	4	3	1			2
TABELLARIA												
T. fenestrata					2			3				
TRACHYNEIS												
T. aspera	2	2	3	3				1				
TRACHYSPHAENIA												
T. australis					1			1			3	2
TRICERATIUM												
T. favus				2	5		3					1

DIATOM SPECIES AND SALINITY GROUPINGS FOUND IN ALL CORES

ACHNANTHES	
A. brevipes Agardh	BM
A. brevipes Agardh v. parvula (Kützing) Cleve	B
A. clevei Grunow	
A. delicatula (Kützing) Grunow	B
A. exigua Grunow	Z
A. hauckiana Grunow	B
A. hungarica Grunow	ZB
A. lanceolata (de Brébisson) Grunow	ZB
A. lanceolata (de Brébisson) Grunow v. rostrata (Östrup) Hustedt	ZB
A. lanceolata (de Brébisson) Grunow v.ventricosa Hustedt	ZB
A. marginulata Grunow	
A. microcephala (Kützing) Grunow	Z
A. septentrionalis (Östrup) v. rhombica (Östrup) A. Cleve	
ACTINOPTYCHUS	
A. undulatus (Bailey) Ralfs	MB
ANOMOEONEIS	
A. serians (Brébisson) Cleve v. irregularis(Donkin)	(Z)
A. follis v. hannae	
AMPHORA	
A. ostrearia (De Brébisson)	M
A. ovalis (Kützing)	ZB
A. ovalis (Kützing) v. libyca (Ehrenberg) Cleve	ZB
A. turgida Gregory	
BIDDULPHIA	
B. rhombus (Ehrenberg) W. Smith	M
CALONEIS	
C. amphisbaena (Bory) Cleve v. subsalina (Donkin) Cleve	B
C. formosa (Gregory) Cleve	B
C. procera (Östrup) v. parallela	
C. silicula (Ehrenberg) Cleve	ZB
C. silicula (Ehrenberg) Cleve v. ventricosa (Donk)	(ZB)
CAMPYLODISCUS	
C. adriaticus Grunow	
C. balearicus	
COCCONEIS	
C. distans (Gregory) bahusiensis	
C. peltoides Hustedt	MB
C. placentula Ehrenberg v. euglypta	(ZB)
C. pseudomarginata Gregory	
C. scutellum Ehrenberg	MB
C. scutellum Ehrenberg v. stauroneiformis W. Smith	MB
COSCINODISCUS	
C. apicilatus Ehrenberg v. ambiguous Grunow	M
C. nitidus Gregory	M

CYCLOTELLA	
C. antiqua W. Smith	Z
C. bodanica Eulenst lemanensis	(Z)
C. meneghiniana Kützing	BZ
CYMATOSIRA	
C. belgica Grunow	M
CYMBELLA	
C. amphicephala Naeg.	
C. amphicephala v. intermedia Cleve	
C. gracilis (Rabenhorst) Cleve	Z
C. norvegica Grunow	Z
C. sinuata Gregory	ZB
C. sinuata Gregory v. ovata Hustedt	
C. turgida (Gregory) Cleve	ZB
C. ventricosa Kützing	ZB
DIDYMOSPHENIA	
D. geminata (Lyngberg) M. Schmidt	
DIMEROGRAMMA	
D. minor (Gregory) Ralfs	M
D. minor (Gregory) Ralfs v. nana (Gregory) Van Heurck	M
DIPLONEIS	
D. aestuarii Hustedt	BM
D. crabo Ehrenberg	
D. didyma (Ehrenberg) Cleve	
D. fusca (Gregory) Cleve	M
D. fusca (Gregory) Cleve v. subrectangularis Cleve	(M)
D. interrupta (Kützing) Cleve	B
D. ovalis(Hilse) Cleve	ZB
D. ovalis (Hilse) Cleve v. oblongella (Naegeli) Cleve	ZB
D. smithii (De Brébisson) W. Smith	
D. weissflogii (Schmidt) Cleve	M
D. stroemi Hustedt	M
EUNOTIA	
E. antiqua A. Bg.	
E. bidentula W. Smith	
E. diodon Ehrenberg v. minor Grunow	
E. exigua (de Brébisson) Rabenhorst	Z
E. faba (Ehrenberg) Grunow	Z
E. grunowii forma subundulata	
E. major (W.Smith) Rabenhorst compacta	
E. pectinalis (Dillwyn) Rabenhorst	Z
E. pectinalis (Dillwyn) Rabenhorst f. elongata V. Heurk	(Z)
E. pectinalis (Dillwyn) Rabenhorst f. impressa (Ehrenberg) Hustedt	(Z)
E. robusta Ralfs v. tetradon	
FRAGILARIA	
F. breviastrata Grunow	ZB
F. capucina Desmazieres	Z
F. construens (Ehrenberg) Grunow	ZB
F. construens (Ehrenberg) Grunow v. venter (Ehrenberg) Grunow	ZB
F. lepostauron (Ehrenberg) Hustedt	Z
F. pinnata Ehrenberg	ZB

F. schulzi Brockmann	
F. virescens Ralfs	Z
F. virescens Ralfs v. oblongella Grunow	(Z)
GOMPHONEMA	
G. acuminatum Ehrenberg v. coronata (Ehrenberg) W. Smith	ZB
G. angustatum (Kützing) Rabenhorst	ZB
G. constrictum Ehrenberg	ZB
G. gracile Ehrenberg	ZB
G. lanceolatum Ehrenberg	
G. parvulum Kützing	ZB
G. parvulum Kützing v. exillissimum Grunow	(ZB)
GRAMMATOPHORA	
G. macilenta W. Smith	
G. marina (Lyngbye) Kützing	M
G. oceanica (Ehrenberg) Grunow v. macilenta (W. Smith) Grunow	M
GYROSIGMA	
G. attenuatum (Kützing) Rabenhorst	ZB
HANTZSCHIA	
H. amphioxys (Ehrenberg) Grunow	ZB
H. amphioxys (Ehrenberg) Grunow f. capitata (Müller)	ZB
MASTOGLOIA	
M. lacustris Grunow v. alpina Brun.	
MELOSIRA	
M. arenaria Moore	Z
M. granulata (Ehrenberg) Ralfs	ZB
M. moniliformis (Müller) Agardh	BM
M. sulcata (Ehrenberg) Kützing	M
M. sulcata (Ehrenberg) Kützing v. siberica	
M. westii W. Smith	M
MERIDION	
M. circulaire Agardh	ZB
M. circulaire Agardg f. constricta (Ralf) van Heurck	ZB
NAVICULA	
N. avenacea de Brébisson	B
N. cincta (Ehrenberg) Van Heurck	ZB
N. clementis Grunow	B
N. digitoradiata (Gregory) Ralfs	B
N. distans	M
N. elegans W. Smith	B
N. flanitica Grunow	MB
N. forcipata Greville	MB
N. gracilis (Ehrenberg) Kützing	ZB
N. grevillei Agardh	M
N. halophila (Grunow) Cleve	B
N. hasta	
N. humerosa De Brébisson	MB
N. hungarica Grunow v. capitata (Ehrenberg) Cleve	Z
N. jarnefetli Hustedt	
N. lyra Ehrenberg v. elliptica	
N. mutica Kützing	BZ

N. mutica Kützing v. cohnii (Hilse) Grunow	BZ
N. oblonga Kützing	ZB
N. palpebralis v. angulata (Gregory) Cleve	(M)
N. peregrina (Ehrenberg) Kützing	B
N. peregrina (Ehrenberg) Kützing v. minor	BZ
N. peregrina (Ehrenberg) Kützing v. polaris (Lagst.) Cleve	
N. plicata Donkin	MB
N. punctata W. Smith v. marina (Ralfs)	
N. pupula Kützing	ZB
N. pusilla W. Smith	ZB
N. radiosa Kützing	ZB
N. rhyncocephala Kützing	ZB
N. rotaena (Rabenhorst) Grunow	Z
NEIDIUM	
Neidium sp.	(Z-ZB)
NITZSCHIA	
N. hungarica Grunow	BZ
N. linearis W. Smith	Z
N. littoralis Grunow	
N. navicularis (De Brébisson) Grunow	B
N. palea (Kützing) W. Smith	ZB
N. panduriformis Gregory	M
N. punctata (W. Smith) Grunow	BM
N. tryblionella Hantzsch	BZ
OPEPHORA	
O. martyi Héribaud	ZB
O. pacifica (Grunow) Petit	M
O. schwartzii (Grunow) Petit	
PINNULARIA	
P. bilobata	
P. borealis Ehrenberg	ZB
P. gibba Ehrenberg	Z
P. lata (De Brébisson) W. Smith	
P. lata (De Brébisson) W. Smith v. minor Grunow	
P. major (Kützing) Cleve	ZB
P. microstauron (Ehrenberg) Cleve	Z
P. microstauron (Ehrenberg) Cleve v. ambigua Meister	Z
P. nobilis Ehrenberg	Z
P. obscura	
P. sublanceolata (Boye Petit) Cleve	
P. viridis (Nitzsch) Ehrenberg	ZB
PLAGIOGRAMMA	
P. staurophorum (Gregory) Heiberg	M
PLEUROSIGMA	
P. aestuarii (De Brébisson) W. Smith	BM
PODOSIRA	
P. stelliger (Bailey) Mann	M
RHABDONEMA	
R. minutum Kützing	M

RHAPHONEIS	
R. amphiceros Ehrenberg	MB
R. amphiceros Ehrenberg v. elongata Per.	
R. belgica Grunow	
R. nitida (Gregory) Grunow	
R. surirella (Ehrenberg) Grunow	MB
RHOPALODIA	
R. gibberula (Ehrenberg) v.producta (Grunow)	(B)
RHOICOSPHENIA	
R. curvata (Kützing) Grunow	ZB
SCOLIOPLEURA	
S. tumida (De Brébisson) Rabenhorst	BM
STAURONEIS	
S. anceps Ehrenberg	Z
S. parvula v. producta	
S. phoenicenteron Ehrenberg	ZB
S. smithii Grunow	ZB
SURIRELLA	
S. fastuosa (Ehrenberg) Kützing	
S. ovata Kützing	ZB
S. smithii Ralfs	
SYNEDRA	
S. parasitica W. Smith	ZB
S. parasitica (W. Smith) Hustedt v. lanceolata	(ZB)
S. parasitica (W. Smith) Hustedt v. subconstricta Grunow	ZB
S. pulchella (Ralfs) Kützing	BZ
S. pulchella (Ralfs) Kützing v. lanceolata	B
S. tabulata (Agardh) Kützing	BM
S. ulna (Nitzsch) Ehrenberg	ZB
S. vaucheriae Kützing	Z
TABELLARIA	
T. fenestrata (Lyngbye) Kützing	ZB
T. flocculosa (Roth) Kützing	Z
TRICERATIUM	
T. alternans Bailey	M
T. favus Ehrenberg	M
TRACHYSPHAENA	
T. australis Petit	M
TRACHYNEIS	
T. aspera (Ehrenberg) Cleve	M

Brackets indicate the salinity group of the main species.

NUMBERS OF TAXA IN EACH SALINITY GROUPING FOR EACH CORE

MBF SB2

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
0.5-0.6	12	30	5	2	0	0	0	1	50
0.9-1.0	60	106	14	19	0	0	1	0	200
1.3-1.4	132	185	34	41	0	0	1	5	398
1.7-1.8	118	225	18	31	1	0	4	3	400
2.1-2.2	195	141	27	22	0	0	0	17	402
2.5-2.6	215	166	7	20	0	0	4	16	428
2.9-3.0	138	158	55	34	1	0	1	13	400
3.3-3.4	175	182	20	18	0	0	3	10	408
3.7-3.8	211	117	43	19	0	0	2	7	399
4.0-4.1	193	108	75	6	0	0	2	16	400
4.3-4.4	159	124	89	11	1	0	3	19	406

MBF BH6

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
0-0.25	70	108	10	7	0	0	4	1	200
0.85-1.05	70	273	28	32	0	0	2	7	412
1.45-1.65	576	139	55	48	5	10	78	13	405
2.05-2.25	34	153	53	78	2	5	73	2	400
2.65-2.85	19	133	38	113	9	12	71	5	400
3.05-3.25	26	97	19	105	6	16	128	5	402
3.65-3.85	7	52	11	105	6	40	171	1	393
4.45-4.75	28	112	7	47	6	27	169	4	400
5.25-5.45	72	90	49	62	2	14	104	12	405

MBF A3

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
0.1-0.2	78	202	68	33	0	0	0	13	394
0.7-0.8	62	243	20	60	0	0	3	6	394
0.9-1.0	51	217	29	80	0	0	3	19	399
1.2-1.3	52	246	42	41	0	0	3	17	401
1.6-1.7	94	186	16	123	0	0	4	10	433
2.0-2.1	109	137	35	135	0	0	2	19	437
2.4-2.5	87	193	15	69	0	0	1	35	400
2.8-2.9	96	195	25	57	0	0	15	33	421
3.1-3.2	103	184	16	46	2	2	34	20	407
3.4-3.5	59	193	29	59	0	8	35	18	401
3.6-3.7	79	154	21	45	4	4	31	56	394
3.8-3.9	90	168	23	70	0	0	20	29	400

MBF BH11

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
1.2-1.4	13	36	0	0	0	0	1	2	52
1.8-2.0	106	200	38	39	0	1	7	9	400
2.4-2.6	65	185	27	51	6	7	48	11	400
3.0-3.2	34	148	41	24	3	5	123	23	401
3.8-4.0	52	146	18	47	6	10	115	10	404
4.4-4.6	8	58	3	10	1	10	107	3	200
4.8-5.0	21	65	27	35	5	12	124	10	299
5.4-5.6	28	53	13	27	3	3	65	9	201
6.0-6.2	24	104	12	90	0	21	132	7	390
6.6-6.8	42	91	14	86	2	23	121	10	389
6.8-7.0	41	92	7	35	5	11	205	4	400

MBF RM2

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
4.1-4.2	7	41	1	27	5	41	270	8	400
5.0-5.1	19	42	6	27	6	58	125	19	402
6.0-6.1	17	37	18	25	7	65	213	19	401
7.1-7.2	40	48	25	26	6	53	174	21	393

MBF S2

Depth in core (m)	Fresh	Fresh-Brackish	Brackish -Fresh	Brackish	Brackish -Marine	Marine-Brackish	Marine	Unknown	Total
0.1-0.2	5	174	12	71	6	18	107	7	400
0.5-0.6	23	85	7	68	4	19	197	6	409
1.2-1.3	19	19	5	17	5	24	309	3	401
1.6-1.7	22	20	7	24	8	38	280	1	400
1.9-2.0	41	33	12	42	5	13	146	6	298
2.3-2.4	4	199	2	57	7	26	89	22	406
2.5-2.6	52	64	12	59	8	20	164	22	401
2.7-2.8	67	73	9	67	6	18	148	14	402
3.2-3.3	23	5	1	4	2	3	10	2	50
3.8-3.9	6	11	0	5	3	5	170	0	200
4.4-4.5	1	67	0	39	0	37	235	49	428
5.0-5.1	41	49	4	100	0	18	158	31	401

APPENDIX 3 MOLLUSCAN ANALYSIS DATA

MOLLUSCAN SHELL COUNTS FROM BOREHOLE S2

depth (m)	weight (g)	Species Hv	Hu	Mb	Ce	Rs	Gb	Lt	Av	Tb	A	B	C	D	E	U
0.3	61.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.8	81.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1	94.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	97.5	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
1.3	118.7	-	2	8	1	-	-	-	-	-	1	-	-	-	-	-
1.4	200.1	84	-	27	1	-	-	1	-	-	1	-	-	-	-	2
1.5	183.5	129	1	7	1	2	-	-	-	-	-	-	-	-	-	-
1.6	137.5	93	13	6	1	-	-	-	-	-	1	-	-	-	1	1
1.7	135.0	60	18	4	1	-	-	1	-	-	-	-	-	-	-	1
1.8	157.3	54	37	18	2	1	-	-	-	-	1	-	-	1	-	2
1.9	162.4	45	11	6	2	1	-	-	-	-	1	-	-	-	-	-
2.0	130.0	13	12	2	1	1	-	-	1	-	1	-	-	-	-	-
2.1	168.9	25	5	8	1	-	-	-	-	-	1	-	-	-	-	1
2.2	156.9	3	8	2	1	1	-	-	-	1	-	1	2	-	-	-
2.3	120.3	19	6	10	1	1	-	-	1	-	1	-	-	-	-	-
2.4	143.9	7	8	1	1	1	1	-	-	-	-	-	3	1	1	-
2.5	172.9	5	1	1	1	6	-	-	-	-	1	-	-	1	-	-
2.6	155.2	3	6	4	4	1	-	-	-	-	1	-	1	2	-	-
2.7	113.9	2	5	1	1	1	-	-	1	-	1	1	-	-	1	-
2.8	94.4	3	-	1	1	1	-	-	-	-	-	-	-	-	-	-
2.9	78.2	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-
3.2	116.0	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
3.4	114.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.5	97.7	-	-	1	1	1	-	-	-	-	1	-	-	-	-	-
3.6	143.1	1	1	3	1	-	-	-	-	-	1	-	-	-	-	-
3.7	184.5	4	7	4	3	4	-	-	-	-	1	-	-	-	-	-
3.8	139.5	26	28	1	1	1	-	-	-	-	6	-	-	1	-	-
3.9	97.8	7	2	1	1	2	-	-	-	-	1	-	-	1	-	1
4.0	114.3	1	2	7	1	1	-	1	-	-	1	-	2	-	-	1
4.1	138.9	2	7	4	1	6	2	-	-	-	1	-	3	-	1	1
4.2	109.8	2	3	8	3	8	-	1	-	-	1	-	-	-	-	-
4.3	238.4	2	7	15	1	21	1	-	-	-	2	-	2	1	3	-
4.6	137.7	17	7	9	6	3	-	1	-	-	1	-	-	3	-	2
4.7	213.9	4	32	25	3	30	1	-	-	3	6	1	2	-	2	2
4.8	129.5	5	23	21	1	11	-	1	1	-	7	-	6	-	2	-
4.9	171.4	5	44	37	2	18	3	1	-	3	-	-	2	-	1	2
5.0	140.7	49	205	47	8	19	5	1	-	2	6	1	1	-	1	2
5.1	101.7	15	108	21	3	8	-	-	-	-	1	-	1	1	3	3

Key to Species Names:

Hv *Hydrobia ventrosa*
Hu *Hyrobia ulvae*
Mb *Macoma balthica*
Ce *Cardium edule*
Rs *Rissoa parva*
Gb *Gibberula* spp.
Lt *Littorina saxatilis*
Av *Alvania* spp.
Tb *Tubonilla* spp.
A,B,C,D,E,U Unknown

MOLLUSCAN SHELL COUNTS FROM BOREHOLE RM2

Species

depth (m)	weight (g)	Hv	Hu	Mb	Ce	Rs	Gb	Lt	Av	A	B	C	D	E	U
2.6	91.0	2	-	1	1	-	-	-	-	-	-	-	-	-	-
2.8	81.6	-	1	1	1	-	-	-	-	-	-	-	-	-	-
2.9	68.8	-	-	1	1	-	-	-	-	-	-	-	-	-	-
3.0	91.8	-	-	1	1	1	-	1	-	-	-	-	-	-	-
3.1	88.0	1	1	1	1	1	-	1	-	-	-	-	-	-	-
3.2	77.5	-	1	1	1	-	-	-	-	1	-	-	-	-	-
3.3	86.8	-	-	1	1	2	-	-	-	-	-	-	-	-	-
3.4	94.9	1	1	1	1	-	-	-	-	-	-	-	-	-	-
3.5	68.6	-	-	1	1	-	-	-	-	-	-	-	-	-	-
3.6	93.6	4	8	1	1	1	-	-	-	1	1	-	-	-	-
3.7	72.1	8	17	6	1	-	-	-	-	1	-	-	-	-	-
3.8	62.6	8	14	6	4	-	-	1	-	-	-	-	1	-	1
3.9	45.3	6	12	2	3	3	-	-	-	-	-	-	-	-	-
4.0	75.9	20	24	14	3	1	-	1	1	1	-	-	1	-	1
4.1	71.1	30	69	5	4	-	-	1	-	1	1	1	-	-	1
4.2	59.2	13	32	18	1	1	-	1	-	-	-	-	-	-	-
4.3	60.9	13	15	12	1	2	-	-	-	-	-	-	1	-	-
4.4	49.9	3	9	3	1	1	-	-	-	-	-	1	-	-	-
4.5	52.2	7	19	14	1	-	-	-	-	1	-	-	-	-	-
4.6	55.2	13	16	11	1	3	-	1	-	1	-	1	-	-	-
4.7	53.1	4	14	8	3	5	-	-	-	-	-	1	-	-	-
4.8	46.1	2	11	7	1	6	1	-	-	-	-	-	-	1	2
4.9	53.0	4	6	3	2	3	-	-	-	-	2	-	-	-	-
5.0	50.1	7	21	6	3	-	-	-	-	1	-	-	-	1	-
5.1	54.1	3	9	11	2	6	-	-	-	-	-	3	1	-	-
5.2	62.5	3	15	7	3	9	-	-	-	-	1	4	1	-	-
5.3	64.6	1	5	4	4	6	1	-	-	2	-	1	1	-	-
5.4	80.5	2	3	2	4	-	-	-	-	-	-	2	1	1	1
5.5	65.0	2	2	6	2	3	-	-	1	1	-	-	1	-	-
5.6	70.3	1	4	5	1	3	1	-	-	2	-	2	1	-	-
5.7	72.1	1	10	2	1	3	1	-	-	-	2	2	-	1	-
5.8	79.4	2	9	6	7	5	-	-	-	3	-	4	-	-	-
5.9	64.7	2	9	8	2	8	-	-	-	-	-	3	-	1	3
6.0	78.4	-	12	18	3	11	1	-	-	1	2	2	2	-	2
6.1	91.4	-	9	11	3	7	1	-	-	1	-	-	-	-	3
6.2	98.2	-	14	9	4	8	-	-	-	1	-	-	4	-	2
6.3	82.1	-	16	17	4	10	1	-	-	2	1	5	1	2	-
6.4	76.2	-	9	9	2	5	-	-	-	1	-	-	-	-	-
6.5	70.0	-	3	1	1	1	-	-	-	2	1	1	-	-	1
6.6	98.8	-	8	10	1	5	-	-	-	-	1	1	1	-	-
6.7	78.2	-	4	3	-	3	1	1	-	-	-	-	-	-	1
6.8	85.0	2	5	12	1	3	-	-	-	-	-	-	-	-	-
6.9	85.3	-	4	3	-	2	-	-	-	1	1	-	1	-	-
7.0	90.5	-	2	6	1	1	-	1	-	-	-	-	-	-	-
7.1	63.6	-	5	1	1	1	-	-	-	-	-	1	1	-	-
7.2	66.6	2	8	4	1	2	-	-	-	-	1	-	1	1	-

Key to Species Names:

Hv *Hydrobia ventrosa*
Hu *Hyrobia ulvae*
Mb *Macoma balthica*
Gb *Gibberula* spp.
Lt *Littorina saxatilis*
Av *Alvania* spp.
Ce *Cardium edule*
Rs *Rissoa parva*
A,B,C,D,E,U Unknown

MOLLUSCAN SHELL COUNTS FROM BOREHOLE RM1

depth (m)	weight (g)	Hv	Hu	Mb	Ce	Rs	Gb	Lt	Av	Tb	A	B	C	D	E	U
		Species														
3.0	67.0	-	1	-	1	-	1	-	-	1	1	-	1	-	-	-
3.1	74.7	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
3.2	66.1	-	1	1	1	-	-	-	-	-	1	-	1	-	-	-
3.3	70.0	-	1	4	-	2	-	1	-	-	-	-	-	-	-	-
3.4	63.7	2	4	2	1	2	1	1	-	-	-	-	-	-	-	-
3.5	70.7	3	2	1	2	1	-	-	-	-	-	-	-	1	1	-
3.6	75.3	1	3	2	3	-	2	1	-	-	1	-	-	-	-	-
3.7	121.5	3	3	2	6	2	-	2	-	-	-	1	1	-	-	-
3.8	99.5	3	3	4	1	2	-	-	-	-	1	1	-	-	1	-
3.9	115.0	1	3	3	1	2	-	1	-	-	2	1	-	-	1	-
4.0	128.5	1	-	2	1	2	1	-	-	1	-	-	-	-	-	-
4.1	98.9	-	-	10	1	6	1	-	1	-	4	-	-	1	-	-
4.2	123.5	1	-	1	-	1	-	1	-	-	1	1	-	-	-	1
4.3	99.0	-	-	3	2	-	-	-	-	-	1	-	-	-	-	-
4.4	74.3	-	-	4	1	1	-	-	-	-	1	-	-	-	1	-
4.5	103.1	1	1	1	4	10	-	1	-	1	2	2	-	-	1	1
4.6	74.1	-	-	4	3	1	-	-	-	-	1	1	-	-	-	-
4.7	87.4	-	1	1	2	2	-	-	-	1	1	2	-	-	-	-
4.8	97.4	1	-	1	1	2	-	-	-	-	2	1	-	-	1	2
4.9	98.9	-	1	3	3	2	1	-	1	-	-	-	-	-	1	-
5.0	73.3	-	-	2	1	6	-	-	-	-	-	-	1	1	-	-
5.1	97.1	2	-	10	4	14	2	-	1	-	5	1	2	-	-	-
5.2	108.1	1	2	8	1	7	1	1	-	1	1	-	-	-	-	-
5.3	103.2	-	-	6	2	4	-	-	-	-	1	2	-	1	-	-
5.4	81.4	-	3	1	1	7	2	1	1	-	1	-	-	-	-	-
5.5	106.4	3	2	9	1	8	-	-	-	-	1	1	2	-	-	-
5.6	138.7	4	6	20	5	24	1	-	-	1	7	-	1	2	1	1
5.7	105.3	-	3	23	2	34	1	-	-	-	6	5	5	1	2	2
5.8	119.1	1	2	28	11	23	2	2	-	7	2	5	-	-	2	-
5.9	104.2	-	1	12	4	28	2	1	1	-	3	2	-	-	2	-
6.0	85.0	-	2	12	3	13	-	-	1	1	4	-	3	2	1	-
6.1	72.5	-	-	8	1	9	1	-	-	1	1	-	2	-	-	-
6.2	79.7	-	-	8	4	5	-	-	-	1	-	-	-	-	-	-
6.3	85.4	1	1	4	2	1	-	-	-	-	1	1	-	-	1	1
6.4	70.5	1	1	6	1	2	-	1	-	-	1	-	-	1	-	-
6.5	96.4	-	2	11	1	18	-	-	-	2	4	-	3	1	1	-
6.6	100.2	1	2	16	1	38	1	-	-	1	4	2	4	2	1	-
6.7	72.5	-	2	8	1	8	-	-	-	-	2	-	1	1	1	-
6.8	80.0	-	1	5	1	3	-	-	-	2	1	-	1	-	-	-
6.9	86.3	-	-	1	1	1	1	-	-	1	-	1	1	-	-	-
7.0	115.6	-	-	1	1	2	-	-	-	1	1	-	-	-	-	3
7.1	112.0	-	1	2	-	-	-	-	-	-	1	-	-	-	-	-
7.2	40.7	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-

Key to Species Names:

Hv	*Hydrobia ventrosa*	Gb	*Gibberula* spp.
Hu	*Hyrobia ulvae*	Lt	*Littorina saxatilis*
Mb	*Macoma balthica*	Av	*Alvania* spp.
Ce	*Cardium edule*	Tb	*Tubonilla* spp.
Rs	*Rissoa parva*	A,B,C,D,E,U	Unknown

MOLLUSCAN SHELL COUNTS FROM BOREHOLE 12

Species

depth (m)	weight (g)	Hv	Hu	Mb	Ce	Rs	Gb	Lt	A	B	C
2.6	184.4	-	-	-	-	-	-	-	-	-	-
2.8	83.8	3	7	1	-	-	-	-	-	-	-
3.0	181.7	1	2	1	-	-	-	-	1	-	-
3.2	84.5	4	1	7	-	-	-	1	-	-	-
3.4	81.8	5	4	2	-	1	-	-	-	-	-
3.6	86.2	1	6	1	-	-	-	-	-	-	-
3.8	88.6	3	9	6	-	1	-	-	-	-	-
4.0	94.1	1	4	3	1	1	-	-	-	-	-
4.2	89.1	3	3	5	1	-	1	-	-	-	-
4.4	136.4	2	4	4	-	1	-	-	-	-	-
4.6	92.2	1	5	1	-	-	-	-	-	-	1
4.8	155.5	4	3	4	-	1	-	-	1	-	-
5.0	134.1	-	1	1	-	1	-	-	-	1	-
5.2	80.2	1	2	1	-	-	-	-	-	1	-
5.4	74.5	-	1	1	-	1	-	-	-	-	-
5.6	73.2	-	2	2	-	-	-	-	-	-	-

MOLLUSCAN SHELL COUNTS FROM BOREHOLE 11

Species

depth (m)	weight (g)	Hv	Hu	Mb	Ce	A
4.2	85.1	-	-	1	1	-
4.4	103.2	-	-	1	-	-
4.6	128.6	-	-	1	-	-
4.8	113.3	-	-	1	-	-
5.0	131.1	-	-	2	-	-
5.2	129.3	-	-	2	-	-
5.4	166.6	-	-	1	-	-
5.6	141.5	-	-	-	-	-
5.8	133.8	-	-	1	-	-
6.0	134.8	-	-	1	-	-
6.2	145.5	-	1	1	-	1
6.4	154.7	-	1	1	-	-
6.6	91.2	1	-	-	-	-
6.8	119.9	-	-	-	-	-

Key to Species Names:

Hv *Hydrobia ventrosa*
Hu *Hyrobia ulvae*
Mb *Macoma balthica*
Ce *Cardium edule*
Rs *Rissoa parva*
Gb *Gibberula* spp.
Lt *Littorina saxatilis*
A,B,C Unknown