Palaeolimnological Studies of Rostherne Mere (Cheshire) and Ellesmere (Shropshire).

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Dedicated to my father,
the late Dr. J. D. Nelms.

ABSTRACT.

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Rostherne Mere (Cheshire) and Ellesmere (Shropshire) were chosen for palaeolimnological studies. Both are large (over 45 ha), deep (over 15 m), eutrophic lowland lakes.

At least 6 Mackereth 6m cores, 1 Mackereth 'Mini'core and 8 marginal Russian cores were taken at each lake.

Palaeomagnetic correlation of cores enabled selection of the best sequences for further study.

Dating was attempted using ^{14}C, ^{210}Pb, ^{137}Cs and palaeomagnetic techniques. Careful analysis of the results enabled construction of consistent, reliable age/depth curves for each selected sediment sequence.

Relative diatom frequencies, planktonic diatom accumulation rates and carbon accumulation rates were investigated at intervals in the selected cores. Rostherne Mere studies included additional analyses of Kjeldahl nitrogen and total phosphorus accumulation rates.

The sequence of diatom communities found were discussed and compared with other present and past limnic diatom floras.

The diatom communities and the accumulation rates found enable reconstruction of the past lake nutrient status. The diatom communities also yield some information on past lake pH.

These interpretations show phases of eutrophication starting ca. 4500bp (Ellesmere), ca. 2000bp, ca. 600bp and 1950 - 1960AD (the last three represented at both Ellesmere and Rostherne Mere). Comparison with other lake sediment studies suggests that the most recent phase of eutrophication is seen in many parts of Britain. This may be due to widespread use of synthetic fertilizers.

Past lake productivity is likely to be related to the development of the lake catchment and hence vegetational history. This hypothesis is strengthened by the similar timing and sequence of phases of eutrophication in Rostherne Mere and Ellesmere, and phases of deforestation and agricultural development in the area.

This study suggests that the oscillating eutrophication of these once alkaline, oligotrophic lakes has been caused by human agricultural activity in the catchment.

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CHAPTER I.

INTRODUCTION.

INTRODUCTION.

The fossil or sub-fossil remains of organisms and their environments are often found in sediments, from the Pre-cambrian (e.g. Barghoorn and Tyler 1965, Oro et al. 1965) to the Quaternary (e.g. Morgan 1973, Hutchinson et al. 1970). Of the organic sediments deposited during the Quaternary (last ca. 2 million years) those from the Flandrian (last 10 thousand years) are the most abundant. Many of these sediments, especially limnic deposits, contain recognisable remains of organisms, including diatoms.

The taxonomy of diatoms has developed over the last two centuries. The foundations of knowledge of their distributional ecology were laid by Cleve (1894, 1895). A large amount of information on the environmental preferences of diatom taxa has been collected (e.g. Hustedt 1937-1939, Cholnoky 1968), and in some cases the characteristic flora of certain lake types recognised (e.g. Jorgensen 1948). The ecology of diatoms has been reviewed by Patrick (1977).

Diatom remains were first used as a palaeoecological tool in the 1920's (e.g. Lundquist 1924, Nipkow 1927). Among the many studies of diatom successions in lake sediments made subsequently, some have revealed the natural development of lakes (e.g. Digerfeldt 1972, Evans and Walker 1977), some of the results of anthropogenic disturbance (e.g. Davis and Norton 1978, Battarbee 1978).

Research into the diatom histories of British lakes has concentrated on a number of types of lake. Late-Devensian and Flandrian sequences have been studied from tarns in thinly populated mountainous regions of Scotland (Pennington et al. 1972), the English lake district (Haworth 1969, Evans 1970) and North Wales

(Evans and Walker 1977, Walker 1978). Diatom histories have been investigated in larger lakes in the glacial valleys of the English lake district (Pennington 1943, Round 1961) and North Wales (Elner and Happey-Wood 1978, 1980). The diatoms have been studied in recent sediments from the large, mainly shallow lowland lakes, Lough Neagh in Northern Ireland (Battarbee 1978) and Loch Leven in Scotland (Haworth 1972). Diatom analyses have been made on sediments from the Mediaeval man-made Broads in East Anglia (Osborne and Moss 1977, Moss 1978), and on late Flandrian sediments from Slapton Ley, a small freshwater lake on the south coast of England (Crabtree and Round 1967).

Recent advances in radioisotope and palaeomagnetic dating techniques have enabled accurate establishment of rates of deposition. This has encouraged the development of methods for counting numbers of diatoms per unit volume of sediment (Battarbee 1973a.), intended for use alongside the traditional relative methods. Numbers (Osborne and Moss 1977, Walker 1978) and biomass (Battarbee 1973b, 1978) accumulating per unit area per annum have been estimated. This has increased confidence in interpretation of results in terms of past productivity.

Chemical measurements have been made on biological materials since the pioneering work of Von Liebig (1803-1873, reviewed in Singer 1959). The chemistry of lake sediments was first investigated in the 1960's (Mackereth 1965, 1966, Crabtree and Round 1967). Sedimentary chemical profiles, presented as mass per unit mass of dry sediment, have been interpreted in terms of rate of catchment erosion (Mackereth 1966, Crabtree and Round 1967, Oldfield et al.1978, Guppy and Happey-Wood 1978). The use of rates of deposition to estimate accumulation rates for chemicals has proved useful in reconstructing past lake productivity

(Digerfeldt 1972, Osborne and Moss 1977).

The development of rapid non-destructive methods for measuring magnetic susceptibility (Molyneux and Thompson 1973), intensity of natural remanent magnetization and declination (Molyneux *et al*. 1972) on whole sediment cores has permitted temporal correlation of sediment sequences (e.g. Thompson *et al*. 1975, Thompson and Morton 1979). Techniques have been developed which enable the measurement of past magnetic directions in cores and single samples (Molyneux 1971, Molyneux *et al*. 1972). Observatory magnetic direction records have been supplemented by measurements on archaeological and lacustrine materials, dated using ^{14}C methods. Archaeomagnetic (Aitken 1970, Thellier 1981) and palaeomagnetic (Thompson and Turner 1979, Turner and Thompson 1981) calibration curves have been produced. These have shown potential in dating sediments used in palaeolimnological studies (Elner and Happey-Wood 1980).

The Meres of the Shropshire/Cheshire plain form a number of groups of more or less eutrophic pools and lakes. They occupy an area with a long history of agricultural exploitation, and are close to the industrial centres of north west England. The Late-Devensian and Flandrian cladoceran succession has been studied at Crose Mere (Beales 1976) but has yielded little information on the history of productivity in the lake during the Flandrian. The preservation and sequence of diatoms and other algae in the uppermost sediments has been investigated at Rostherne Mere and Ellesmere (Livingstone 1979). There are pollen diagrams from Flandrian peats in north Cheshire (e.g. Birks 1964, 1965) including a few ^{14}C dates (Godwin and Switsur 1966). Several Flandrian pollen diagrams have been produced for sites in Shropshire (Hardy 1939, Turner 1964, 1965, Beales 1980.)

It was decided to study some aspects of the palaeolimnology of two of the eutrophic Shropshire/ Cheshire Meres. The aim was to throw light on the history of their eutrophication. The study would include palaeomagnetic correlation of several sediment cores from both lakes, and selection of suitable sediment sequences for further work. The detailed diatom history, and some aspects of the chemical history would be elucidated, and chronologies supplied from palaeomagnetic and radioisotope methods. Rostherne Mere (Cheshire) and Ellesmere (Shropshire) were chosen for their relatively large size (more than 45 ha.), depth (ca. 28m in Rostherne Mere, ca. 18m in Ellesmere), large bird population and well known present day algal flora. The phytoplankton of Rostherne Mere, throughout the year, was recently investigated by Reynolds (1978). The results of older investigations have also been published (Pearsall 1923, Griffiths 1925, Lind 1944, Belcher and Storey 1968). The phytoplankton of Ellesmere has been studied, again throughout the year, by Reynolds (1973).

CHAPTER II.

INTRODUCTION TO SITES.

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Location and General Description.

These meres are located in the north-west of Britain (Fig. 1), in the Shropshire/Cheshire plain. This lies between the estuaries of the Mersey and Dee, and the South Shropshire Hills, to the north and south. The Welsh Mountains and the Pennines form the west and east border of the plain. The Shropshire/Cheshire plain is linked to the Midland Plateau through a gap between the hills, to the south-east, the Midland gap.

Most of the Shropshire/Cheshire plain is at less than 100m OD. The Mid-Cheshire Ridge, running north-south, to the east of Chester, rises to a maximum height of 230m OD.

The location of Rostherne Mere (plate 1, page 8) and Ellesmere (plate 2, page 8), the sample sites chosen, may be found in Fig. 1b. An enlargement of the area around Rostherne Mere (Fig. 2a) and Ellesmere (Fig. 3a) is given, based on the 1:50000 Ordnance Survey maps.

Rostherne Mere is a National Nature Reserve, managed by the Nature Conservancy Council. The site has become important for both ornithological and limnological research.

The main inflow into Rostherne Mere is through Rostherne Brook, a small stream which flows into the lake from the south (Fig. 2a). Rostherne Brook rises in Mere Moss Wood near Over Tabley, 4km to the south, and passes through the small eutrophic lake, the Mere, before entering Rostherne Mere. The outflow, Blackburn's Brook, drains into the River Bollin, and ultimately the Mersey. In flood the flow of Blackburn's Brook may reverse.

Plate 1. Rostherne Mere viewed from the church, looking north east.

Plate 2. Ellesmere viewed from the south west shore, looking north east.

The immediate environs of Rostherne Mere may be seen in Fig. 2b. The bathymetric survey is redrawn from Tattershall and Coward (1914), the remainder of the map is based on the 1:2500 Ordnance Survey. Rostherne Mere is ca. 1170m long, with an area of 48.7ha. The maximum depth given by Tattershall and Coward (1914) was 100ft. (ca. 30m), but Reynolds (1979) states 27.5m, noting that "the bottom is very soft and its limits are determined with difficulty". The mean depth of the lake is ca. 13.7m, and a long retention time of 2 years has been calculated (Harrison and Rogers 1977). The surface of the mere is ca. 21m OD. Parts of these banks are wooded, but much of the area is used for cattle grazing. These pastoral meadows are currently fertilized with synthetic fertilizers. A recent survey showed that fields within the National Nature Reserve were being treated with up to 300kg ha^{-1} of Nitrogen per annum (T. Wall pers. comm.). The important human activities within the catchment of Rostherne Mere include agriculture, the communities of Rostherne village and Mere, and the A556, the Roman Watling Street. The proximity of the Manchester conurbation, which starts 2km to the north-east, and Manchester Ringway airport 7km to the east seems to have had remarkable little effect on the area.

The area around Ellesmere (Fig. 3a) is characterised by a number of meres, with undulating ridges between. Part of the catchment is pastoral, the remainder urban. The sewage of the town of Ellesmere is not put into the mere, so the urban contribution is only surface runoff.

Ellesmere is owned and managed by Shropshire (Salop) County Council for public recreation. Rowing boats are available for hire, and angling is a popular local pastime.

The area immediately around Ellesmere is shown in Fig. 3b. The bathymetric contours were redrawn from the spot depths of Wilson (1966), with additional depth measurements along the transect W-E. The remainder of the map is based on the 1:50000 Ordnance Survey. The maximum length of the mere is ca. 1000m, and the maximum depth 18.8m. The area of Ellesmere is 46.1ha, and the mean depth ca. 7.8m. The surface of the lake is ca. 88m OD, with banks sloping up to 10-20m higher than this to the south-west and north-east. The north-east and south-east margins are mainly wooded, with cattle meadows extending to the waterside in a few places. The north-west margin is public parkland, while to the south-west is mainly carparking, except for a hotel and the Mere's Centre, run by Shropshire County Council to stimulate interest in the Meres. The main Shrewsbury to Wrexham road runs close to the south-west edge of the lake. Local folklore dates the origin of the island in Ellesmere to widening operations on this road in the early 19th. century. The road is overlooked by the remains of Ellesmere Castle.

The distribution of lakes in the British Isles is shown in Fig. 4a. With the exception of the Mediaeval man-made Broads, lakes are concentrated in the north western part of the British Isles. The unique position of the Meres, the nearest significant group of natural lowland lakes to the population centres of England may be clearly seen.

The distribution of the main Meres and Mosses of the Shropshire/Cheshire plain is shown in Fig. 4b (based on Reynolds (1979), Fig. 4). The sites are scattered across the plain in groups, generally away from the main rivers except in the Shrewsbury area. Rostherne Mere is the most northerly of the rather scattered north Cheshire group. Ellesmere is the largest of the much more closely spaced Ellesmere group.

Geology and Possible Origins.

Rostherne Mere and Ellesmere, like the other Shropshire/Cheshire Meres, lie in hollows in the undulating surface of the glacial drift which covers much of the Shropshire/Cheshire plain (Fig. 5a, map based on Geological Survey). This drift is generally absent from the higher ground, varying to over 100m deep in places. Rostherne Mere lies partly in sands and gravels, partly in boulder clays, resulting in the variable soils in the vicinity noted by Harrison and Rogers (1977). Ellesmere lies in boulder clays, in very deep drift.

Beneath the glacial drift of much of the Shropshire/Cheshire plain lie Triassic rocks (Fig. 5b, map based on Geological Survey). Under the drift around Rostherne Mere lie Keuper sandstones, marls and salt beds. The rock under the drift at Ellesmere is Bunter sandstone.

The Devensian glaciation, most recent of the Quaternary glaciations, was responsible for shaping the present landscape of the Shropshire/Cheshire plain. The sequence of events during the Devensian glaciation in this area have been discussed (Reynolds 1979, Peake 1981). A great reservoir of ice from the mountain glaciers of Scotland and Cumbria built up in the Irish Sea. This was pushed southward, carrying with it an immense amount of debris from the northern mountains and from the floor of the Irish Sea. Part of this ice sheet was forced southward across the Shropshire/Cheshire plain (Fig. 6a, map based on Peake 1981). Smaller glaciers from the Welsh mountains pushed into the western margin of the plain. The southward advance of the main Irish Sea glacier was finally halted by the South Shropshire Hills at the Wolverhampton line (Fig. 6a). The great depth of ice involved is emphasised by the deposition glacial drift at heights of 350m on Longmynd and 250m on Wenlock Edge (Peake 1981).

The work of Morgan (1973) in South Staffordshire suggests that this area was free of ice after ca. 16000 BP, although the retreat of the actual ice front was followed by cold conditions for a long time, suggested by the number of fossil ice features in the drift. The melting of this main glacier deposited a great thickness of glacial drift over the Shropshire/Cheshire plain. A small readvance of the ice (Fig. 6a, the Welsh and Ellesmere readvance) formed the particularly undulating landscape of moraine ridges around Ellesmere. It is thought that the final retreat of ice after the Welsh and Ellesmere readvance was rapid (Reynolds 1979). Evidence from pollen assemblages at Crose Mere (Beales 1976, 1980) suggest that the Ellesmere district was ice free before 12000 BP (Reynolds 1979).

The origin of the Meres is a source of intense local interest and folklore. A variety of mechanisms have been discussed by Reynolds (1979). The more plausible of these include melting of stagnant ice blocks to form kettle holes, damming of hollows with moraine material and post glacial subsidence. It is likely that in many cases more than one such mechanism was involved. The great morphometric diversity of the Meres does not suggest that they were all formed in the same way.

Rostherne Mere is ca. 30m deep, but lies in drift shallower than this. The origin of the mere cannot be entirely due to kettle hole formation or moraine damming. Rostherne Mere occurs close to the margin of the Upper Keuper salt beds (Fig. 6b, based on Tallis 1973, Fig. 3). A major fault (the Bucklow fault) passes close to the north-west of the mere (Fig. 6c, based on Geological Survey), marking the north-west boundary of the salt beds. It is possible that this structural feature permitted the ingress of water into the saliferous beds, with subsequent "wet head" solution of the salt, and subsidence. This could have occurred at any time during the Flandrian, possibly enlarging a pre-existing ice formed feature (Pritchard 1961).

Ellesmere lies in very thick drift. A kettle hole origin has been suggested on geomorphological grounds (Reynolds 1979), for the small deep part of Ellesmere seen in the bathymetric map (Fig. 3b). The shallower water in the remainder of the lake may be retained by damming between the moraine ridges prominent to the north-east and south-west.

Limnology.

The water chemistry has been investigated at Rostherne Mere (Gorham 1957a, Grimshaw and Hudson 1970) and at Ellesmere (Gorham 1957b, Reynolds 1973). The most recently available chemical data are summarised in Table 4 of Reynolds (1979), for these and 48 other Meres. These data suggest that the waters of Rostherne Mere and Ellesmere are calcareous and rich in phosphate and to a lesser extent nitrate. Major ions are plentiful, but silica, especially in Ellesmere, is relatively scarce. It has been suggested that under certain circumstances availability of silica may limit diatom productivity in the Meres (Reynolds 1979). An increase in the maximum concentrations of nitrate and phosphate in recent years in Rostherne Mere has been noted (Reynolds 1978). The input of nutrients in bird faeces has been suggested as a possible cause, termed 'guanotrophy' (Brinkhurst and Walsh 1967). Enrichment from agricultural and urban runoff has been implicated (Grimshaw and Hudson 1970, Reynolds 1978).

The detailed periodicity of the phytoplankton of Rostherne Mere during 6 years between 1967 and 1977 has been studied (Reynolds 1978). The phytoplankton between 1963 and 1966 was investigated in less detail (Belcher and Storey 1968). Sampling in both these studies was carried out with a hosepipe sampler (Lund and Talling 1957). Earlier collections were made using nets, and did not include nannoplankton. The phytoplankton was sampled from 1941-1943 (Lind 1944), in 1922 (Griffiths 1925) and from 1912-1913 (Pearsall 1923).

Winter and spring phytoplankton is not abundant. The diatom maximum is usually April-May. *Asterionella formosa* is often the dominant diatom, formerly with *Fragilaria crotonensis*, latterly more often with *Melosira granulata*. *Stephanodiscus astraea* is usually present, although numbers vary considerably from year to year. Pearsall (1923) recorded *Coscinodiscus lacustris*, probably referring to *Stephanodiscus astraea*, (see Battarbee 1976). In recent years *Stephanodiscus hantzschii* has also achieved prominence. The summer phytoplankton maximum may be either blue-green algae or *Ceratium hirundinella*, a dinoflagellate. In the samples taken before the 1960's the dominant blue-green algae were either *Aphanizomenon flos-aquae* or *Coelosphaerium kutzingianium*. Today *Aphanizomenon flos-aquae* and *Anabaena* spp. are found in early summer, but the bulk of the summer blue-green maximum is *Microcystis aeruginosa*. Small cryptomonads have been found in most of the hosepipe samples examined (Belcher and Storey 1968, Reynolds 1978). There are considerable variations in the numbers and species of algae recorded each year.

The phytoplankton periodicity of Ellesmere in 1967 and 1968 was investigated by Reynolds (1973). Like Rostherne Mere there is little early spring phytoplankton. *Asterionella formosa* and *Melosira granulata* formed the bulk of the vernal diatom population. A late spring population of *Anabaena circinalis* was succeeded by summer dominance of *Microcystis* spp. with *Ceratium hirundinella*.

The incorporation and preservation of diatoms and other algae has been investigated in the uppermost sediments of both lakes (Livingstone 1979). In both cases well preserved algae were found, and at Rostherne Mere it was found possible to relate recent records of phytoplankton succession (Belcher and Storey 1968, Reynolds 1978) to distribution of algal remains in the sediment (Livingstone and Cambray 1978).

Both Rostherne Mere and Ellesmere have a rich invertebrate fauna. A species list is given in the appendix to Reynolds (1979) for 10 selected Meres including Rostherne Mere and Ellesmere. Reynolds (*loc. cit.*) states "An updated species list... includes over 250 "taxa", but it is still far from being exhaustive". Among the groups particularly well represented in Rostherne Mere and Ellesmere are gastropods, oligochaetes, leeches, Cladocera, copepods and the larvae of chironomid midges. The profundal fauna of Rostherne Mere was investigated by Brinkhurst and Walsh (1967). In water in excess of 15m deep they found only chironomid larvae and oligochaetes, and in water over 25m deep no active fauna at all. This was found to be due to the permanent deoxygenation of superficial sediments in deep water. It was postulated that this might be due to excessive nutrient input into the lake from bird faeces ('guanotrophy').

Among the fish, the Perch (*Perca fluviatilis*), Roach (*Rutilus rutilus*) and Pike (*Esox lucius*) are common in Rostherne Mere and Ellesmere, in common with most other Meres. Ruffe (*Gymnocephalus cernua*) is reported to be found in Ellesmere (Reynolds 1979). Smelt (*Osmerus eperlanus*) has not been caught in Rostherne Mere, once the only inland locality, since 1922 (Ellison and Chubb

1968). The fish at Rostherne Mere are only netted for experimental purposes. At Ellesmere angling is an important part of the general amenity use of the Mere.

Both Rostherne Mere and Ellesmere support large roosts of gulls and waterfowl. Quantitative data are only available for Rostherne Mere (Harrison and Rogers 1977). Since the early 1960's overnight roosts of over 10000 Black Headed Gulls (Larus ridibundus) have been noted almost every winter. This roost normally starts in August, reaches a peak of up to 15000 birds in November, and finishes in April. Earlier reports are generally not quantitative, but in January 1953 5000 birds were recorded, and in February 1914 600-1000. Black Headed Gulls are reported to have been uncommon at Rostherne Mere until the 1890's. Other gulls currently roost at Rostherne Mere during the winter, including 3000-6000 Herring Gull (Larus argentatus), ca. 3000 Common Gull (Larus canus) and 1000-7000 Lesser Black Backed Gulls (Larus fuscus) in passage in September-October.

Mallard (Anas platyrhynchos) overwinter at Rostherne Mere; between 1500 and 4000 have been recorded every winter since 1948. Earlier records mention "some thousands". Currently the other common overwintering duck is the Teal (Anas crecca crecca). This roost varies considerably from year to year, maxima in the range 300-3000 being usual. Teal were definitely much less abundant in 1914 when "half a dozen or more birds... for several days together" were sufficient to cause comment.

Gulls and ducks are the most conspicuous birds at Ellesmere. There is "...a substantial bird population" (Reynolds 1979).

CHAPTER III.

METHODS.

METHODS.

Field Work.

Rostherne Mere.

In September 1979 a polypropylene line was stretched across the lake between S and N (Fig. 2b). All the coring operations were conducted from the Nature Conservancy 5m boat secured to this line. The departmental 6m Mackereth pneumatic corer (Mackereth 1958) was used to take 8 cores in water from *ca*. 6 to *ca*. 27m deep.

Preliminary cores taken from Rostherne Mere in 1978, prior to the start of this project, showed that there was more than 6m of lake sediment. A 1.5m extension to the 6m coring tube and stationary piston was constructed. An Extension core, sampling from *ca*. 1.7 - 6.9m mud depth, was obtained in water 27m deep in October 1979. A single 10cm diameter 'Mini'core was collected in *ca*. 27m water depth using the departmental 1m Mackereth pneumatic minicorer (Mackereth 1969) in October 1979.

In December 1979 a 12m corer (Barton and Burden 1979) was tested in Rostherne Mere, on the line S - N, by the Department of Geophysics, University of Edinburgh. A 10.5m core was obtained after some problems with the corer. This core was seriously damaged when frozen in storage at Edinburgh.

8 marginal sediment cores were taken in water less than 3m deep, in September 1979, using a Russian peat borer. At 3 sites complete sequences were collected, and at 5 sites the corer was inserted as far as possible and a single 0.5m sample taken. The line S - N was removed in early 1980.

Ellesmere.

A polypropylene line was placed across the lake between W and E (Fig. 3b) for two weeks in July 1980. The majority of the coring was carried out with the departmental 5m boat secured to the line.

Experience at Rostherne Mere had shown that in water less than 20m deep, the 6m Mackereth corer would take cores less than 6m long (Table A). In Ellesmere the maximum water depth is ca. 18m. An extension to the length of the corer anchor chamber by 0.6m was constructed, and gave longer cores in tests at Rostherne Mere.

TABLE A.

With standard 1.3m anchor chamber		With extended 1.9m anchor chamber	
Water depth	Core length	Water depth	Core length
6.25m	3.5m	5.0m	4.0m
15.0m	4.3m	9.0m	4.75m

In July 1980 5 cores on line W - E, and 1 from core site 5, were collected with the 6m Mackereth corer in water from ca. 10m to ca. 18m deep. No 1.5m extension core was taken. A single 10cm diameter 'Mini'core was obtained in ca. 17.5m water depth. 11 marginal sites were investigated using a Russian peat borer in soft sediment and an auger in firm sediment.

Treatment of Samples.

The long Mackereth cores were sealed in their tubes with rubber bungs and tape, and carefully labelled.

The 'Mini'core was recovered through an observation hatch in the centre of the boat. A gantry was used to hold the corer vertical (Plate 3, below) while the base was immediately plugged with a tight fitting piston and purpose built pump. The corer was disengaged from the top of the core tube. The core sample, in the core tube, was carefully moved to the lake margin, and securely lashed to a post in a building adjacent to the lake.

The Russian core samples were either transferred to 0.5m long plastic gutter sections, and sealed in polythene sheet, or plastic cuboids were used to take contiguous aligned samples (Thompson 1979).

Plate 3. Ellesmere, showing the departmental 5m boat and gantry used to hold the 'Mini'corer vertical.

Laboratory Methods.

Whole Core Measurements.

All the long cores, sealed in their tubes, were subjected to non-destructive palaeomagnetic analyses before subsampling (see below).

Subsampling of Cores.

Rostherne Mere core 5 and Extension Core, and Ellesmere cores 4, 5 and 6 were cut into 1.5m lengths and then sliced lengthwise. A circular electric saw was used to cut through most of the core tube wall along diametrically opposite sides. The remaining tube wall was then cut with a sharp knife. A length of wire was drawn through the sediment core, cutting the sediment in half lengthwise. The two halves were slid apart and stored separately sealed in layflat polythene tube. This method does not disturb the vertical arrangement of the sediment, but destroys the core tube.

The remaining 6m Mackereth cores were extruded into polythene lined wooden troughs, sealed in polythene sheet and protected with wood lids. This method enables re-use of the core tubes, but can result in stretching or compression of the core sample.

The 10.5m core was sliced lengthwise because it was not possible to extrude it,

The length of each core was measured, and marks made at 0.1m intervals on the core tube or trough. Lithostratigraphy was assessed by eye on cleaned sediment surfaces.

Triplicate 1cm^3 samples were taken at intervals of 0.1m from Rostherne Mere core 5 and Extension core.

Similar samples were taken at intervals of 0.1m or less from Ellesmere core 6. These samples were used for diatom and chemical analyses, and determination of mass of dry and ignitable components. The 1cm^3 samples were taken with a modified graduated syringe. Small samples of about 20mm^3 were removed from Rostherne Mere core 3 and Ellesmere core 4 at 0.2m intervals for diatom analyses. Similar examples were taken from Rostherne Mere core 10.5 at irregular intervals.

Sections of up to 0.1m length were removed from the Rostherne Mere Extension core and core 5 and Ellesmere core 6 for ^{14}C analyses.

Plastic cuboids were pushed into one half of Rostherne Mere core 5, removed and sealed with lids and tape, to give contiguous, aligned samples for single sample palaeomagnetic measurements.

The 'Mini'cores from each lake were subsampled the day after collection in a temporary laboratory set up adjacent to the lake. The sediment was extruded using a water pump to raise the piston inserted after recovery. A removable 0.01m thick ring 0.1m diameter was placed on top of the core tube. The sediment was pumped to the top of the ring, and a plate slid between the core tube and the ring, removing a 1cm thick slice from the top of the sediment core. Three 1cm^3 samples were taken from the slice for diatom and chemical analyses using a modified graduated syringe. A plastic cuboid was filled using a non-ferrous spatula, for susceptibility measurements. The remainder was sealed in a polythene bag for ^{137}Cs and ^{210}Pb analyses.

Samples of about 20mm^3 were taken at 0.25m intervals from Rostherne Mere Russian core G and Ellesmere Russian core R.

Palaeomagnetic Analyses.

Whole Core Measurements.

Whole core susceptibility was measured on all the Mackereth cores at the Department of Geophysics, University of Edinburgh. Measurements were made automatically at 28mm intervals as the cores were pushed through a susceptibility bridge (Molyneux and Thompson 1973).

Whole core intensity of natural remanent magnetization (NRM intensity) and declination were measured simultaneously using a spinner fluxgate magnetometer (Molyneux *et al*. 1972) at the Department of Geophysics, University of Edinburgh. The readings were made at 50mm intervals, and each reading was computer integrated over a period of 20 seconds.

Single Sample Measurements.

NRM intensity, declination and inclination were measured on aligned contiguous fresh single samples from Rostherne Mere core 5. These were stored for 24 hours prior to measurement in a zero field mu-metal shield to remove viscous magnetic components. The measurements were made using a computerised spinner fluxgate magnetometer (Molyneux 1971) at the Department of Geophysics, University of Edinburgh. Six samples from this core were subjected to demagnetization using an alternating field demagnetizer (Collinson 1975) at peak fields of 1.5, 2.8, 5.2, 10.4, 20.7, 40.7 and 80.7 milliTesla. The intensity of remanent magnetization and its direction were measured after each demagnetization, taking care to avoid samples gaining viscous components. The median destructive field was calculated.

Single sample susceptibility and saturation isothermal remanent magnetization (SIRM) after exposure to a 1 Tesla field were measured on contiguous fresh samples from the top 1.5m of Rostherne Mere core 5, the fresh cuboid samples from Rostherne Mere 'Mini'core and Russian core G, and Ellesmere 'Mini'core and Russian core R.

Radionuclide Dating of Deposits.

Samples for ^{14}C analysis were sent to the N.E.R.C. Radiocarbon Laboratory at the Scottish Universities Research and Reactor Centre, East Kilbride. 9 horizons were selected from the Rostherne Mere core 5 and Extension core for ^{14}C analysis, with reference to the palaeomagnetic ages suggested by declination data. The inorganic carbon content of the samples varied from a trace to 1.5% (Harkness pers. comm.). An attempt was made to conduct ^{14}C analyses on this inorganic fraction, to enable a'hard water' correction to be made to the ^{14}C age of the organic carbon fraction.

The suspected Late-Devensian age of the pink basal clay, and the requirement for a sufficiently detailed rate of deposition enabled selection of 6 samples from Ellesmere core 6 for ^{14}C analysis.

In all cases loss on ignition was used as an approximate measure of organic content to decide the length of 4.2cm diameter core needed for ^{14}C analysis. Lengths of between 5 and 10cm were used.

The ^{14}C ages of palaeomagnetic features in the Rostherne Mere Extension core and core 5 were calibrated according to Thompson and Turner (1979), based on the dendrochronological calibration curve of Clark (1975). The symbol BP is used to denote the dendrochronologically calibrated dates, and the symbol bp to denote uncalibrated ^{14}C ages. This follows the notation of Clark (1975).

The Atomic Energy Research Establishment at Harwell conducted the ^{137}Cs and ^{210}Pb analyses.

^{137}Cs analyses were carried out on each of the top thirty $1cm^3$ slices of the Rostherne Mere and Ellesmere 'Mini'cores.

Ten slices, 2 or 3cm thick, were selected from the Rostherne Mere 'Mini'core, and from the Ellesmere 'Mini'core for ^{210}Pb analysis, with reference to the ^{137}Cs results, and also the ^{137}Cs analyses from Rostherne Mere reported by Livingstone and Cambray (1978) and Gaskell and Eglington (1976).

Diatom Analyses.

Diatom Cleaning and Counting Routine.

All samples for diatom analysis were cleaned using a mixture of one part Normal potassium dichromate to two parts concentrated sulphuric acid. After at least 30 minutes in this solution the samples were centrifuged at 3500 r.p.m. and washed several times with distilled water.

The mountant used for the prepared coverslips was Naphrax (R.I. 1.74). The mounted preparations were warmed on a hotplate for 24 hours to drive off the solvent. Counting was carried out using x 1000 magnification, under oil immersion, on a Vickers microscope. Fragmented specimens were counted if the central area, or more than half the frustule, was present. *Asterionella formosa* fragments were included where the larger apical inflation was present. Girdle bands and, in *Tabellaria* spp., intercalary bands were not counted.

Absolute Diatom Counts.

The statistically reliable evaporation tray method of Battarbee (1973a) was adopted for the preparation of material for absolute diatom analyses. In view of the time consuming nature of the technique, some abbreviation was considered desirable. The variation between replicate trays has been shown to be the least source of variation (Battarbee 1973a). In the present study trays were not replicated, one only being used per sample.

1cm^3 samples were cleaned and disseminated in 2 litres of distilled water. A 25ml subsample was evaporated in a tray containing four 19mm diameter coverslips. Evaporation proceeded without disturbance in a cupboard. A lamp was used to keep the air temperature at between 25 and 30°C during evaporation. The prepared coverslips were mounted.

Traverses of measured width were made across each of the four coverslips. In almost all cases more than 800 diatoms were encountered within one to four traverses.

Volume of Diatoms.

The dimensions of selected diatom species were established. The dimensions clearly vary between lakes (Battarbee 1973b) so were established separately for each lake. A random sample of 100 cells was measured with an eyepiece graticule and a Vernier focusser. Where a diatom taxon occurred at two separate levels in the sediment, and was entirely absent between those levels the dimensions of the two populations was recorded separately. The mean volume of each of the selected species and populations was calculated.

Absolute Diatom Calculations.

The number of diatom cells per mm^3 of fresh sediment was worked out, in total, and for selected groups and species. This has been termed numerical concentration (units mm^3) throughout this thesis.

Selected numerical concentrations, with the relevant rates of deposition, were used to estimate numbers of diatom cells accumulating per square metre per annum (units $m^{-2}a^{-1}$), termed numerical accumulation rate.

The numerical accumulation rates and the diatom volume measurements were employed to estimate the volume of diatom cells accumulating per square metre per annum (units $mm^3m^{-2}a^{-1}$) hereafter termed volume accumulation rate.

Relative Diatom Counts.

Sediment samples of about $20mm^3$ were cleaned and mixed with a small volume of distilled water, to give a pale opalescent suspension. Drops of this suspension were placed on coverslips, evaporated to dryness and mounted. In almost all cases 500 or more diatoms were counted from each sample. For each species the percentage of the total diatom sum was calculated.

Diatom Identification.

Diatoms were largely identified with reference to the works of Hustedt (1930, 1930 - 66) with the following exceptions. The genera Diatoma, Cymbella and Gomphonema were identified from the Flora of Patrick and Reimer (1966, 1975). Fragilaria elliptica and F. pinnata were separated according to Haworth (1975). Tabèllaria spp. were not divided at all. It was not found possible to apply the treatment of Knudson (1952) reliably to the wide range of Tabellaria spp. forms encountered.

Correspondence Analysis of Diatom Data.

This multivariate numerical technique, also called Reciprocal Averaging, was developed by Hill (1973, 1974), and is especially suited to providing a readily interpreted multidimensional representation of the relationships of samples to one another. It has been used for objective zonation of pollen and diatom profiles (Elner and Happey-Wood 1980) and has been applied to recent macrofossil assemblages (Birks 1973). Correspondence analysis is a specialized analogue of the more widely used Principal Components Analysis (Prentice 1980).

Correspondence analysis was carried out on diatom volume accumulation rate data from the Rostherne Mere Extension core, core 5 and 'Mini'core. Interpretation was restricted to indications of gross changes in diatom stratigraphy, and any possible correlations between the 'Mini'core and core 5.

Chemical Analyses.

Dry Mass.

$1cm^3$ samples from selected cores from Rostherne Mere and Ellesmere were dried for 24 hours at 110^oC and weighed. This will result in the loss of almost all interstitial water, part of any ammonia present, and perhaps a very small amount of organic matter and structural water from clays. The mass after drying has been termed concentration of dry mass (units mg mm^{-3}). This concentration of dry mass has been used, with sedimentation rate, to estimate annual accumulation of dry mass, called dry mass accumulation rate (units g m^{-2} a^{-1}) in this thesis.

Mass Lost on Ignition at 450°C.

1cm^3 wet samples were dried at 110°C for 24 hours, weighed, ignited at 450°C for 4 hours and reweighed. This temperature was chosen to maximise the contribution of organic material to the mass lost. Losses will include most organic material, much structural water from clay minerals, some dehydration of gypsum, any remaining ammonia and some volatile salts. At temperatures below 375°C combustion of organic material may be inefficient, and above 500°C volatilization of salts may become increasingly important (Allen 1974). The mass lost on ignition at 450°C, per 1cm^3 wet sediment sample, is termed concentration of mass lost on ignition. This emphasizes that while it is based on the same measurements as percentage loss on ignition, the results are presented in a different form (cf. Digerfeldt 1972). The concentration of mass lost on ignition and the rates of sediment deposition were used to estimate the mass lost on ignition accumulating per square metre per annum, called accumulation rate for mass lost on ignition (units g m^{-2} a^{-1}).

Carbon, Nitrogen and Phosphorus Analyses.

Samples of 1cm^3 from selected Rostherne Mere cores were chosen, at intervals of up to ca. 1m, for carbon, nitrogen and phosphorus analyses. Similar samples were selected for carbon analyses from Ellesmere core 6 and 'Mini'core.

Organic Carbon.

Organic carbon was determined by the method of Guppy and Happey-Wood (1978). The sediment samples were air dried, ground to a powder, oven dried and mixed with one part Molar potassium dichromate and two parts concentrated sulphuric acid. Oxidisation was terminated after 30 minutes by dilution and centrifugation. Blanks and glucose standards were prepared similarly. The absorption of green chromous ions at 585mm was measured.

This method could readily be adapted for the routine measurement of organic carbon at the same time as preparation of diatom samples for absolute diatom counts. The method for organic carbon measurement was not decided, in this project, until after the completion of the diatom preparations, so this was not done. The sediment should be air dried, powdered and then oven dried, to facilitate oxidation of ferrous ions which might otherwise cause interference.

Kjeldahl Nitrogen.

Nitrogen was measured using a Kjeldahl technique. Samples and blanks were digested by heating in a concentrated sulphuric acid mixture with a catalyst (100 parts KSO_4:10 parts $CuSO_4.5H_2O$:1 part Se). When frothing had ceased, refluxing was continued for 1 hour. The efficiency of the Markham distillation unit was checked using ammonium sulphate solution. After cooling and dilution, aliquots of the digest were steam distilled into 1% boric acid indicator solution, using the Markham distillation unit with an excess of NaOH. The distillates were titrated against dilute sulphuric acid.

Total Phosphorus.

A dry-ashing technique was used to prepare sediment samples for total phosphorus measurement. This was preferred to boiling the samples in perchloric acid or hydrogen peroxide on safety grounds. Phosphates may be leached out of glassware, so porcelain crucibles and plastic vessels and spectrophotometer cuvettes were used. These were all washed in dilute HCl, rinsed in deionised water, washed in 5% Decon 90 (a phosphorus-free surface active cleanser) and thoroughly rinsed in deionised water before use.

Each $1cm^3$ fresh sample and blank was evaporated dry with 5ml of 20% w/v magnesium acetate solution prior to ignition in a muffle furnace (with filtered ventilation) at 500^oC for 3 hours (Allen 1974).

When cool 5ml HCl was added, the mixture covered and heated on a steam bath for 15 minutes. 1ml of HNO_3 was added, and the mixture evaporated; heating was continued for an hour after dryness was attained. 1ml of 50% v/v HCl was added, and the residue diluted to 10ml with deionised water, and warmed to ensure complete dissolution. After filtration the samples were made up to 50ml with deionised water. Aliquots of this solution were treated using a standard molybdenum blue method (Allen 1974). Development with stannous chloride was carefully timed for 30 minutes for each sample. Standards were freshly prepared for each batch of samples using NaH_2PO_4.

For carbon and phosphorus, standard curves were prepared, and the amounts of each per unit volume of wet sediment read off. The amount of nitrogen per unit volume of sediment was calculated from the volume of dilute H_2SO_4 required to titrate a known aliquot of distillate to the end point.

The mass of chemical per unit volume of wet sediment is termed concentration (units $mg\ mm^{-3}$) throughout this work. The rates of sediment deposition were used with the concentrations of the chemicals to estimate the mass of chemical accumulating per square metre per annum, called accumulation rate (units $g\ m^{-2}\ a^{-1}$).

CHAPTER IV.

RESULTS AND DISCUSSION.

RESULTS AND DISCUSSION.

Rostherne Mere.

Correlation and Chronology of Cores.

Position and Stratigraphy.

The position and stratigraphy of Mackereth cores taken along line S - N (Fig. 2b) is shown in Fig. 8. A key to the stratigraphic symbols used is shown in Fig. 7. The sediment sampled consisted almost entirely of fine textured brown lake mud, rather blacker near the top of the sequences. Grey sand occurred at the base of Rostherne Mere core 8 (3.47 - 3.53m).

The position and stratigraphy of marginal Russian cores taken near the ends of transect S - N (Fig. 2b) is presented in Fig. 9. Depths of *ca*. 6m were penetrated in cores A, C and D at the southern margin. At the northern margin depths of *ca*. 3.5m were reached in cores E, G and H. Cores B and F encountered excessive wood. The majority of the sediment sampled consisted of coarse detrital brown lake mud. Grey sand bands were found near the bottom of cores A and C. Grey sand occurred at the base of cores E and G, with grey clay beneath this in core H.

Correlation of Long Cores.

In order to attempt to correlate the sediment cores obtained along transect S - N (Fig. 2b), three independent palaeomagnetic parameters were investigated. The correlation of sediment sequences has been achieved using susceptibility (e.g. Thompson *et al*. 1975, Thompson and Morton 1979), intensity of natural remanent magnetization (Thompson and Wain-Hobson 1979) and declination (Thompson and Morton 1979, Thompson and Wain-Hobson 1979).

The results of whole core susceptibility measurements made on Mackereth cores 1 - 8 from Rostherne Mere are shown in Fig. 10. The values recorded, between 80 and 150 microSI units, were moderately low; results from 0 to over 1000 microSI units have been reported (Stober and Thompson 1979, Turner and Thompson 1981). The initial impression is one of overall homogeneity. but use of an appropriate scale in Fig. 10 has revealed a wealth of small scale variation. Tentative temporal correlations are numbered 1 - 19. It was not found possible to extend such correlations to the more marginal cores 1, 7 and 8. Core 6 was clearly anomalous with large susceptibility peaks, later shown to be a function of magnetic contamination of the core tube (Table 12, page 131).

Measurements of susceptibility made on core 10.5 showed that the frost damage had drastically altered the magnetic character of the sediment (Table 13,page 131), and no further magnetic measurements were made on this core.

Whole core intensity of natural remanent magnetization (NRM intensity) results are presented in Fig. 11. In general the readings were unusually low, from <u>ca</u>. 2 - 10 mA m^{-1}, compared to maxima from other lacustrine sediments of 100 mA m^{-1} (Thompson and Wain-Hobson 1979), and of 200 mA m^{-1} (Turner and Thompson 1979). Tentative correlations between Rostherne Mere cores 3 - 5 and Extension are denoted by Roman numerals I - XV (Fig. 11). No correlation was considered possible for the remaining cores. Core 6 showed anomalous NRM intensity peaks.

The whole core relative declination measurements are shown in Fig. 12. The meaningless results for the anomalous core 6 are omitted. Rotation of the core tube during core operations (<u>cf</u>. Barton and Burden 1979) caused a trend in the results for core 3 (Fig. 13a). To facilitate comparison with other records a simple detrending procedure was adopted. The data was recomputed around a vertical axis from measurement of distance in degrees from a chosen axis (Fig. 13b). For correlation purposes this procedure is adequate, but a more sophisticated approach would be required if the data were used for any study of past magnetic direction. A number of east/west declination swings may be seen in Fig. 12, similar to those reported from other British lakes (e.g. Mackereth 1971, Turner and Thompson 1981). These swings have been denoted A - E in accordance with Mackereth (1971), with the addition of E' (Turner and Thompson 1981). No correlation was possible with the more marginal cores 1, 7 and 8.

The tentative correlations produced from these three independent palaeomagnetic parameters (susceptibility, NRM intensity, declination) are compared in Fig. 14. There is close correspondence between the independently derived correlations, increasing confidence in their validity greatly. In particular there is good temporal correlation between Rostherne Mere cores 3, 4, 5 and Extension, with rather weaker correlation with the lower part of core 2.

The palaeomagnetic data were used to select suitable sediment sequences for further study. Examination of the susceptibility (Fig. 10) and NRM intensity (Fig. 11) records of the basal sediments indicated that the oldest sediments were in the Extension core. The sediments above 3m in this core appeared disturbed. The Extension core is particularly well correlated with cores 4 and 5, but the declination record of core 4 is markedly inferior to that of core 5 (Fig. 12). Rostherne Mere core 5 and the Extension core were chosen for further detailed work including chronological, absolute diatom and some chemical analyses. Core 3 is well correlated with both core 5 and the Extension core (Fig. 14), and contains sediment older than any correlated core except the Extension core (Figs.

10 and 11). Rostherne Mere core 3 was selected for less detailed relative diatom counts.

Correlation of 'Mini'core.

Correlation of the Rostherne Mere 'Mini'core with the Mackereth 6m cores proved difficult. The susceptibility and saturation isothermal remanent magnetization (SIRM) profiles based on single sample measurements did not at first sight appear similar (Table 14,page 132). Examination of biostratigraphy showed a decline to low percentages of Stephanodiscus hantzschii, in the lowest sample analysed in the 'Mini'core (0.7m) (Fig. 32) and below 0.3m in core 5 (Fig. 27). Correspondence analysis of the volume accumulation rate data for all the samples analysed for the Extension core, core 5 and 'Mini'core (Fig. 48a) showed that the four uppermost samples were most unusual. Correspondence analysis, leaving out these four samples, showed that the samples from 0.02 and 0.10m in core 5 were similar to those from 0.35 - 0.45m in the 'Mini'core (Fig. 48b). Re-examination of the susceptibility and SIRM data (Table 14,page 132) showed that the 'Mini'core records from 0.72 - 0.50m were similar to the core 5 records for 0.30 - 0.10m. Above 0.50m in the 'Mini'core there was a considerable trough in both susceptibility and SIRM, not represented in core 5. The top 10cm of core 5 are likely to be disturbed by the coring device, so this disparity is not surprising. This rather tenuous correlation between the 'Mini'core has been referred to only in the construction of Fig. 47, where the use of time as the ordinate means that small errors in alignment will not be serious. These rather poor correlations are summarised in Table 15 , page 133.

Correlation of Russian Core G.

An attempt to correlate this core with the deep water Mackereth cores using palaeomagnetic measurements was unsuccessful due to the low susceptibility and intensity of natural remanent magnetization. The very low percentage frequency of planktonic diatoms in some samples (Fig. 39a) initially rendered biostratigraphic correlation impossible. Special counts of planktonic and occasionally planktonic diatoms were made on most samples, up to a planktonic/ occasionally planktonic sum of at least 250 (Fig. 39b). The non-planktonic diatom, *Navicula scutelloides* was largely restricted to above *ca.* 1.9m in Mackereth core 5 (Fig. 28) and 0.37m in Russian core G (Fig. 40). The planktonic diatoms *Asterionella formosa* and *Stephanodiscus astraea* become frequent above *ca.* 2.0 - 3.0m in core 5 (Fig. 27), 0.25m in Russian core G (Fig. 39b) and the planktonic species *Stephanodiscus hantzschii* and *Fragilaria crontonensis*, not very frequent below *ca.* 1.5m in core 5 (Fig. 27), are only found in the topmost sample in Russian core G (0.10m, Fig. 39). Below 0.5m in Russian core G it was not found possible to produce correlations at all. These rather weak biostratigraphic correlations are summarised in Table 16, page 133.

Palaeomagnetic Dates.

Whole core relative declination for Rostherne Mere cores 3 and 5, and Extension core, and single sample inclination for the upper *ca.* 4.5m of core 5 are shown in Fig. 15. East and West swings in declination have been labelled A - F, in accordance with Mackereth (1971), with the addition of E', distinguished in more recent, better resolved declination profiles (Turner and Thompson 1981). Turning points in inclination have been labelled α and β, as in Thompson and Turner (1979). The past magnetic directions found in the sediments of Rostherne Mere are strikingly similar to those reported for other British Late-Flandrian sediments (e.g. Thompson and Wain-Hobson 1979, Turner and Thompson 1981).

In order to investigate the stability of the natural remanence measured, six samples from Rostherne Mere core 5 were subjected to alternating field demagnetization. The results are shown in Fig. 16. The polar stereographic plots showed that the direction of magnetization did not alter significantly during stepwise demagnetization until fields of 40 or 80 mT, and was therefore stable. The intensity of magnetization declined gradually, and the median destructive field lay between 27 and 40 mT (Table 8 below), again showing stability. The intensity of magnetization after demagnetization at 20 mT was unknown due to a calibration error.

Table 8 .

Median destructive field (MDF) of natural remanent magnetization of 6 samples from core 5.

Sample m	MDF mT	Sample m	MDF mT
0.72	27	3.46	40
2.20	35	4.23	37
2.92	30	5.46	35

The age of the palaeomagnetic features has been discussed with reference to both archaeomagnetic evidence, from ancient kilns (Aitken 1970, 1974, Thellier 1981) and palaeomagnetic evidence, from lacustrine sediments (Thompson and Turner 1979, Thompson and Wain-Hobson 1979, Thompson and Edwards 1982).

Archaeomagnetic curves for London (from Aitken 1970) and Paris (from Thellier 1981) are shown in Fig. 17. The diagrams as originally presented (Fig. 17a and b) are not easily compared with palaeomagnetic records, and so are replotted in the same format as standard palaeomagnetic curves (Fig. 17 c - f). A similar curve has been prepared for London by A. J. Clark (Thompson pers. comm., Turner and Thompson 1981). These archaeomagnetic curves provide an independent temporal calibration for the palaeomagnetic curve in the last two millenia.

Comparison of ^{14}C age with Flandrian declination records is possible for sites in mainland Britain (Thompson 1979, Thompson and Wain-Hobson 1979) and in Ireland (Thompson and Edwards 1982), reproduced in Fig. 18. This diagram also shows the calibration curve of Thompson and Turner (1979). The ^{14}C dates prior to ca. 3000 bp are generally in quite good agreement both with each other, and with the calibration curve. The release of 'old carbon' during catchment erosion, subsequent to human activity, has caused a much wider scatter of dates since 3000 bp (cf. Pennington et al. 1976).

The calibration curve of Thompson and Turner (1979) was based on archaeomagnetic and ^{14}C dates from mainland Britain. The generally good agreement of this curve with the data from Ireland gives confidence in its use. The basis of the palaeomagnetic calibration has been stressed at length because it is central to the Rostherne Mere chronology used in this thesis, but is not yet a familiar palaeolimnological tool.

^{14}C Analyses.

The dates obtained from ^{14}C analyses of 9 samples from Rostherne Mere cores 5 and Extension are shown in Table C . The inorganic carbon contents of the samples are also shown (Harkness pers. comm.).

Table C .

^{14}C ages and inorganic carbon (IC) in 9 samples from cores 5 and Extension (Ext).

NERC code	Core	Sample m	^{14}C age bp	IC %
SRR-1886	5	2.075-2.125	1030 ± 70	Trace
SRR-1887	5	2.800-2.850	480 ± 80	ca. 0.1
SRR-1888	5	3.525-3.575	580 ± 100	0.1
SRR-1889	Ext	3.575-3.625	1120 ± 70	0.5
SRR-1890	Ext	4.275-4.325	2620 ± 70	0.4
SRR-1891	Ext	4.975-5.025	2090 ± 70	0.5
SRR-1892	Ext	5.575-5.625	1070 ± 140	Trace
SRR-1893	Ext	6.375-6.425	2250 ± 70	1.5
SRR-1894	Ext	6.575-6.625	2190 ± 80	1.2

An attempt to measure ^{14}C age on the inorganic fraction, in order to apply a correction for possible 'hard water' error was thwarted by insufficient carbonate.

The chronological information available for the Rostherne Mere cores 5 and Extension is summarised in Fig. 19. The ^{14}C dates are extremely scattered, and some are significantly younger than the palaeomagnetic age, particularly those with inorganic carbon contents of 0.1% or less. The well resolved and soundly calibrated palaeomagnetic ages are unlikely to be significantly incorrect, and they have been used, after conversion to dendrochronological years BP using the calibration curve of Clark (1975), to construct an age/depth curve. From this have been derived rates of sediment deposition (Table 1 , page 120), used to estimate rates of accumulation from concentration data.

The ^{14}C ages of palaeomagnetic declination features between A and G from 14 sites (including the four low carbonate dates from Rostherne Mere (page 40) and one from Ellesmere (page 82)) in the British Isles are shown in Fig. 20a. The results are quite scattered, and many ^{14}C ages appear too old. This is usually attributed to anthropogenic disturbance of catchment soils liberating 'old carbon' into lake inflows, diluting the carbon input into the sediment (Pennington et al. 1976). Four of the ^{14}C dates are considerably too young, shown in greater detail in Fig. 20b. These significantly young ^{14}C dates from Rostherne Mere and Loch Lomond (Dickson et al. 1978) are difficult to understand. The effect of 'hard water' error is to give dates too old. The age and magnitude of these deviations preclude atmospheric ^{14}C concentration variations as a mechanism (Suess 1970, Clark 1975). It is possible for large scale vertical mixing to cause anomalous ^{14}C ages (Baxter and Harkness 1975). The presence in the sediments of Rostherne Mere of both palaeomagnetic (pages 33 - 36) and biostratigraphic (pages 46 - 50) intercore correlatives does not favour such an interpretation. Biological or geochemical ^{14}C fractionation may be responsible for such anomalously young ^{14}C ages.

The extent of young ^{14}C ages in lacustrine sediments is obviously of some importance given the wide use of the technique in palaeolimnological studies. A particularly fruitful approach is likely to be palynological correlation of adjacent palaeomagnetically suitable lake sequences with unambiguously ^{14}C dated bog profiles, currently under investigation by Thompson and Edwards (1982). Further resolution of this problem may come from palaeomagnetic and ^{14}C studies of little disturbed high mountain tarns.

^{210}Pb Dating.

Analyses of ^{210}Pb content made on 10 samples from the Rostherne Mere 'Mini'core were used as the basis for establishment of a chronology for the upper sediments. The constant initial concentration model (e.g. Pennington et al. 1976) has been shown to be inappropriate in situations involving a change in rate of deposition (e.g. Battarbee and Digerfeldt 1976). Livingstone (1979) showed both that the uppermost sediments of Rostherne Mere have been deposited at a varying rate, and that the constant initial concentration model produces meaningless results. The constant rate of supply (c.r.s.) model (Appleby and Oldfield 1978) is unaffected by changes in rate of deposition. Use of this model enabled Livingstone (1979) to derive a meaningful age/depth relationship from his ^{210}Pb data.

Unsupported ^{210}Pb levels were calculated from interpolated ^{226}Ra levels derived from determinations at three levels (0.01 - 0.03m, 1.71 ± 0.17 pCig^{-1}; 0.28 - 0.30m, 1.52 ± 0.15 pCig^{-1}; 0.63 - 0.65m, 2.21 ± 0.22 pCig^{-1}). The unsupported ^{210}Pb results are shown in Fig. 21a. Calculation of dates using the constant initial concentration model produced meaningless results (Table 2 , page 121). An age / depth curve (Fig. 21b) was calculated using the c.r.s. model (Appleby pers. comm.).

The ^{210}Pb c.r.s. based age/depth curves for the Rostherne Mere 'Mini'core (Fig. 21b) and for the core of Livingstone (1979) are very similar. Confidence in the application of the c.r.s. model is increased by the similarity of the calculated ^{210}Pb flux density (0.17 pCi cm^{-2} a^{-1}) for the Rostherne Mere 'Mini'core to the flux densities calculated for other sediment sequences from this area (Appleby pers. comm.). Flux density, a physical quality, is defined as flux per unit of cross sectional area (Thewlis 1973). In this case the units are pCi cm^{-2} a^{-1}, from which it may be seen that flux density is equivalent to accumulation rate in palaeolimnology (Thompson 1980).

^{137}Cs Profile.

The peak fallout of nuclear weapon test derived ^{137}Cs in 1963 has been investigated in lake sediments (e.g. Ritchie et al. 1973, Pennington et al. 1976). The results of ^{137}Cs analyses on the top 30 1cm slices of the Rostherne Mere 'Mini'core are shown in Fig. 22. The position of the ^{210}Pb dated 1963 horizon is also shown. The ^{137}Cs peak is at 0.04 - 0.05m, suggesting that the profile is similar to that reported by Gaskell and Eglinton (1976), and very different from that shown in Livingstone and Cambray (1978). This seems remarkable in view of the similarity of the ^{210}Pb profiles of the Rostherne Mere 'Mini'core (Fig. 21) and that in Livingstone (1979).

There are various possible mechanisms for the production of anomalous ^{137}Cs distributions in lake sediments. Deposition of ^{137}Cs in lake catchment, with later erosion and redeposition can be responsible Mchenry et al. 1973). This would be characterised by a large overall input of ^{137}Cs since 1963. Vertical diffusion of ^{137}Cs in the sediment, due to biological or geochemical processes, would also cause anomalous distribution in the sediment, but would be unlikely to result in a greatly excessive apparent ^{137}Cs input since 1963. Comparison of some ^{137}Cs parameters from the Rostherne Mere 'Mini'core and the core shown in Livingstone and Cambray (1978) is made in Table 3 , page 122 .

The small difference between the total ^{137}Cs which has accumulated since 1963 suggests that vertical diffusion may have occurred(cf. Appleby and Oldfield 1978). It seems that ^{137}Cs dating may not be reliable even within one lake basin, and should probably only be used for sediment dating in conjunction with other techniques.

Diatom Analyses.

Presentation of Results.

The results of relative diatom analyses at closely spaced intervals in the Rostherne Mere Extension core, core 5 and 'Mini'core are shown as diatom diagrams (Figs. 23, 27, 28 and 32), including all taxa which comprised 2% or more of the diatom sum for any sample in the core. The diatom taxa are grouped according to preferred habitat (Table 4 , page 122). The value of detailed presentation of minor taxa was felt to be small. A species list of taxa which did not occur at 2% in any sample is included for each core (Tables 5 , 6 , 7 , pages 126- 128).

Relative diatom counts made on samples taken at wider intervals in Rostherne Mere cores 3, 10.5 and marginal core G are presented as similar diatom diagrams (Figs. 36 - 40). All taxa which occurred at greater than 2% are included in the diagram, other taxa are presented as species lists (Tables 8 , 9 , 10, pages 128- 130).

The mean volume determined from measurements of 100 individuals of each planktonic or occasionally planktonic diatom species are shown in Table 11, page 130. Melosira granulata and Melosira granulata var. angustissima occur twice because they were found as two temporally discrete populations, differing in mean volume.

Absolute diatom analyses on samples from the Rostherne Mere Extension Core, core 5 and 'Mini'core are presented as triplets of diagrams. The numerical concentrations (see page 27), in total, and for those preferring various habitats are shown in Figs. 24, 29 and 33. The numerical concentration of planktonic and occasionally planktonic diatoms may be found in Figs. 24b and 25a, 29b and 30a and 33b and 34a. The numerical accumulation rate (see page 27) for planktonic and occasionally planktonic diatoms in Rostherne Mere Extension core, core 5 and 'Mini'core are shown in Figs 25b, 30b and 34b. The estimated planktonic and occasionally planktonic diatom volume accumulation rates (see page 27) are presented in Figs. 25c, 30c and 34c.

For each individual planktonic or occasionally planktonic diatom species the diatom diagrams showing estimated volume accumulation rate may be found in Figs. 26 (Extension core), 31 (core 5) and 35 ('Mini'core).

Relative Diatom Analyses.

The relative diatom analyses on the Rostherne Mere Extension core and core 5 are described first, those made on the 'Mini'core, core 3, core 10.5 and the Russian core G follow. It should be noted that, as might be expected from the very variable flora of the present day (Belcher and Storey 1968, Reynolds 1978), there are many oscillations in relative abundance.

Extension Core and Core 5.

In the lowest part of the Extension core (Fig. 23) from 6.8 - 5.8m the dominant planktonic diatoms were generally Melosira italica subsp. subarctica and Cyclotella comta. Cyclotella comensis and Stephanodiscus astraea var. minutula were present at lower percentages, the former becoming abundant from 6.1m. The most common non-planktonic species found were Fragilaria elliptica and Fragilaria brevistriata with smaller numbers of Gomphonema dichotomum (Fig. 23).

From 5.7m to 4.2m (the topmost sample) in the Extension core (Fig. 23), and from the lowest sample, 5.6m to 3.8m in core 5 (Figs. 27 and 28) the dominant diatom was generally Melosira italica subsp. subarctica, although particularly great oscillations in relative abundance may be seen above ca. 4.4m (Fig. 27). Cyclotella comta and the occasionally planktonic Cyclotella ocellata became increasingly prevalent through this part of the sequence. Cyclotella comensis, after a maximum at 5.4m (Figs. 23 and 27) was found, like Stephanodiscus astraea var. minutula, at small percentages. The frequency of non-planktonic diatoms was far lower than in the previous section. Fragilaria spp. and Gomphonema dichotomum were the most often encountered non-planktonic species (Figs. 23 and 28).

Between 3.7 and 3.0m in core 5 (Figs. 27 and 28) the dominant planktonic diatom was *Cyclotella comta*, with isolated maxima of *Stephanodiscus astraea* (3.6m) and *Cyclotella ocellata* (3.4m). Other planktonic diatoms were rather infrequent, but included *Melosira italica* subsp. *subarctica*, *Stephanodiscus astraea* var. *minutula*, and *Cyclotella comensis*. The most prevalent non-planktonic diatoms were *Fragilaria* spp., with *Gomphonema dichotomum* (Fig. 28).

Above 2.9m in core 5 (Figs. 27 and 28), the most constant member of the diatom community was *Stephanodiscus astraea*, dominated by a succession of different planktonic species. *Cyclotella comta* became insignificant by 2.7m, reappearing intermittently, especially between 0.3 and 0.9m (Fig. 27). *Cyclotella ocellata*, occasionally planktonic, became important from 3.0m upwards, almost disappearing again above 0.5m (Fig. 28). *Tabellaria* spp., some of which are planktonic, were abundant from 2.7 - 2.4m (Fig. 27). At 2.4 and 2.3m *Melosira granulata* and *Melosira granulata* var. *angustissima* were common (Fig. 27). A marked peak in relative abundance of the non-planktonic species *Fragilaria construens* var. *binodis* at *ca*. 2.1m (Fig. 28) depressed the planktonic percentages (Fig. 27), partially masking the increasing abundance of *Asterionella formosa*. This species reached a maximum at 0.4m before declining. *Fragilaria crotonensis* became common above 1.9m, increasing to dominance from 0.1 - 0.02m (Fig. 27). *Stephanodiscus hantzschii* was found in small numbers from 2.8m, achieving abundance above 0.3m (Fig. 27). The non-planktonic diatoms were dominated by *Fragilaria construens* var. *binodis* and other *Fragilaria* spp., with smaller percentages of *Cymbella minuta* and *Achnanthes minutissima* (Fig. 28). The overall percentage of non-planktonic diatoms declined to a very low level by the topmost sample.

'Mini'core.

In the 'Mini'core (Fig. 32) *Asterionella formosa* was generally abundant throughout. From the lowest sample investigated, at 0.7m, to 0.4m *Fragilaria crotonensis* was also very abundant, appearing only irregularly in large numbers above 0.35m. *Stephanodiscus hantzschii* was present throughout the core, and was sporadically very abundant above 0.25m. *Stephanodiscus astraea* was found in small percentages in all samples analysed in the 'Mini'core (Fig. 32). *Melosira granulata* var. *angustissima* was found in abundance from 0.25 - 0.07m, and *Melosira granulata* from 0.16 - 0.07m and at 0.01m. *Nitzschia palea* occurred in significant numbers in the uppermost sediment samples. Non - planktonic diatoms were very infrequent (Fig. 32). *Diatoma tenue* would be better regarded as occasionally planktonic, but its omission from further calculation is unlikely to be important due to its infrequency and small volume.

Core 3.

In Rostherne Mere core 3 the relative diatom analyses (Figs. 36 and 37) portray a similar sequence of events to that seen in the Extension core (Fig.23) and core 5 (Figs. 27 and 28). As was expected from the palaeomagnetic correlations (page 35 , Fig. 14), the oldest part of the sequence in the Extension core (Fig. 23) was absent from core 3 (Figs. 36 and 37).

From 5.0 - 4.6m the dominant planktonic diatoms were *Melosira italica* subsp. *subarctica* and *Cyclotella comensis* with *Cyclotella comta* (Fig. 36). Non-planktonic *Fragilaria* spp. were abundant (Fig. 37). This flora is similar to that found from *ca*. 6.1 - 5.8m in the Extension core (Fig. 23).

Between 4.4 and 3.2m in core 3 *Melosira italica* subsp. *subarctica* was dominant, with a decreasing contribution from *Cyclotella comensis*, and small percentages of *Cyclotella comta* and *Stephanodiscus astraea* var. *minutula*. Variable frequencies of the occasionally planktonic *Cyclotella ocellata* were also recorded. This is similar to the flora from 5.7 - 4.2m in the Extension core (Fig. 23), and from 5.6 - 3.8m in core 5 (Fig. 27).

Cyclotella comta dominates the planktonic diatoms in core 3 (Figs. 36 and 37) from 3.0 - 2.6m, with an isolated occurrence of *Stephanodiscus astraea* (2.8m), and small percentages of other planktonic species (Fig. 36). There is a considerable contribution from non-planktonic diatoms, chiefly *Fragilaria* spp. (Fig. 37). This assemblage is like that found between 3.7 and 3.0m in core 5 (Figs. 27 and 28).

Above 2.4m in core 3 there was a fairly constant contribution from *Stephanodiscus astraea*, dominated by a succession of other planktonic diatoms (Fig. 36). *Cyclotella comta* declined to insignificance by 2.2m, and occurred only intermittently above this. The occasionally planktonic *Cyclotella ocellata* was generally important from 2.4 - 0.6m (Fig. 37). *Tabellaria* spp. were found particularly at 2.2m (Fig. 36). *Melosira granulata* and *Melosira granulata* var. *angustissima* were briefly significant at 2.0m. *Asterionella formosa* was abundant from 1.6m upwards. *Fragilaria crotonensis* became abundant from 1.2m, and dominant from 0.6m. Non-planktonic diatoms, mainly *Fragilaria construens* var. *binodis* and *Fragilaria elliptica*, decline in frequency towards the top of the core (Fig. 37). This sequence of assemblages is similar to that found above 3.0m in core 5 (Figs. 27 and 28).

Core 10.5.

Below 9.8m in core 10.5 (Fig. 38), the dominant planktonic diatom was *Melosira italica* subsp. *subarctica*. From 9.0 - 5m the most frequent planktonic diatoms were *Melosira italica* subsp. *subarctica* and *Cyclotella* spp., a similar flora to that found below 5.8m in the Extension core (Fig. 23). Between 4.5 and 3.5m in core 10.5 (Fig. 38) *Melosira italica* subsp. *subarctica* again achieved dominance, with small percentages of *Cyclotella* spp. and *Stephanodiscus astraea* var. *minutula*, similar to the flora found between 5.7m in the Extension core (Fig. 23) and 3.9m in core 5 (Fig. 27). At 3.0m planktonic diatoms were infrequent in core 10.5 (Fig. 38), the most common being *Cyclotella comta*, like the diatom assemblage between 3.8 and 3.1m in core 5 (Fig. 27). The planktonic diatoms in core 10.5 (Fig. 38) at 2.4m are dominated by *Cyclotella comta* and *Stephanodiscus astraea*, and at 2.0m by *Stephanodiscus astraea* and *Melosira granulata*, similar to the core 5 assemblages at *ca*. 2.8 - 3.0m and 2.4 - 2.3m respectively (Fig. 27).

The non-planktonic diatoms (Fig. 38) found most frequently at all levels in core 10.5 were *Fragilaria* spp. and *Gomphonema dichotomum* and *Epithemia zebra* made isolated contributions (Fig. 38).

Russian Core G.

In the marginal Russian core G, the diatom analyses showed rather low planktonic percentages (Fig. 39a). Special counts were made, only including planktonic and occasionally planktonic diatoms, and the results were expressed as percentage of planktonic and occasionally planktonic sum (Fig. 39b).

From the lowest sample analysed, at 3.0m, to 0.5m, the dominant non-planktonic diatoms were *Fragilaria* spp., with a contribution from *Gomphonema dichotomum* from 1.83m upwards (Fig. 40). Other occasionally frequent diatoms included *Achnanthes minutissima*, *Melosira varians*, *Navicula graciloides* and *Gomphonema olivaceum* (Fig. 40). The very infrequent planktonic species from 3.0 - 2.5m (Fig. 39a) were dominated by *Cyclotella comta*, with small amounts of other *Cyclotella* spp. and *Melosira italica* subsp. *subarctica* (Fig. 39b). From 2.25 - 0.5m *Cyclotella comta* and *Melosira italica* subsp. *subarctica* were generally co-dominant planktonic species (Fig. 39b), of the much more frequent planktonic flora (Fig. 39a). Other *Cyclotella* spp., *Stephanodiscus astraea* var. *minutula* and occasionally *Fragilaria capucina* were present at lower frequencies (Fig. 39b).

From 0.37m to the topmost sample at 0.10m, the most important non-planktonic taxa were *Amphora perpusilla*, *Navicula scutelloides*, *Achnanthes haukiana*, *Achnanthes clevei* and *Cocconeis thumensis*, with *Fragilaria* spp. (Fig. 40). The planktonic assemblage at 0.25 and 0.16m was co-dominated by *Cyclotella comta* and *Melosira italica* subsp. *subarctica*, with smaller percentages of *Asterionella formosa*, *Stephanodiscus astraea* and *Cyclotella ocellata* (Fig. 39b). The very infrequent planktonic assemblage at 0.10m (Fig. 39a) was dominated by *Stephanodiscus hantzschii* and *Asterionella formosa* with smaller percentages of *Stephanodiscus astraea*, *Fragilaria crotonensis* , *Cyclotella* spp., *Melosira italica* subsp. *subarctica* and the occasionally planktonic *Fragilaria capucina* (Fig. 39b). The characteristic diverse planktonic flora established above *ca.* 2.0 - 3.0m in Mackereth core 5 (Fig. 27) is represented only above 0.25m in Russian core G (Fig. 39b).

Absolute Diatom Analyses.

Numerical Concentration.

Inspection of the diagrams showing numerical concentration of diatoms (see page 27) in samples from the Extension core, core 5 and 'Mini'core (Figs. 24, 25a, 29, 30a, 33 and 34a), shows that planktonic diatoms were generally more numerous than non - planktonic. A notable exception was between _ca_. 2.0 and 1.5m in core 5, where numerical concentration of non - planktonic diatoms (Fig. 29c) reached its highest levels before declining to very low levels at the top of the 'Mini'core (Fig. 33c).

Numerical Accumulation Rates.

The numerical accumulation rate for planktonic and occasionally planktonic diatoms showed an irregular increase from _ca_. 6.8m in the Extension core (Fig. 25b) to _ca_. 4.6m in the Extension core (Fig. 25b), _ca_. 4.7m in core 5 (Fig. 30b), followed by an irregular increase to high numbers above 0.10m in core 5 (Fig. 30b) and in the 'Mini'core (Fig. 34b).

Volume Accumulation Rates.

The volume accumulation rate for planktonic and occasionally planktonic diatoms was generally low from 6.8 - 5.8m in the Extension core (Fig. 25c), starting to rise from 6.1m, but not exceeding 1×10^4 mm^3 m^{-2} a^{-1}. From 5.7 - 4.2m in the Extension core (Fig. 25c) and from the lowest sample in core 5, 5.6m to 4.3m in core 5 (Fig. 30c), the volume accumulation rate fluctuated between _ca_. 1×10^4 and 5×10^4 mm^3 m^{-2} a^{-1}. Between 4.2 and 3.1m in core 5 (Fig. 30c) the volume accumulation rate for planktonic diatoms was normally less than 1×10^4 mm^3 m^{-2} a^{-1}. From 3.0m - 1.2m in core 5 the volume accumulation rate rose irregularly from _ca._ 3 x 10^4 to _ca._ 27 x 10^4 mm^3 m^{-2} a^{-1}. The volume accumulation rate dropped abruptly to _ca._ 5 x 10^4 mm^3 m^{-2} a^{-1} at 1m, and remained near this value until 0.5m in core 5 (Fig. 30c). Above 0.4m the volume accumulation rate for planktonic and occasionally planktonic diatoms fluctuated from _ca._ 8 x 10^4 - 16 x 10^4 mm^3 m^{-2} a^{-1}.

In the 'Mini'core (Fig. 34c) the planktonic and occasionally planktonic diatom volume accumulation rate, for the part of the core for which ^{210}Pb dates are available, dropped from _ca._ 12 x 10^4 mm^3 m^{-2} a^{-1} at 0.5m to _ca._ 5 x 10^4 mm^3 m^{-2} a^{-1} at 0.3m. Another maximum of _ca._ 15 x 10^4 mm^3 m^{-2} a^{-1} at 0.15m was followed by a decline to the sediment surface, to _ca._ 6 x 10^4 mm^3 m^{-2} a^{-1}.

Volume Accumulation Rates of Selected Individual Species.

Diagrams have been prepared showing the volume accumulation rates of selected planktonic and occasionally planktonic taxa in the Extension core, core 5 and 'Mini'core (Figs. 26, 31 and 35). A generalised description of these follows; reference will also be made to the planktonic relative percentage diagrams (Figs. 23, 27 and 32).

In the lowest part of the Extension core, from 6.8 - 5.8m (_ca._ 2900 - 2200BP) the diatom volume accumulation rates were generally low (Fig. 26). _Melosira italica_ subsp. _subarctica_ and _Cyclotella comta_ were the most important species with smaller contributions from _Stephanodiscus astraea_ var. _minutula_ and _Cyclotella comensis_.

From 5.7 - 4.2m in the Extension core (Fig. 26), 5.6m (the lowest sample analysed) to 4.3m in core 5 (Fig. 31) _Melosira italica_ subsp. _subarctica_ and _Cyclotella comta_ were the most rapidly accumulating planktonic diatoms. *Cyclotella comta* reached a maximum accumulation rate at *ca*. 4.5m, but the accumulation rate of *Melosira italica* subsp. *subarctica* fluctuated from considerably less to considerably more than that for *Cyclotella comta*. *Stephanodiscus astraea* var. *minutula* made significant and *Cyclotella comensis* small contributions throughout this period. *Stephanodiscus astraea* became important from 4.5 - 4.2m (Extension core, Fig. 26) and 4.6 - 4.4m (Core 5, Fig. 31) simultaneously with a small *Cyclotella ocellata* maximum.

Between 4.2 and 3.1m in core 5 the most important planktonic diatom was *Cyclotella comta*. Small contributions were made by *Cyclotella comensis*, *Melosira italica* subsp. *subarctica*, *Stephanodiscus astraea* var. *minutula* and *Cyclotella ocellata*. There were isolated peaks of *Melosira italica* subsp. *subarctica* (3.9m) and *Stephanodiscus astraea* (3.6m).

From 3.0m upward the large diatom *Stephanodiscus astraea* was dominant at all levels, increasing to a large maximum at 1.1m. After an abrupt drop at 1.0m the volume accumulation rate of this diatom gradually increased toward the top of the core. *Cyclotella comta* was accumulating at varying rates throughout the period, with the occasionally planktonic *Cyclotella ocellata* which became insignificant above 0.6m. Small contributions were made by *Tabellaria* spp. (particularly from 2.7 - 2.4m), *Melosira granulata* (2.4 - 2.3m), *Asterionella formosa* (from 1.9m), *Fragilaria crotonensis* (from 1.4m) and *Stephanodiscus hantzschii* (from 0.1m).

In the 'Mini'core (Fig. 35), until the topmost samples, *Stephanodiscus astraea* was the most rapidly accumulating diatom. *Fragilaria crotonensis* made a significant contribution between 0.5 and 0.4m. *Asterionella formosa* was important in all the samples, but particularly from 0.15m upward. Melosira granulata var. angustissima became significant from 0.15 - 0.10m, and Melosira granulata and Stephanodiscus hantzschii were also important above 0.15m.

Chemical Analyses.

Dry Mass.

The concentration of dry mass (see page 28), in mg mm^{-3}, for samples from the Rostherne Mere Extension core, core 5 and 'Mini'core is shown in Figs. 41a, 42a and 43a. The dry mass accumulation rates (see page 28) in g m^{-2} a^{-1} for these cores are presented in Figs. 41b, 42b and 43b.

The concentration of dry mass from the base of the Extension core, ca. 6.8m (Fig. 41a) to ca.3.0m depth in core 5 (Fig. 42a), varied around 0.20mg mm^{-3}. From ca. 3.0m in core 5 a small increase was seen, values recorded being ca. 0.25 mg mm^{-3}. Above 0.5m in core 5 (Fig. 42a) and throughout the 'Mini'core (Fig. 43a) values drop, to less than 0.1 mg mm^{-3} at the sediment surface.

The dry mass accumulation rate was about 500 g m^{-2} a^{-1} from the base of the Extension core, 6.8m (Fig. 41b) to ca. 3.0m in core 5 (Fig. 42b). Above 2.7m in core 5 the dry mass accumulation rate declined irregularly from ca. 2000 g m^{-2} a^{-1} to less than 1000 g m^{-2} a^{-1} near the top of the core. In the 'Mini'core (Fig. 43b) from 0.5 - 0.3m, the dry mass accumulation rate varied irregularly between 500 and 800 g m^{-2} a^{-1}. Above 0.3m the rate increased irregularly to ca. 1200 - 1300 g m^{-2} a^{-1} between 0.09 and 0.03m.

Mass Lost on Ignition.

The concentration of mass lost on ignition (see page 29) in mg mm^{-3}, for samples from the Extension core, core 5 and 'Mini'core may be found in Figs. 41c, 42c and 43c. The accumulation rate for mass lost on ignition (see page 29), in g m^{-2} a^{-1}, for these three cores is shown in Figs. 41d, 42d and 43d.

The concentration of mass lost on ignition showed a very gradual, irregular decline from *ca.* 0.06 mg mm^{-3} at the base of the Extension core, 6.8m (Fig. 41c), through core 5 (Fig. 42c), to values of *ca.*0.02 mg mm^{-3} at the top of the 'Mini'core (Fig. 43c).

The accumulation rate for mass most on ignition was between *ca.* 70 and 100 g m^{-2} a^{-1} from 6.8 - 5.6m in the Extension core (Fig. 41d). There was a maximum of *ca.* 150 - 200 g m^{-2} a^{-1} at 5.3m in the Extension core (Fig. 41d), 5.3m in core 5 (Fig. 42d), followed by an irregular decline to an accumulation rate of *ca.* 100 g m^{-2} a^{-1} by 4.4m in the Extension core (Fig. 41d) and 4.2m in core 5 (Fig. 42d). The accumulation rate for mass lost on ignition remained at *ca.* 100 g m^{-2} a^{-1} from 4.2 - 3.0m in core 5 (Fig. 42d). Between 2.9 and 1.1m in core 5 the accumulation rate varied irregularly between *ca.* 200 and 350 g m^{-2} a^{-1}. Above 1.1m in core 5 (Fig. 42d) the accumulation rate for mass lost on ignition varied between *ca.* 100 and 200 g m^{-2} a^{-1}, with a small maximum at 0.5m.

The accumulation rate for loss on ignition in the 'Mini'core (Fig. 43d), from 0.45 - 0.24m, varied between *ca.* 140 and 200 g m^{-2} a^{-1}. Above 0.21m there was an irregular increase to a maximum value of *ca.* 400 g m^{-2} a^{-1} at 0.04m.

Organic Carbon.

The organic carbon concentration (see page 31) in mg mm^{-3}, for samples from the Rostherne Mere Extension core, core 5 and 'Mini'core may be seen in Fig. 44a. The organic accumulation rate (see page 31) in g m^{-2} a^{-1}, for these samples is shown in Fig. 44b.

The organic carbon concentration (Fig. 44a) has shown an irregular decline from between 0.015 and 0.02mg mm^{-3} at the base of the Extension core through core 5, to between

0.004 and 0.006 mg mm^{-3} near the top of the 'Mini'core.

The organic carbon accumulation rate (Fig. 44b) varied between *ca.* 20 and 40 g m^{-2} a^{-1} from the lowest sample analysed in the Extension core (6.6m), to *ca.* 3.0m in core 5. Between 2.5 and 1.02m the accumulation rate was higher, from *ca.* 65 - 85 g m^{-2} a^{-1}. At 0.72m in core 5 and at 0.54m and 0.42m in the 'Mini'core (Fig. 44b) the organic carbon accumulation rate was *ca.* 35 g m^{-2} a^{-1}. There was an irregular increase to maximum values of *ca.* 120 g m^{-2} a^{-1} at 0.03m in the 'Mini'core.

Kjeldahl Nitrogen.

The Kjeldahl nitrogen concentration (see page 31), in mg mm^{-3}, for the Rostherne Mere Extension core, core 5 and 'Mini'core may be found in Fig. 45a. The Kjeldahl nitrogen accumulation rate (see page 31) in g m^{-2} a^{-1} for these cores is shown in Fig. 45b.

From 6.8 - 5.9m in the Extension core the Kjeldahl nitrogen concentration was between *ca.* 1 x 10^{3} and 1.5 x 10^{-3} mg mm^{-3}. The concentration rose to *ca.* 2 x 10^{-3} mg mm^{-3} at 5.3m in core 5, and declined to *ca.* 1.1 x 10^{-3} mg mm^{-3} by 2.4m. There was a maximum Kjeldahl nitrogen concentration of *ca.* 1.6 x 10^{-3} mg mm^{-3} at 1.4m in core 5, followed by an irregular decline to *ca.* 0.5 x 10^{-3} mg mm^{-3} at 0.02m in the 'Mini'core (Fig. 45a).

The Kjeldahl nitrogen accumulation rate from 6.8 - 6.3m in the Extension core was *ca.* 4.5 g m^{-2} a^{-1}. The rate declined from a maximum of *ca.* 4.5 g m^{-2} a^{-1} at 5.3m (core 5) to *ca.* 2.5 g m^{-2} a^{-1} by 4.3m. After 3.1m the Kjeldahl nitrogen accumulation rate rose to a maximum of *ca.* 8.5 g m^{-2} a^{-1} at 1.4m in core 5. The rate declined to a minimum of *ca.* 3 g m^{-2} a^{-1} at 0.39m in the 'Mini'core, and then rose irregularly to a maximum of *ca.* 9 g m^{-2} a^{-1} at 0.02m.

Total Phosphorus.

The total phosphorus concentration (see page 31), in mg mm^{-3}, for samples from the Extension core, core 5 and 'Mini'core is shown in Fig. 46a. The total phosphorus accumulation rate (see page 31), in g m^{-2} a^{-1}, for these cores is presented in Fig. 46b.

The total phosphorus concentration (Fig. 46a) showed a decline from *ca.* 8 x 10^{-4} mg mm^{-3} at 6.8m in the Extension core to *ca.* 2 x 10^{-4} mg mm^{-3} at 4.1m in core 5, followed by an irregular rise to *ca.* 4.5 x 10^{-4} mg mm^{-3} at 1.5 and 0.9m in core 5 (Fig. 46a). The total phosphorus concentration in the 'Mini'core (Fig. 46a) declined from between *ca.* 1 x 10^{-4} and 2 x 10^{-4} below 0.3 to *ca.* 0.7 x 10^{-4} near the top of the core.

The total phosphorus accumulation rate (Fig. 46b) was *ca.* 1 g m^{-2} a^{-1} from 6.8m (Extension core) to 5.0m (core 5). A minimum of *ca.* 0.3 g m^{-2} a^{-1} at 4.1m was followed by a rise to an overall maximum of *ca.* 2.4 g m^{-2} a^{-1} at 1.5 and 0.9m (core 5). In the 'Mini'core there was an irregular rise from low rates of *ca.* 0.5g m^{-2} a^{-1} to a low maximum of *ca.* 1.2 g m^{-2} a^{-1} near the sediment surface.

Discussion.

Correlation.

Correlation of lake sediment cores has been achieved by comparison of records of susceptibility (e.g. Thompson and Morton 1979), intensity of natural remanent magnetization (e.g. Thompson and Wain-Hobson 1979) and declination (e.g. Thompson and Morton 1979). Measurements of these three independent parameters on Mackereth cores from Rostherne Mere have enabled proposal of possible correlations for cores 2 - 5 and Extension (Figs 10 - 12). These correlations have been compared in Fig. 14, showing the generally good agreement, with particularly strong correlation between cores 3, 5 and the Extension core. This enables comparison of microfossil records in these sediment cores, with correlations completely independent of the microfossil data.

The sediment at the base of the Extension core is older than that in any of the other correlated cores (Figs. 10 - 12) but the Extension core appears rather disturbed above ca. 3.0m. The Extension core is particularly well correlated with cores 5 and 4 (Fig. 14) but the declination record of core 5 is superior to that of core 4 (Fig. 12). This enabled selection of core 5 and the Extension core for detailed diatom analyses, and also for all the chemical analyses. Core 3 was well correlated with both core 5 and the Extension core (Fig. 14) and was selected for less detailed diatom analyses.

Measurements of susceptibility, intensity of natural remanent magnetization (NRM intensity) and declination, made on Mackereth cores 1, 6, 7 and 8 did not enable correlation. The large peaks in susceptibility (Fig. 10) and NRM intensity (Fig. 11) in core 6, were later shown to be due to magnetic contamination of the core tube

(Table 12, page 131). The palaeomagnetic records of the more marginal Mackereth cores 1, 7 and 8 did not show the orderly sequence of features seen in the deeper water cores (Figs. 10 - 12). The declination, which is particularly sensitive to disturbance, was very variable in parts of cores 1, 7 and 8 (Fig. 12). This may reflect post - depositional sediment movement, related perhaps to sloping core sites, perhaps to increasing faunal and wave activity in the shallower water (Fig. 6).

Core 10.5 was frost damaged in storage. Susceptibility measurements clearly showed the effect of the damage (Table 13, page 131). The anomalous susceptibility record may have been caused by microscopic rearrangement of magnetic particles, expansion of freezing interstitial water displacing sediment, or drying in the fractured core tube. The only further investigations carried out on this core were widely spaced diatom analyses.

The marginal Russian cores had extremely low susceptibilities (Table 17, page 134), and their intensity of natural remanent magnetization (NRM intensity) was too low to measure on the sensitive fluxgate magnetometer used. This prevented correlation with the deep water Mackereth cores 3 - 5 and the Extension core, based on palaeomagnetic parameters. Susceptibility and NRM intensity are, in part, directly proportional to the amount of allochthonous inorganic material present in the sediment (Thompson et al. 1975, Oldfield et al. 1978). The very small amount of such inorganic material in the highly organic muds in the Rostherne Mere Russian cores may be responsible for the low levels of susceptibility and NRM intensity. A rather poor correlation between Mackereth core 5 and Russian core G has been established, based on changes in the diatom assemblages. The general restriction of the planktonic diatoms *Asterionella formosa* and *Stephanodiscus astraea*, and the non-planktonic diatom *Navicula scutelloides* to levels above

2.0 - 3.0m in core 5 (Figs. 27 and 28), 0.37 - 0.25m in Russian core G (Figs. 39b and 40) and the similar restriction of the planktonic species Stephanodiscus hantzschii and Fragilaria crotonensis to levels above ca. 1.5m in core 5 (Fig. 27), and to the sample at 0.10m in Russian core G (Fig. 39b), suggest a rather tenuous correlation (Table 16, page 133).

The correlation of the 'Mini'core with the Mackereth long cores proved very difficult. Measurements of susceptibility and saturation isothermal remanent magnetization (SIRM), on single samples from the 'Mini'core and the top of core 5 did not produce easily correlated records (Table 14, page 132). Reference to biostratigraphy suggested that the decline in Stephanodiscus hantzschii to small frequencies in the lowest sample analysed (0.7m) in the 'Mini'core (Fig. 32) might be correlated with the decline to small percentage of this species between 0.30 and 0.40m in core 5 (Fig. 27). Correspondence analysis of all the absolute diatom analyses except the top 4 from the 'Mini'core (Fig. 48b) showed that the planktonic diatom assemblage of samples from 0.02 - 0.10m in core 5 was similar to that from 0.35 - 0.45m in the 'Mini'core. Reappraisal of the palaeomagnetic data in the light of these tentative biostratigraphic correlations (Table 15, page 133)shows that there was some similarity in the susceptibility and SIRM records of core 5 (0.3 - 0.1m) and the 'Mini'core (0.72 - 0.50m). Above 0.50m in the 'Mini'core there was a pronounced trough in both susceptibility and SIRM (Table 14, page 132) not seen above 0.1m in core 5. The top 0.1m of the 6m Mackereth cores is likely to have been badly disturbed by the coring device, so this apparent mis-match does not rule out correlation. The poor correlation between core 5 and the 'Mini'core from Rostherne Mere has been used as little as possible, only in the construction of Fig. 47. In Fig. 47 the use of time as the ordinate means that a small error in alignment would not be serious. To emphasize the inadvisability of referring the 'Mini'core dates to the long cores, and vice-versa, all the 'Mini'core dates in Fig. 47 and elsewhere are given in years AD, and all the long core dates are in years BP.

Chronology.

Mackereth Long Cores.

Dating of the well defined, stable, palaeomagnetic direction data from the Rostherne Mere Extension core and core 5 (Figs. 15 and 16) against the soundly calibrated European Geomagnetic Master Curve of Thompson and Turner (1979) (Figs. 17 and 18), gives a sound age/depth curve (Fig. 19). Comparison of the 9 ^{14}C dates obtained from the Extension core and core 5, with this palaeomagnetic age/depth curve emphasize the widely scattered nature of the ^{14}C dates (Fig. 19). Four of the ^{14}C dates contain only small amounts of inorganic carbon (Table C , page 40, Fig. 19), and are perhaps least likely to have been affected by 'hard water' error (due to incorporation of carbon from ancient carbonates into the organic matter of modern organisms). Two of these 'low inorganic carbon' ^{14}C dates are considerably younger than the age given by palaeomagnetic methods (Fig. 19). Comparison of ^{14}C ages of palaeomagnetic features from different British sites (Thompson 1979, Thompson and Edwards 1982), (Fig. 20a), shows that many of the ^{14}C ages for samples less than ca. 3000 years old are excessive. This phenomenon is generally held to be due to erosion of catchment soils by human agricultural activity permitting the release of 'old carbon' into the lake system (e.g. Pennington et al. 1976). Four of the ^{14}C dates are considerably too young, two from Loch Lomond (Dickson et al. 1978) and the two from Rostherne Mere. These are shown in more detail in Fig. 20b. Dickson et al. (loc. cit) considered that the anomalously young ^{14}C dates from Loch Lomond were due to errors in palaeomagnetic dating, or possibly vertical mixing of modern nuclear weapon test material derived ^{14}C from surface sediments. In view of the well resolved palaeomagnetic direction records now available for Loch Lomond (Thompson and Turner 1979, Turner and Thompson 1981), and Rostherne Mere (Fig. 15), soundly calibrated against archaeomagnetic and observatory records since ca. 2000 bp (Thompson and Turner 1979) (Fig. 17) the former possibility now seems unlikely. Atmospheric ^{14}C concentration variations (e.g. Suess 1970, Clark 1975) cannot account for anomalies of this age. Large scale vertical mixing might cause such anomalous dates, but discrete biostratigraphic (pages 46 - 50) and palaeomagnetic (Figs. 10 - 12), (Thompson and Morton 1979, Turner and Thompson 1981), intercore correlatives would be exceedingly unlikely in such a case. The contamination of deeper sediments during coring cannot be entirely ruled out, but there is no evidence for extensive downsmearing of the upper sediments. Geochemical or biological fractionation of carbon isotopes should be revealed by comparison of stable $^{13}C:^{12}C$ ratio (Table 18, page 135) but it is possible that $^{14}C:^{12}C$ fractionation may have occurred at some time, although such a mechanism is hard to imagine.

^{14}C dating is widely used in palaeolimnological research, so attention must be given to discovering the extent of anomalously young ^{14}C dates in lake sediments. The palynological correlation of unambiguously ^{14}C dated bog sites with adjacent lake sites may be fruitful (Thompson and Edwards 1982), as may be palaeomagnetic and ^{14}C analyses of little disturbed high mountain tarn sediments. It will obviously be wise, in future studies, to continue to use both ^{14}C and palaeomagnetic techniques, since each may complement the other.

'Mini'core.

A ^{210}Pb chronology (Fig. 21b) was constructed (Appleby pers. comm.) using the constant rate of supply (c.r.s.) model of Appleby and Oldfield (1978). The constant initial concentration method (Pennington et al. 1976) was unable, due to changing sedimentation rate, to produce a sensible age/depth curve (Table **2,page 121**). The c.r.s. ^{210}Pb chronology of Livingstone (1979) for a core from Rostherne Mere, is very similar to the c.r.s. ^{210}Pb chronology for the Rostherne Mere 'Mini'core (Fig. 21b). The ^{210}Pb flux calculated for the Rostherne Mere 'Mini'core (0.17 p Ci cm^{-2} a^{-1}, Appleby pers. comm.) is similar to that calculated for other sediment sequences from the area (Appleby pers. comm.), increasing confidence in the applicability of the c.r.s. ^{210}Pb model.

The peak atmospheric fallout of nuclear weapons test derived ^{137}Cs in 1963 has been shown to have caused a peak in ^{137}Cs in recent lake sediments (Ritchie et al. 1973, Pennington et al. 1976, Livingstone and Cambray 1978). The ^{137}Cs profile for the Rostherne Mere 'Mini'core (Fig. 22) has a peak at 0.04 - 0.05m, appearing similar to that reported by Gaskell and Eglinton (1976) and very different to that shown in Livingstone and Cambray (1978). The similarity of the ^{210}Pb age/depth curves of the Rostherne Mere 'Mini'core (Fig. 21) and that in Livingstone (1979) makes the disparity in ^{137}Cs peaks extraordinary.

The amount of ^{137}Cs deposited since 1963 in the Rostherne Mere 'Mini'core and in the core of Livingstone and Cambray (1978),(Table 3 ,page 122) suggests that vertical diffusion within the lake sediment may be the cause of the anomalous ^{137}Cs distribution in the 'Mini'core. Vertical diffusion due to geochemical or biological processes has been suggested as a cause of anomalous ^{137}Cs profiles (Appleby and Oldfield 1978). The absence of profundal fauna below 25m water depth in Rostherne

Mere, reported by Brinkhurst and Walsh (1967), does not suggest a biological mechanism (both the core of Livingstone and Cambray (1978) and the Rostherne Mere 'Mini'core were taken in water more than ca. 27m deep). The possible unreliability of ^{137}Cs profiles, even within the same lake basin, suggests that the technique is probably unsuitable for sediment dating except in conjunction with other methods.

Problems of Interpretation of Diatom Analyses.

The factors affecting the incorporation of diatoms into sediments, and the interpretation of diatom sequences have been discussed by Round (1964) and Battarbee (1979). Some of these factors are outlined below.

Faunal activity may vertically redistribute diatom remains. Single microfossil specimens may be redistributed within the sediment, but by dealing with larger populations quantitative redistribution becomes unimportant (Stockner and Lund 1970).

Mass erosion and redeposition may occur in turbulent marginal waters, or unstable, steeply sloping parts of lake basins, but is unlikely to seriously affect deep water sediments.

Littoral diatoms are variably, and often poorly, represented in deep water sediments (e.g. Battarbee 1978). Planktonic diatoms in deep water sediments may be recruited from three main sources; production within the lake, production within the lake catchment, or reworking of older deposits. The phytoplankton produced at the Mere at Mere, part of the catchment of Rostherne Mere (Fig. 2a) has been shown to have little effect on the phytoplankton flora of Rostherne Mere (Belcher and Storey 1968). Planktonic diatom accumulation rates in deep water cores are not likely to be seriously affected by reworking of marginal deposits. These marginal deposits often contain few planktonic diatoms (e.g. page 50).

Some proportion of diatom productivity will be lost through the outflow; small and less dense taxa particularly so. This effect will be of little consequence in lakes with large volumes and small outflows. Destruction or fragmentation of diatom frustules by grazing herbivores, mechanical attrition or chemical dissolution may occur. Possible factors involved include silica content of cell walls, temperature, pH, water / mud silica gradient, benthic invertebrate activity, water depth and sediment accumulation rate.

Of particular relevance to interpretation of diatom remains in terms of lake productivity is the possible limitation of diatoms by silica (Lund 1950). Silica levels in Meres do occasionally drop to levels which may limit diatoms (Reynolds 1979). In conditions of high trophic status an increase in lake productivity may result only in an increase in production of other algae, particularly blue - green algae.

The results of absolute diatom analyses are particularly sensitive to deposition rate, preparation and counting errors, and Battarbee (1979) has warned of the avoidance of 'overinterpretation' and the possible insignificance of troughs and peaks represented by single samples. These factors must be taken into consideration when interpretation of diatom data from sediment cores is attempted. Such interpretations, in terms of past lake productivity, are best made with the aid of independent lake production related parameters such as accumulation rate of organic matter, organic carbon or nitrogen.

Problems of Interpretation of Chemical Data.

Chemical data have frequently been presented as percentage of dry mass or ignited mass, and as various ratios (e.g. Mackereth 1966, Davis and Norton 1978). This may result in some independence from rate of sediment deposition, but the results are difficult to interpret and may be misleading. The presentation of chemical data in terms of accumulation rate has enabled much clearer interpretation in terms of past lake productivity (Digerfeldt 1972, 1975). The possible misinterpretation caused by expressing chemical data as percentage of dry mass is clearly illustrated by Digerfeldt (1972) with content of organic material.

The drying of sediment at 110°C will result in the loss of the majority of interstitial water, as well as a part of any ammonia, and perhaps a little organic material and structural water from clay minerals. The mass remaining after treatment at 110°C is approximately equal to the mass of non - aqueous material, called for convenience dry mass. The dry mass accumulation rate will approximate to the total accumulation rate for non - aqueous sedimentary material. This is likely to be sensitive to changes in lake productivity, but due to its sensitivity to changes in allochthonous input, is not a reliable indicator of changing lake productivity.

The ignition of sediment (already dried at 110°C) at 450°C will result in the loss of almost all organic material, a considerable part of any structural water in clay minerals, any remaining ammonia and some volatile salts. The use of a lower temperature may result in inefficient combustion of organic material and the use of a higher temperature may increase the contribution from volatile salts. In sediment where the clay minerals, and other significant inorganic constituents, are infrequent, or constant and organic material is abundant mass lost on ignition will be approximately proportional to mass of organic matter, but if there are variations in clay content of sediment or organic material is sparse, then mass lost on ignition is an unreliable indicator of organic material (Mackereth 1966). The origin of organic material in the lake may be allochthonous or autochthonous. In oligotrophic small lakes with large inflows, the former may be predominant, but in large eutrophic lakes with small inflows, autochthonous production will supply the majority of organic material present in deep water cores.

Overhanging vegetation may contribute organic material to marginal sediments.

The wet oxidation method of organic carbon measurement chosen (Guppy and Happey - Wood 1978) may be sensitive to the presence of ferrous iron. The thorough powdering, and drying of sediment at 110°C should maximise oxidation of ferrous salts to ferric. Thorough centrifugation is required to avoid interference from fine suspended particulate matter. This wet oxidation method will not include charcoal, but as any charcoal present is almost certain to be allochthonous, this is not likely to constitute a problem in studies of past lake productivity. The sources of organic carbon in the lake sediment are allochthonous and autochthonous, both from production and reworking. In large, eutrophic lakes with small inflows, allochthonous sources and within lake reworking should be unimportant compared to autochthonous production.

The Kjeldahl technique used for nitrogen determination measures organic and ammonium nitrogen. Nitrate and nitrite nitrogen are not measured. Nitrate and nitrite salts are absent from deoxygenated sediments (Digerfeldt 1972), so that under these conditions Kjeldahl nitrogen approximates to total nitrogen. Sedimentary nitrogen may come from allochthonous or autochthonous organic sources, or direct precipitation of nitrogenous salts. The majority of such salts (nitrates, nitrites and ammonium salts) are water soluble, so direct precipitation of nitrogen is unlikely to be significant in most lakes.

In the case of any interpretation of organic material dependant variables, such as mass lost on ignition, organic carbon or Kjeldahl nitrogen, it should be noted that decomposition near the sediment surface may result in the partial release of organic residues back into the lake water. The rate and extent of this decomposition are likely to be especially dependent on temperature, oxygenation and rate of sediment deposition. The rate of decomposition is unlikely to have remained constant through time.

Digerfeldt (1972, 1975) used measurements of mass lost on ignition, organic carbon and Kjeldahl nitrogen to reconstruct past lake productivities. The diatom history yielded substantially similar results. This shows that despite all the possible factors affecting diatom and chemical accumulation rates in lakes, they are still capable of giving similar indications of past lake productivity, thus increasing confidence in their use for this purpose.

Total phosphorus in the sediment is likely to present a more complex picture than other organic materials. Part of the phosphorus may arrive in the sediment bound in autochthonous or allochthonous organic material, part as complex co - precipitates with iron. Some phosphorus will be released from decomposing organic matter, but more significantly, under reducing conditions insoluble ferric iron complexes become soluble ferrous iron compounds, liberating co - precipitated phosphorus into solution. At the shallow Barton Broad, phosphorus retention in sediment (given in g m^{-2} a^{-1}, and therefore equivalent to accumulation rate) and diatom analyses were used to reconstruct the history of cultural eutrophication (Osborne and Moss 1977). In Lake Trummen accumulation of phosphorus was thought to be more closely related to soil leaching and maturation, and to anthropogenic input than to past productivity (Digerfeldt 1972). Redox variations were suggested as the mechanism for changes in phosphorus accumulation rates unrelated to catchment or lake productivity history (Digerfeldt 1975). Mn and Fe analyses of cores can yield information on past profundal redox levels, and this might, in the future, enable useful interpretations of phosphorus analyses.

Phases in Lake Development.

Prior to 3000BP. Sparse diatom analyses on the frost damaged core 10.5 (below ca. 7m, Fig. 38) are sufficient to show that a Melosira italica subsp. subarctica / Cyclotella comta / Cyclotella comensis flora had been in existence for some time before the base of the earliest dated, correlated sediment in the Extension core (ca. 6.5m, Fig. 23).

Phase 1 (Fig. 47), ca. 3000 - 2000BP. During this phase the diatom, mass lost on ignition, carbon and nitrogen accumulation rates were low (Fig. 47). The dominant planktonic diatoms were Melosira italica subsp. subarctica and Cyclotella comta. The former is found in a wide range of lakes (e.g. Lund 1954, Battarbee 1978) and is said to be alkaliphilous (Foged 1954). Cyclotella comta is a pH indifferent species tolerant of a wide range of lake types. Other planktonic species present regularly included the pH indifferent Cyclotella comensis and the alkaliphilous Stephanodiscus astraea var. minutula (Fig. 26). The non - planktonic diatoms represented in the deep water core were dominated by alkaliphilous Fragilaria spp. (Fig. 23). During phase 1 the lake was rather poor in diatoms and nutrients compared to today, and rather alkaline.

Phase 2 (Fig. 47), ca. 2000 - 1400BP. There was an increase in accumulation rate of Melosira italica subsp. subarctica after ca. 2200BP (Fig. 47), an increase in accumulation rate for mass lost on ignition after ca. 2100BP and an increase in Kjeldahl nitrogen accumulation rate after ca. 2000BP. There were fluctuations in the accumulation rate of Melosira italica subsp. subarctica, with notable maxima at ca. 1850BP and 1600BP followed by a decline to consistently low values by ca. 1400BP. The Cyclotella comta accumulation rate rose gradually to a maximum at ca. 1500BP followed by rather lower values by

1400BP (Fig. 47). Other planktonic diatoms included the alkaliphilous species *Stephanodiscus astraea* var. *minutula* and *Stephanodiscus astraea* (the latter from *ca.* 1500 - 1400BP), and the pH indifferent species *Cyclotella comensis* and *Cyclotella ocellata* (Fig. 31). The non - planktonic diatom flora was dominated by alkaliphilous *Fragilaria* spp. (Fig. 28). The rate of accumulation of mass lost on ignition rose rapidly between *ca.* 2050 and 1900BP to twice its previous level. The accumulation rate was maintained until *ca.* 1500BP, followed by a decline until *ca.* 1300BP (Fig. 47). The organic carbon accumulation rate at *ca.* 2000 and 1500BP was *ca.* 1.5 x its previous level, but at *ca.* 1750BP was at about the same level as phase 1 (Fig. 47). The Kjeldahl nitrogen accumulation rate at *ca.* 1900BP was approximately twice that previously, declining somewhat by *ca.* 1600BP, and declining to phase 1 levels by 1400BP (Fig. 47).

During phase 2 the lake appears to have been more eutrophic, with a slightly different diatom flora to phase 1. Rosthene Mere remained alkaline, and less eutrophic than today.

Phase 3 (Fig. 47), ca. 1400 - 600BP. During this period the planktonic diatom volume accumulation rate was low (Fig. 47). The most rapidly accumulating planktonic diatom was *Cyclotella comta*, with isolated contributions from *Melosira italica* subsp. *subarctica* at *ca.* 1200BP and *Stephanodiscus astraea* at *ca.* 1000BP (Fig. 47). Other planktonic diatoms present included the alkaliphilous *Stephanodiscus astraea* var. *minutula*, and the pH indifferent *Cyclotella comensis* and *Cyclotella ocellata* (Fig. 31). The non - planktonic diatoms were dominated by alkaliphilous *Fragilaria* spp. (Fig. 28).

The accumulation rate for mass lost on ignition was rather low from *ca.*1400 - 600BP, as were carbon accumulation rates at *ca.* 1200, 1000 and 600BP. Kjeldahl nitrogen accumulation rates were also low at 1400, 1000 and 700BP (Fig. 47).

During phase 3, the waters of Rostherne Mere were rather poor in diatoms, moderately alkaline and perhaps as nutrient poor as during phase 1 (page 72), certainly less eutrophic than phase 2 or today.

Phase 4 (Fig. 47), ca. 600 - 280BP. The dominant diatom was Stephanodiscus astraea. This is an alkaliphilous diatom (or alkalibiont, Battarbee 1978) and said to be characteristic of eutrophic waters, although absent from highly eutrophic waters (Hustedt 1949). Cyclotella comta was accumulating at varying rates, with maxima at ca. 600 and 350BP (Fig. 47). Tabellaria spp., some of which are planktonic, and which occur in a wide range of lake types, occurred from ca. 450 - 400BP. Melosira granulata, an alkaliphilous diatom, characteristic of eutrophic waters, was briefly important at ca. 400BP (Fig. 31). Asterionella formosa, an alkaliphile usually associated with nutrient rich waters,reached a maximum at ca. 300BP (Fig. 47). Fragilaria crotonensis, characteristic of alkaline, nutrient rich waters,is found from ca. 350BP, reaching a maximum at ca. 280BP (Fig. 47). The overall diatom accumulation rate was high from ca. 600 - 400BP, then rising to a considerable maximum at 280BP (Fig. 47). The most important non - planktonic diatoms were alkaliphilous Fragilaria spp. (Fig. 28). Organic carbon accumulation rate and accumulation rate for mass lost on ignition were ca. 3 times their previous value, and Kjeldahl nitrogen was accumulating at between 3 and 4 times its previous level (Fig. 47). Both diatom and chemical records indicate a major increase in lake productivity at ca. 600BP. The mass lost on ignition, carbon and nitrogen records generally suggest that this was followed by a period of stable eutrophic conditions, whereas at first sight the diatom record seems to suggest a further increase in lake productivity between ca. 400 and 280BP. It is possible that this rise in diatom accumulation rate was in fact due to diatoms taking a progressively larger share of the lake productivity from ca. 400 - 280BP. The general correspondence of organic material, carbon and nitrogen results makes this the preferred hypothesis. It is possible that palaeopigment analysis (e.g. Vallentyne 1960) might be able to resolve such problems.

During phase 4 there was a diverse, eutrophic diatom flora, nutrient status was higher than any previous phase, although perhaps not as high as at present. There is no evidence of a change from rather alkaline conditions.

Phase 5 (Fig. 47), ca. 280BP - 1960AD. There was a marked drop in accumulation rate of Stephanodiscus astraea, organic material, organic carbon and Kjeldahl nitrogen. The overall diatom accumulation rate returned to that seen in the early part of phase 4. After 100BP the rate fluctuated at rather higher values. The accumulation rates of organic material, organic carbon and Kjeldahl nitrogen remained at about ⅔rds of their phase 4 value until the early 1960's AD. This suggests that during phase 5 lake productivity was rather lower than phase 4 or today. From ca. 100BP diatoms may have formed a more important part of the phytoplankton flora.

Phase 6 (Fig. 47), ca. 1960 AD - present day. The accumulation rates for mass lost on ignition, organic carbon and Kjeldahl nitrogen have reached higher levels since the early 1960's AD than those recorded for earlier sediments (Fig. 47). This rise has not been found in planktonic diatom volume accumulation rate which has remained variable (Fig. 47). The actual diatom populations recorded do however show alteration. Melosira granulata var. angustissima (an alkaliphile which prefers eutrophic waters), Melosira granulata, Asterionella formosa and Stephanodiscus hantzschii (an alkaliphile characteristic of very eutrophic waters) are showing signs of replacing Stephanodiscus astraea (absent from extremely eutrophic waters) as the dominant planktonic diatoms (Fig. 35). Correspondence analysis of all the diatom accumulation rate data from the Extension core, core 5 and 'Mini'core (Fig. 48a) emphasises the unusual nature of the top four samples (0.01, 0.05, 0.10 and 0.15m) from the 'Mini'core. Nitzschia palea, found at increased frequencies above 0.02m in the 'Mini'core (Fig. 32) requires large concentrations of organic nitrogen (Archibald 1972) and is very tolerant of polluted waters (Evans and Macan 1976). In Rostherne Mere it is found in the mucilage around colonies of the planktonic blue - green alga Microcystis aeruginosa (Reynolds 1978). Non - planktonic diatoms, dominated by the alkaliphilous Fragilaria spp. became less frequent, being almost absent from the present day sediments. This combination of evidence suggests that lake productivity since the early 1960's AD has been very high. The composition of the diverse planktonic diatom flora shows evidence of this high productivity, but the unaltered planktonic diatom volume accumulation rate suggests that diatoms were no more abundant during phase 6 than the later part of phase 5. The decline in non - planktonic diatoms to their present low values (Figs. 32 and 33) could be related to a decline in available habitats due to changes in water level (Harrison and Rogers 1977) or depth of the euphotic zone with increasing algal blooms through the summer months.

The changes in the total phosphorus accumulation rate (Figs. 46 and 47) are rather different to those recorded for mass lost on ignition, organic carbon and Kjeldahl nitrogen. There was an irregular decline from ca. 2900BP to a minimum at ca. 1300BP. Total phosphorus accumulation rate then rose to a maximum between ca. 350

and 230BP, followed by an abrupt drop by _ca_. 1900AD. There was then an irregular rise to the present value, about half that between _ca_. 350 and 230BP. The high accumulation rates near the base of the sequence, may be related to slow de-oxygenation of sediment surface and hypolimnion compared to the present day in the lake resulting in redox conditions favourable to phosphorus sedimentation. Changing redox conditions as well as changing supply of phosphorus may also be reflected in the recent unexpectedly low accumulation rate. Brinkhurst and Walsh (1967) suggested that increased phosphorus loading as a result of increasing bird populations might be responsible for the reducing conditions found currently in the superficial sediments ('Guanotrophy'). Grimshaw and Hudson (1970) and Reynolds (1978) considered that agricultural and urban runoff were more important sources of phosphorus than birds, a view supported by the calculated values of Livingstone (1979). It is likely that whatever the source of nutrients their present day abundance will have affected sediment redox potential. The sensitivity of phosphorus accumulation rate to factors other than organic production in the lake may make it an unreliable indicator of past lake productivity.

The diatom, mass lost on ignition, organic carbon and Kjeldahl nitrogen histories of the lake suggest that the trophic status of Rostherne Mere has increased in a series of oscillations, the first a minor event starting _ca_. 2000 years ago (phase 2), the second much more significant starting _ca_. 600 years ago (Phase 4) and a recent phase, also of great significance, starting between _ca_. 1955 - 1960AD (Phase 6).

Ellesmere.

Correlation and Chronology of Cores.

Position and Stratigraphy.

The position and stratigraphy of Mackereth cores taken along the line W - E, and at core site 5 (Fig. 3b) are shown in Fig. 49. In all cases the uppermost sediment was dark brown lake mud, blacker towards the top. Below a transition zone, and absent only from the 'Mini'core, was pale brown clayey mud, beneath which, after a rather gradual transition, was dark brown lake mud. In cores 4 and 6 the lower part of this dark brown lake mud was noticeably finer in texture, represented by double hatching in Fig. 49. The lowest sediment in cores 3, 4 and 6 was pink clay, rather sandy below 4m in core 6. The details of individual stratigraphic properties are shown in Table 19, page 135.

The position and stratigraphy of marginal Russian cores taken near the ends of the line W - E (Fig. 3b) may be seen in Fig. 50. At the western (Island) margin, Russian core A penetrated into sands and clays which may represent the dumped fabric of the probably artificial island. Cores B - F struck solid rock, perhaps also dumped. Russian cores F - J sampled increasing depths of soft brown lake mud. At the eastern margin, the shallow water cores K - N show a sequence from an upper layer of coarse grey sand, through brown gravelly mud to a basal layer of grey clay or gravel. The Russian cores O - R show progressively less upper sand and a deepening layer of brown lake mud. The basal sequence consists of grey clay beneath coarse grey sand.

Correlation of Long Cores.

Measurements of palaeomagnetic susceptibility and intensity of natural remanent magnetization (NRM intensity) made on the Ellesmere Mackereth 6m cores proved useful in correlating the cores. The low NRM intensity for much of the sequence in some cores (Fig. 52 and para. 3, page 79) precluded use of declination measurements for general correlation. The presence of discrete stratigraphic layers was also used to construct correlations. In the case of the pale brown clayey mud layer (Table 19, page 135, Fig. 49), a mid - point was selected, by eye, in the upper and lower transition zones, except in the case of the upper boundary in cores 1 and 2, which was too diffuse. These mid - points were used for correlation. The pink clay / mud boundary in cores 3, 4 and 6 was clear, as was the change to finer textured mud near the base of the muds in cores 4 and 6.

Fig. 51 shows susceptibility measurements made on Mackereth whole cores 1 - 6 and single samples from the 'Mini' core from Ellesmere. The lake mud values ranged from 0 - 80 micro SI units, and those for the pink clays up to 250 micro SI units. The lake mud values are unusually low compared with other lake muds (e.g. Stober and Thompson 1979, Turner and Thompson 1981). The records from Ellesmere, although low, are quite variable. This has facilitated selection of possible temporal correlations, numbered 1 - 10 in Fig. 51.

Whole core intensity of natural remanent magnetization (NRM intensity) measurements made on Mackereth 6m cores 1 - 6 are shown in Fig. 52. The NRM intensities were generally very low, especially in the brown lake muds (Fig. 49) where NRM intensity approached 0 mAm^{-1}. In the pale brown clayey muds values of up to 4 mAm^{-1} were recorded, and in the basal pink clays up to 10 mAm^{-1}. These compare to maxima in other lake muds of 100 mAm^{-1} (Thompson and Wain - Hobson 1979) and 200 mAm^{-1} (Turner and Thompson 1981). The low NRM intensity in the Ellesmere sediments has not prevented tentative temporal correlation between the cores, indicated by Roman numerals I - IX in Fig. 52.

The possible correlations based on stratigraphy, susceptibility and NRM intensity in the 6m Mackereth cores are compared in Fig. 53. The correlations correspond closely. There is particularly good correlation between cores 3, 4 and 6. It is clear that the relative rates of deposition at different sites have varied through time (producing depth / depth plots which do not approximate to a straight line in Fig. 53). Particularly great changes in relative rates of deposition appear to have occurred at the level of NRM intensity feature VII (Figs. 52 and 53).

The palaeomagnetic / stratigraphic correlations were used to select sediment sequences suitable for further study. Cores 3, 4 and 6 all contained the basal pink clay (Fig. 49), logically the oldest sediment. Core 3 had a very abbreviated lower brown mud layer compared to cores 4 and 6 (Fig. 49). The upper part of core 6 contained a more detailed, extended record than that of core 4 (Figs. 49, 51, 52). It was felt that core 6 was most likely to contain a complete sequence of sediments, and would be most suitable for detailed palaeolimnological studies. Core 4 was chosen for less detailed diatom analyses.

Correlation of 'Mini'core.

The possible correlation of the 'Mini'core with the Mackereth 6m cores, and particularly core 6, based on susceptibility (Fig. 51) was insufficient in itself for general use. Biostratigraphy was investigated, and a drop in percentage of Cyclotella comta and Stephanodiscus dubius from ca. 10 - 20% to less than 5% was noted between 0.95 and 0.90m in the 'Mini'core (Fig. 63), and between 0.08 and 0.01m in core 6 (Fig. 58). The correlation based on susceptibility and biostratigraphy are shown in Table 20, page 135.

This rather tenuous, but consistent, correlation suggests that there is a considerable amount of sediment absent from the top of core 6 (and also the other Mackereth 6m cores), and that the youngest sediment present in core 6 is older than ca. 1870AD.

^{14}C Dates.

The results of ^{14}C analyses of 6 samples from Ellesmere core 6 are shown in Table D (below) and Fig. 54. The samples showed no evidence of inorganic carbon (Harkness pers. comm.).

Table D .

^{14}C Ages in 6 samples from core 6.

NERC code	Sample m	^{14}C age bp
SRR 1880	0.95 -1.05	1270±50
SRR 1881	1.45 -1.55	940±50
SRR 1882	1.975-2.025	1670±60
SRR 1883	2.375-2.425	2160±50
SRR 1884	2.775-2.825	3780±50
SRR 1885	3.175-3.225	7690±60

Palaeomagnetic Dates.

In general the intensity of natural remanent magnetization (NRM intensity) of the Ellesmere sediment was very low (Fig. 52). The whole core declination of samples with NRM intensity above 2 mAm^{-1} (Fig. 52), from cores 3, 4 and 6 are shown in Fig. 55a. Only samples from the pale brown clayey mud and pink clay (Fig. 49) fulfil this requirement. There was a pronounced east / west trend in the records from the pale brown clayey mud, with a westerly maximum at ca. 3.25m (Core 3), 0.95m (Core 4) and 1.50m (Core 6) clearly seen in Fig. 55a. The ^{14}C age of a sample from 1.45 - 1.55m in core 6 is 940 ± 50 years bp, strongly suggesting that this feature is westerly maximum D (Mackereth 1971), dated from archaeomagnetic evidence (e.g. Aitken 1970, Thellier 1968) at 1000bp (Thompson and Turner 1979). There is an easterly maximum seen in the declination records (Fig. 55) at ca. 2.05m (Core 3) and ca. 1.00m (Core 6) dated, from archaeomagnetic records (Aitken 1970, Thellier 1968), at 600bp (Thompson and Turner 1979). Close correspondence with the correlations derived from susceptibility, intensity of natural remanent magnetization and stratigraphy has increased confidence in this interpretation (Fig. 55b).

Stratigraphic / Palynological / Palaeomagnetic Date.

The basal pink clay in cores 3, 4 and 6 has the appearance of Late - Devensian solifluction clay. The dark brown lake mud overlying this clay in core 6 contains a spatially compressed, early Flandrian pollen sequence (J. B. Innes pers. comm). The palaeomagnetic declination record from the pink clay in core 6 (Fig. 55a) shows a westerly maximum below the clay/mud interface, followed by an easterly maximum deeper into the clay, similar to the east/west sequence K-L reported by Mackereth (1971) from Windermere. Feature K in Windermere was dated, from the pollen assemblage zone, to ca. 10,000bp by Mackereth (loc. cit). It is felt that the stratigraphic / palynological / palaeomagnetic information dates the clay/ mud interface at Ellesmere to ca. 10,000bp.

Age / Depth Curve.

All the available ^{14}C, palaeomagnetic and stratigraphic/ palynological / palaeomagnetic dates for Ellesmere core 6 are shown in Fig. 54. The topmost ^{14}C date (0.95 - 1.05m, 1270 ± 50 years bp) is older than the ^{14}C date beneath it (1.45 - 1.55m, 940 ± 50 years bp) and considerably older than the palaeomagnetic age for 1.0m (ca. 600bp). Such inversions of ^{14}C age are common in recent sediments, and are generally held to be due to input into the lake system of 'old carbon' released from soils by agricultural activity (e.g. Pennington et al. 1976). The remaining dates form a consistent monotonic series, covering the whole of the Flandrian. The rate of deposition calculated from the age / depth curve is given in Table 21 , page 136.

^{210}Pb Dating.

^{210}Pb analyses were carried out on 10 samples from the Ellesmere 'Mini'core (Table 22 , page 137). ^{226}Ra contents were interpolated from three analyses (Table 22 , page 137). Unsupported ^{210}Pb levels were calculated using the interpolated ^{226}Ra data (Table 22 , page 137 , Fig. 56a). The constant rate of supply (c.r.s.) model of Appleby and Oldfield (1978) estimates a ^{210}Pb flux density of 0.35 pCi cm^{-2} a^{-1} (Appleby pers. comm.). This is higher than for the Rostherne Mere 'Mini'core (0.17 pCi cm^{-2} a^{-1}) and other sites in the district (Appleby pers. comm.). This may be due to sediment focussing in the steep sided, deep part of Ellesmere (Fig. 3b) in which the 'Mini'core was taken (Fig. 49). The c.r.s. dating model (Appleby pers. comm.), (Fig. 56b) should be treated with some caution where sediment focussing is suspected because if the sediment focussing has not occurred at a constant rate, it will have an adverse effect on the accuracy of the resultant chronology.

A ^{210}Pb chronology prepared using the constant initial concentration (c.i.c.) model (Krishnaswamy et al. 1971, Pennington et al. 1976) yielded a monotonic series of dates (Fig. 56b). Both the c.r.s. and c.i.c. models show changes in rate of sedimentation, so the c.i.c. model cannot be used without caution, as a chronology. To produce a reliable chronology, the c.r.s. and c.i.c. chronologies (Fig. 56b) were compared. Where the c.i.c. ages varied 10% or less from the c.r.s. ages, the latter were used. Where agreement was less good, an interpolation method was used to calculate the chronology. The mean dry mass accumulation rate, r (m) was calculated, between two acceptable c.r.s. dates, of which the younger was termed t_0. An estimate of actual ^{210}Pb age, t, in years AD, of unacceptable c.r.s. dates, was made from known increase in cumulative dry mass, m, using the following equation

$$t = t_0 - (m / r (m)).$$

The preferred ^{210}Pb chronology, using the acceptable c.r.s. dates and interpolated dates where necessary, is shown in Fig. 56c. Table 23 , page 137, shows the origin of each date in the preferred chronology. This table shows that the preferred chronology is in fact very similar to the c.r.s. chronology.

^{137}Cs Profile.

^{137}Cs, derived from the testing of nuclear weapons, reached a peak atmospheric fallout in the Northern Hemisphere in 1963AD. The distribution of ^{137}Cs in lake sediments has been used as a chronological tool (e.g. Pennington _et al_. 1976). The results of ^{137}Cs analyses on the top 30 one cm slices of the Ellesmere 'Mini'core are shown in Fig. 57a. There was a rather diffuse peak, centred above the ^{210}Pb 1963 horizon (unequivocably dated by both c.r.s. and c.i.c. methods, Table 22 , page 137). Correction of the ^{137}Cs profile for radioactive decay, using a half life of 30 years (Harrison 1972), using the preferred ^{210}Pb chronology (Fig. 56c) as a timescale, gives the profile shown in Fig. 57b). There was a rather diffuse peak, stretching from 0.11 - 0.18m, compared to the preferred ^{210}Pb 1963AD horizon at 0.175m (Figs. 56c and 57b). There may be some tendancy towards the displaced ^{137}Cs peak observed in the Rostherne Mere 'Mini'core (Fig. 22). This may be due to slight upward diffusion of ^{137}Cs in the sediment, or delayed input from ^{137}Cs initially deposited in the lake catchment. The possible sediment focussing suggested by the high ^{210}Pb flux density (page 83) renders any resolution of this problem impossible. In general the ^{137}Cs profile, after correction for radioactive decay of ^{137}Cs (Fig. 57b) supports the recent part of the ^{210}Pb chronology (Fig. 56c).

Diatom Analyses.

Presentation of Results.

Relative diatom analyses at closely spaced intervals in the Ellesmere 'Mini'core and core 6 are shown as diatom diagrams (Figs. 58, 59, 63), including all taxa which occurred at frequencies of 2% or greater in any sample in the core. The diatom taxa are grouped according to their preferred habitat (Table 4,page 122). Species lists of any taxa less frequent than 2% in all samples in a core are presented as Tables 24, 25,pages 138-139.

Relative diatom counts made at less frequent intervals in Ellesmere core 4 are shown as diatom diagrams in Figs. 67 and 68, including taxa occurring at more than 2% frequency in any sample. Less common taxa are presented as a species list in Table 26,page 139. The results of diatom analyses made on samples from the marginal Russian core R, which contained few diatoms, may be found in Table 27,page 140.

The mean volume of each planktonic or occasionally planktonic diatom taxon, determined from measurements of 100 individuals may be found in Table 11,page 130.

Absolute diatom analyses on samples from the Ellesmere 'Mini'core and core 6 are shown as triplets of diagrams. The numerical concentration of diatoms (see page 27), in total, and for those preferring pelagic or littoral environments, is shown in Figs 60 and 64.

The planktonic diatom numerical concentration is shown in Figs. 61a and 65a. The numerical accumulation rate (see page 27) for planktonic diatoms is shown in Figs. 61b and 65b. The volume accumulation rate (see page 27) for planktonic diatoms is presented in Figs. 61c and 65c.

The volume accumulation rates for individual planktonic and occasionally planktonic diatom taxa encountered are shown as diatom diagrams in Figs 62 and 66.

Relative Diatom Analyses.

Core 6.

In the lowest two samples, 3.30 and 3.28m, in Ellesmere core 6 (Figs. 58 and 59) diatoms were scarce, although 500 were eventually found in both cases. The frustules were more or less corroded, particularly those of *Cyclotella stelligera*. The dominant planktonic taxon was *Melosira italica* subsp. *subarctica*, with a contribution from the occasionally planktonic *Cyclotella stelligera* (Fig. 58). The most frequent non - planktonic species were *Eunotia pectinalis* var. *minor* and *Fragilaria elliptica* (Fig. 59).

From 3.24 - 2.40m, *Melosira italica* subsp. *subarctica* was generally overwhelmingly dominant, with a variable contribution from *Tabellaria* spp., some of which are planktonic (Fig. 58). The commonest of the very infrequent non - planktonic diatoms were *Fragilaria* spp., *Eunotia pectinalis* var. *minor* and *Gomphonema gracile* (Fig. 59).

The common features of the samples from 2.30 and 2.20m were few diatoms and large percentages of the non - planktonic species *Eunotia pectinalis* var. *minor* (Fig. 59). *Melosira italica* subsp. *subarctica* was the most frequent planktonic diatom, present at a small percentage in 2.30m, more frequent in 2.20m (Fig. 58). In addition to *Eunotia pectinalis* var. *minor*, *Cocconeis placentula* and *Navicula viridula* were very common non - planktonic species at 2.30m, and were present at lower percentages with *Fragilaria elliptica* at 2.20m (Fig. 59).

Between 2.1 and 1.1m in Ellesmere core 6, the most frequent planktonic diatom was Melosira italica subsp. subarctica, with the occasionally planktonic Cyclotella stelligera subdominant from 1.8 - 1.5m, and small amounts of Cyclotella comta from 1.5 - 1.3m (Fig. 58). The most abundant non - planktonic diatom was Fragilaria elliptica with small percentages of Cocconeis placentula and Fragilaria pinnata (Fig. 59).

From 1.0m to the topmost sample at 0.08m in core 6 there was a rather sparse mixed planktonic flora of Stephanodiscus dubius, Stephanodiscus hantzschii and Cyclotella comta, with rather lower percentages of Asterionella formosa, Melosira granulata var. angustissima, Stephanodiscus astraea, and Stephanodiscus astraea var. minutula (Fig. 58). The most frequent non - planktonic diatoms were Fragilaria spp., with small percentages of Navicula seminulum and Achnanthes lanceolata var. elliptica, and increasing frequencies of Amphora perpusilla and Navicula scutelloides (Fig. 59).

'Mini'core.

In the Ellesmere 'Mini'core, from 1.05 - 0.95m there was a mixed planktonic flora of Stephanodiscus hantzschii, Cyclotella comta, Stephanodiscus dubius and Asterionella formosa (Fig. 63), similar to that found in sample 0.08m in core 6 (Fig. 58). Between 0.90 and 0m the rather variable planktonic diatom flora in the Ellesmere 'Mini'core was chiefly Stephanodiscus hantzschii and Asterionella formosa with Melosira granulata var. angustissima less frequently (Fig. 63). Stephanodiscus hantzschii was particularly dominant above 0.45m (Fig. 63). A variety of non - planktonic species were present at low percentages, particularly Fragilaria spp., Navicula scutelloides and Cocconeis placentula.

Core 4.

In Ellesmere core 4 the less detailed diatom analyses (Figs. 67 and 68) revealed a similar sequence to that seen in core 6 (Figs. 58 and 59).

The lowest sample analysed, 3.6m, was dominated by the planktonic diatom *Melosira italica* subsp. *subarctica*, with a smaller percentage of rather corroded *Cyclotella stelligera*, an occasionally planktonic species (Fig. 67). Non - planktonic species were rather infrequent, *Fragilaria elliptica* being the most commonly encountered (Fig. 68). This assemblage is similar to that found at 3.30 and 3.28m in core 6 (Figs. 58 and 59).

From 3.4 - 2.2m in core 4 the dominant diatom was the planktonic *Melosira italica* subsp. *subarctica*, with lower frequencies of *Tabellaria* spp., some of which are planktonic (Fig. 67). Non - planktonic diatoms were scarce, but included *Fragilaria elliptica*, *Eunotia pectinalis* var. *minor* and *Gomphonema gracile* (Fig. 68). This flora resembles that found from 3.24 - 2.40m in core 6 (Figs. 58 and 59).

The diatom assemblage found from 2.0 - 1.6m in core 4 (Figs. 67 and 68) is similar to that found at 2.3 and 2.2m in core 6 (Figs. 58 and 59). The most commonly encountered planktonic diatom was *Melosira italica* subsp. *subarctica*, although this was particularly infrequent at 2.0m (Fig. 67). The dominant non - planktonic diatoms were *Cocconeis placentula* and *Eunotia pectinalis* var. *minor*, with smaller numbers of *Navicula viridula* and *Cymbella minuta* (= *Cymbella ventricosa*) (Fig. 68).

From 1.4 - 0.8m in core 4 the most frequent planktonic diatom was *Melosira italica* subsp. *subarctica*, with a considerable contribution from the occasionally planktonic *Cyclotella stelligera* at 1.0 and 0.8m (Fig. 67). The dominant non - planktonic species was *Fragilaria elliptica* (Fig. 60). This flora was similar to that from 2.1 - 1.1m in core 6 (Figs. 58 and 59).

Samples from 0.65 and 0.6m in core 4, did not contain sufficient diatoms to provide a diatom count, even when sediment samples of *ca.* 1cm^3 were used, and several highly concentrated preparations made. This part of core 4 probably corresponds to *ca.* 1.3m in core 6 where diatoms were present at a particularly low concentration (Fig. 60).

From 0.4m to the topmost sample at 0.02m in core 4, there was a rather poorly represented mixed planktonic flora of *Stephanodiscus hantzschii*, *Cyclotella comta*, *Asterionella formosa*, *Melosira granulata* var. *angustissima* and *Melosira italica* subsp. *subarctica* (Fig. 67). The chief non - planktonic species were *Fragilaria* spp., with smaller percentages of *Navicula seminulum*. This diatom assemblage resembles that found above 1.0m in core 6 (Figs. 58 and 59).

Russian Core R.

The results of relative diatom analyses on samples from the Ellesmere Russian core R are shown in Table 27 , page 140. In the samples taken from below 0.49m there were very few diatoms, insufficient to permit a diatom count. Above 0.49m, most of the frequent species were planktonic, characteristic of the lake today. The significance of these results remains unclear.

Absolute Diatom Analyses.

Overall Numerical Concentration.

Core 6.

The overall numerical concentration of diatoms in Ellesmere core 6 (Fig. 60a) has undergone a series of oscillations with conspicuous maxima at *ca.* 2.7 - 2.5m, *ca.* 1.9m and *ca.* 0.7m, and minima at 3.3m, 2.3m and 1.3m. From Figs. 60b and 60c it may be seen that most of the maximum at *ca.* 2.7 - 2.5m was planktonic diatoms, the maximum at *ca.* 1.9m was partly planktonic and partly non - planktonic, whilst that at *ca.* 0.7m was largely non - planktonic.

'Mini'core.

The overall numerical concentration of diatoms in the Ellesmere 'Mini'core (Fig. 64a) was rather variable from *ca.* 1.05 - 0.35m, becoming very variable and rather increased above 0.3m. It can be seen from Figs. 64b and c that the increase after 0.3m was entirely due to planktonic diatoms (Fig. 64b), the numerical concentration of non - planktonic diatoms declining towards the top of the core, to very low levels at the sediment surface (Fig. 64c).

Planktonic Diatom Concentration and Accumulation Rates.

Core 6.

The numerical concentration of planktonic and occasionally planktonic diatoms in core 6 rose from very low levels at 3.30m to very high values from 2.6 - 2.4m (Figs. 61 and 60b). Numerical concentration was very low at 2.3m, higher from 2.1 - 1.8m, very low at 1.3m and then rose to a low maximum at 0.08m (Fig. 61a).

The overall numerical accumulation rate for planktonic and occasionally planktonic diatoms in core 6 (Fig. 61b) rose from very low levels at 3.30m to a considerable maximum at 2.6 - 2.4m, and then declined to very low levels at 2.3m. Rather high accumulation rates were reached from 2.1 - 1.8m, followed by low values at 1.3m, and an irregular rise to rather high levels at 0.08m (Fig. 61b).

The overall volume accumulation rate for planktonic and occasionally planktonic (including _Tabellaria_ spp.) diatoms (Fig. 61c) rose from a very low level of 0.7 mm^3 m^{-2} a^{-1} at 3.30m to values of 2000 - 4000 mm^3 m^{-2} a^{-1} between 2.8 and 2.5m. There was a minimum volume accumulation rate of 7mm^3 m^{-2} a^{-1} at 2.3m, followed by a rise to 1000 - 2000 mm^3 m^{-2} a^{-1} from 2.1 - 1.5m, and another minimum of _ca_. 30 mm^3 m^{-2} a^{-1} at 1.3m. There was then an irregular rise to _ca_. 4000 mm^3 m^{-2} a^{-1} at 0.08m (Fig. 61c).

'Mini'core.

The overall numerical concentration of planktonic and occasionally planktonic diatoms (including _Tabellaria_ spp.) for the Ellesmere 'Mini'core (Fig. 65a and 64b) became increasingly variable, particularly above 0.3m, showing a general increase from the base of the dated part of the core at 0.6m towards the top.

The numerical accumulation rate for planktonic and occasionally planktonic diatoms in the 'Mini'core (Fig. 65b) rose considerably from 0.6m to high and variable values above 0.3m.

From 0.6 - 0.3m in the 'Mini'core the volume accumulation rate for planktonic and occasionally planktonic diatoms varied between 0.5 x 10^4 and 1.5 x 10^4 mm^3 m^{-2} a^{-1}. Above 0.3m, the levels increased to between

1.5 and 5 x 10^4 mm^3 m^{-2} a^{-1}.

Volume Accumulation Rates of Selected Individual Species.

Core 6.

The diatom diagram showing the individual volume accumulation rates for planktonic diatoms, occasionally planktonic diatoms and *Tabellaria* spp. may be seen in Fig. 62.

Between 3.30 and 2.5m the volume accumulation rate of *Melosira italica* subsp. *subarctica*, the dominant planktonic diatom, rose irregularly from very low to very high levels. *Tabellaria* spp., some of which are planktonic, formed a variable component of this flora, being particularly important between 3.13 and 2.5m. *Cyclotella stelligera* was accumulating slowly from 3.30 - 3.17m, although many frustules were poorly preserved, so this taxon may be under - represented. *Cyclotella stelligera* was briefly important at 2.60m. *Asterionella formosa* formed a small part of the assemblage between 2.6 and 2.5m.

Between 2.45 and 2.2m in core 6, the volume accumulation rate of *Melosira italica* subsp. *subarctica*, the dominant planktonic diatom was very low, with a minimum at 2.3m (Fig. 62). Small amounts of *Tabellaria* spp. and *Cyclotella* spp. were present.

From 2.1 - 1.5m, the generally dominant *Melosira italica* subsp. *subarctica* declined gradually from a minor maximum in accumulation rate at 2.0m, while the occasionally planktonic *Cyclotella stelligera* increased, to achieve co - dominance with *Melosira italica* subsp. *subarctica* at 1.5m (Fig. 62). *Asterionella formosa* and the occasionally planktonic *Fragilaria capucina* were usually present. *Cyclotella comta* became important for the first time at 1.5m (Fig. 62).

Between 1.4 and 1.1m *Cyclotella comta* and *Melosira italica* subsp. *subarctica*, the dominant planktonic diatoms, were accumulating slowly, with a minimum at 1.3m (Fig. 62). A small contribution was made by *Cyclotella stelligera*.

From 1.0m to the topmost sample analysed, at 0.08m, in core 6, there was a very mixed planktonic diatom flora, dominated by increasingly abundant *Stephanodiscus* spp. and *Cyclotella comta* (fig. 62). Other planktonic diatoms making smaller contributions included *Asterionella formosa*, *Melosira granulata* var. *angustissima*, *Fragilaria crotonensis*, *Melosira italica* subsp. *subarctica* and the occasionally planktonic *Fragilaria capucina*.

'Mini'core.

In the Ellesmere 'Mini'core, from the lowest sample for which a ^{210}Pb date is available, 0.60m, to 0.40m, the most rapidly accumulating diatom was *Stephanodiscus astraea*, with smaller amounts of other *Stephanodiscus* spp. and *Asterionella formosa*. From 0.35 - 0m, *Stephanodiscus astraea* was less important, except for an isolated peak at 0.04m. The dominant planktonic diatoms were generally *Stephanodiscus hantzschii* and *Asterionella formosa* with smaller amounts of *Melosira granulata* var. *angustissima*, *Stephanodiscus astraea* var. *minutula* and particularly between 0.20 and 0.10m, *Fragilaria crotonensis*.

Chemical Analyses.

Dry Mass.

Core 6.

The dry mass per mm^3 of wet sediment **for samples from** the clay below 3.315m in Ellesmere core 6 was more than 1 mg mm^{-3} (Fig. 69a). *In the* Flandrian lake *mud* the values declined from ca. 0.4 mg mm^{-3} at 3.30m to less than ca. 0.2 mg mm^{-3} by 3.1m, remaining at this level until 2.5m. Between 2.4 and 1.0m the dry mass per mm^3 increased from ca. 0.25 mg mm^{-3} to ca. 0.4 mg mm^{-3}. From 0.9m to the topmost sample at 0.08m, the values were between ca. 0.2 and 0.3 mg mm^{-3} (Fig. 69a).

The dry mass accumulation rate for the Flandrian muds *in core 6 remained at less than* 100g m^{-2} a^{-1} until above 2.4m (Fig. 69b). Between 2.3 and 1.0m there was an increase in accumulation rate from ca. 200g m^{-2} a^{-1} to an overall maximum of ca. 700 g m^{-2} a^{-1} (Fig. 69b). From 0.9 - 0.08m the accumulation rate remained between ca. 250 and 400g m^{-2} a^{-1}.

'Mini'core.

The dry mass per mm^3 in the Ellesmere 'Mini'core (Fig. 70a) declined from ca. 0.2 mg mm^{-3} at 1.05m to ca. 0.2 mg mm^{-3} at 1.05m to ca. 0.1 mg mm^{-3} by 0.05m, and ca. 0.04 mg mm^{-3} at 0m.

The dry mass accumulation rate for the ^{210}Pb dated part of the 'Mini'core (Fig. 70b) remained between 0.4 x 10^3 and 0.5 x 10^3 g m^{-2} a^{-1} from 0.60 - 0.41m, increasing to a rather irregular maximum of ca. 0.8 x 10^3 - 1.0 x 10^3 g m^{-2} a^{-1} between 0.21 and 0.05m, followed by a decline to ca. 0.5 x 10^3 g m^{-2} at 0m (Fig. 70b).

Mass Lost on Ignition.

Core 6.

The mass lost on ignition at 450^{0}C (page 29) per mm^{3} of wet sediment for samples from the Late - Devensian clay below 3.315m in core 6 (Fig. 69c) was ca. 2 x 10^{-2} - 3 x 10^{-2} mg mm^{-3}. In the Flandrian muds the values generally decreased from ca. 12 x 10^{-2} mg mm^{-3} at 3.3m to ca. 4 x 10^{-2} mg mm^{-3} at 0.08m, with an unusual maximum of ca. 13 x 10^{-2} mg mm^{-3} at 2.4m, and an unusual minimum of ca. 2 x 10^{2} mg mm^{3} at 1.0m (Fig. 69c).

The accumulation rate for mass lost on ignition for the Flandrian sediments is ca. 10 g m^{-2} a^{-1} from 3.3 - 2.9m (Fig. 69d). There was a small maximum of ca. 25 g m^{-2} a^{-1} at 2.7m followed by a decline to ca. 20 g m^{-2} a^{-1} at 2.5m. A sharp maximum was found, of ca. 80 g m^{-2} a^{-1} at 2.2m, and values from ca. 40 - 50 g m^{-2} a^{-1} were encountered between 2.0 - 1.5m. From 1.4 - 1.1m in core 6 the accumulation rate for ignitable material was ca. 60 - 70 g m^{-2} a^{-1} followed by an abrupt decline to ca. 35 g m^{-2} a^{-1} at 1.0m (Fig. 69d). After a maximum of ca. 70 g m^{-2} a^{-1} at 0.8m the accumulation rate declined to ca. 55 g m^{-2} a^{-1} at 0.4m, and then increased to ca. 70 g m^{-2} a^{-1} at 0.2m (Fig. 69d).

'Mini'core.

The mass lost on ignition at 450^{0}C per mm^{3} of wet sediment in the 'Mini'core (Fig. 70c) varied between 3.5 x 10^{-2} and 5 x 10^{-2} mg mm^{-3} from 1.05 - 0.17m, followed by an irregular decline to less than 2 x 10^{-2} mg mm^{-3} at 0m (Fig. 70c).

For the ^{210}Pb dated part of the 'Mini'core, above 0.6m, the accumulation rate for mass lost on ignition (Fig. 70d) was ca. 140 g m^{-2} a^{-1} from 0.60 - 0.41m. The accumulation rate then increased to an irregular maximum of *ca.* 300 - 400 g m^{-2} a^{-1} between 0.21 and 0.05m, declining to *ca.* 230 g m^{-2} a^{-1} by 0m.

Organic Carbon.

Core 6.

The concentration of organic carbon as mass per mm^3 of wet sediment in a sample from the Late-Devensian clay at 3.5m in core 6 (Fig. 71c) was *ca.* 0 mg mm^{-3}. The organic carbon concentration of the Flandrian muds declined irregularly from *ca.* 5 x 10^{-2} at 3.315m to *ca.* 1.5 x 10^{-2} mg mm^{-3} at 1.30m. The concentration from 0.97m upwards was *ca.* 2.5 x 10^{-2} mg mm^{-3} (Fig. 71c).

The mass accumulation rate for organic carbon in Ellesmere core 6 (Fig. 71d) rose in a series of steps from *ca.* 2 g m^{-2} a^{-1} at 3.315m and 3.23m. Between 3.03 and 2.83m the accumulation rate was *ca.* 4 g m^{-2} a^{-1}, and from 2.70 - 2.43m it was *ca.* 10 g m^{-2} a^{-1} (Fig. 71d). From 2.20 - 1.60m the values were *ca.* 22.5 g m^{-2} a^{-1}, declining slightly to 20 g m^{-2} a^{-1} at 1.30m, then rising to *ca.* 40 g m^{-2} a^{-1} above 0.80m (Fig. 71d).

'Mini'core.

In the Ellesmere 'Mini'core the organic carbon concentration (Fig. 71a) declined from *ca.*2.3 x 10^{-2} at 0.60 and 0.43m to *ca.* 1.8 x 10^{-2} mg mm^{-3} at 0.03m (Fig. 71a).

The organic carbon accumulation rate in the 'Mini'core (Fig. 71b) increased from *ca.* 85 g m^{-2} a^{-1} at 0.6m to *ca.* 195 g m^{-2} a^{-1} at 0.03m.

Discussion.

Correlation.

The correlations between the Ellesmere Mackereth 6m cores 1 - 6 are based on stratigraphy (Fig. 49), and on measurements of susceptibility (Fig. 51) and intensity of natural remanent magnetization (Fig. 52). Comparison of correlations derived from these three independent parameters (Fig. 53), shows that there is close correspondence between the correlations. The depth / depth plots in Fig. 53 do not, in some cases, approximate to a straight line, suggesting variations in the relative deposition rates at different sites through time. The differing relative deposition rates could be due to post - depositional sediment movements on the sloping basin sides (Fig. 49), areal variations in sediment deposition, or localized erosion and redistribution effects.

Three of the cores 3, 4 and 6 contained basal pink clay (Fig. 49), which, logically, is likely to be the oldest sediment type. These three cores were particularly well correlated with each other (Fig. 53). Core 3 contained a very compressed lower dark brown mud layer compared with cores 4 and 6 (Fig. 49). Core 6 contained a more extended upper mud sequence (Fig. 49), and rather better resolved palaeomagnetic records (Figs. 51, 52 and 55a) than core 4. Core 6 was selected for detailed palaeolimnological analyses. This choice was entirely vindicated by the chronology later established for core 6 (Fig. 54) which shows no signs of any major hiatus.

Core 4 was selected for less detailed analyses, as it was considered that the very abbreviated lower dark brown mud layer in core 3 (Fig. 49) suggested a major discontinuity.

The 'Mini'core was rather weakly correlated with the selected core 6 on susceptibility records (Fig. 51) and biostratigraphy (Table 20,page 135). The correlations imply a considerable loss of sediment from the 6 metre core, with the youngest sediment present older than ca. 1870AD.

The very low magnetic mineral content of the organic marginal muds sampled in Russian core R did not yield measurable intensity of natural remanent magnetization or susceptibility, and the auger samples from the basal clays were unsuitable for magnetic measurement. The almost complete absence of diatoms from the sediments ruled out biostratigraphic correlation.

Chronology.

An age / depth curve has been prepared for Ellesmere core 6. The ages are given in ^{14}C years. Dendrochronological calibration, based on Bristlecone pine chronology (e.g. Suess 1970, Clark 1975), does not extend, at present, beyond ca. 6500 ^{14}C years bp. The Ellesmere sediments cover the last 10,000 ^{14}C years, and as it was preferred to avoid making assumptions about calibration prior to ca. 6500bp (e.g. Mackereth 1971, Thompson and Turner 1979), none of the Ellesmere dates were calibrated prior to calculation of rates of deposition (Table 21, page 136). The effect of dendrochronological calibration, using the method of Clark (1975), can be seen in Table 28,page 141.

It should be noted that the 1σ confidence intervals given, and in general use for ^{14}C dates, are only 68% confidence intervals, unacceptable in almost any other application. The use of 2σ or 95% confidence intervals, advocated by Clark (1975) would give a more realistic assessment of possible errors involved.

Fig. 54 shows that the topmost ^{14}C date (SRR 1800, 0.95 - 1.05m, 1270 ± 50bp), from core 6, is older than the one below (SRR 1881, 1.45 - 1.55m, 940 ± 50bp), and older than the palaeomagnetic age of 600bp for 1.0m. This is likely to be due to input of 'old carbon' to the lake system, from agricultural disturbance of soil profiles (Pennington et al. 1976). All the remaining dates form a consistent, monotonic sequence. The top of the core was regarded as 0 years bp in the calculation of rate of sediment deposition. It is now clear that the age of this sediment is probably of the order of 100 years bp, from the correlation with the ^{210}Pb dated 'Mini'core (page 80 , Table 20 , page 135, Fig. 56c). This would have the effect of raising the calculated rate of deposition. The rate of deposition was already the highest for any part of Ellesmere core 6 (Table 21 , page 136), therefore interpretation is unlikely to be greatly affected.

The ^{210}Pb flux density calculated for the Ellesmere 'Mini'core (0.36 pCi cm^{-2} a^{-1}, Appleby pers. comm.) was higher than that calculated for other sites in the region (Appleby pers. comm.). This could reflect sediment focussing, requiring caution in the application of the constant rate of supply (c.r.s.) model of Appleby and Oldfield (1978). There are objections to the use of the constant initial concentration (c.i.c.) model (Krishnaswamy et al. 1971, Pennington et al. 1976) where sedimentation rates alter through time (Appleby and Oldfield 1978). Both the c.r.s. and the c.i.c. ^{210}Pb-chronologies show changes in rate of sediment deposition (Fig. 56b). Both the c.r.s. and the c.i.c. models may result in inaccurate chronologies in the Ellesmere 'Mini'core, although if past sediment focussing has been relatively constant the c.r.s. model should approximate to the actual chronology. Where agreement between the c.r.s. and c.i.c. chronologies was good the former was used to construct a preferred chronology. Where agreement was less good, an interpolation technique was used (page 84). The resultant preferred chronology (Fig. 56c, Table 23 , page 137) is similar to the c.r.s. chronology (Fig. 56b, Table 22 , page 137) in the interpolated sections.

After correction for radioactive decay (page 85) the ^{137}Cs profile for the Ellesmere 'Mini'core (Fig. 57b) shows a broad peak from 0.11 - 0.16m, compared to the ^{210}Pb 1963AD horizon of 0.175m (c.i.c., c.r.s. and preferred chronologies, Fig. 56). The slight upward displacement of the ^{137}Cs peak may be due to diffusion, or to some delay in recruitment to the sediment of ^{137}Cs fallout onto the lake catchment. The ^{137}Cs profile provides qualified independent confirmation of the upper part of the ^{210}Pb chronology.

The application of a wide range of dating techniques has enabled the construction of reliable, consistent chronologies for Ellesmere core 6 and 'Mini'core.

Problems of Interpretation.

Diatom Analyses.

Problems relating to the interpretation of diatom analyses have been discussed in the section on Rostherne Mere (page 67) and by Round (1964) and Battarbee (1979). Particular problems may include dissolution, disintegration or loss of diatoms in lake waters and sediments, and vertical mixing or erosion and redeposition of lake sediments.

Chemical Analyses.

Discussion of problems relating to the interpretation of chemical analyses may be found in the section on Rostherne Mere (page 68), and some relevant aspects of these problems have been discussed by Digerfeldt (1972, 1975). Problems related to the effect of clay minerals are likely to be of particular relevance to interpretation of results from Ellesmere in view of the variably clayey nature of the sediment, seen clearly in the stratigraphy (Fig. 49).

Phases in Lake Development.

Prior to ca. 10,000bp. The Late Devensian clays at the base of Ellesmere core 6 contained no recognisable diatom remains, although the presence of silica sponge spicules suggests an aquatic origin. A carbon analysis at 3.5m did not yield a measurable amount of carbon (Fig. 71c), but the mass lost on ignition was *ca.* 2.5×10^{-2} mg mm^{-3} (Fig. 69c). This is likely to represent mainly loss of structural water from clay minerals. It is thought that at the time of deposition of these sediments the diatom flora was non - existent, or at least extremely sparse.

Phase 1 (Fig. 72), ca. 10,000 - 8000bp. In the early Flandrian sediments the rate of sediment deposition was very slow (*ca.* 0.004 cm a^{-1}) (Table 21 , page 136 , Fig. 54) and diatom samples are up to *ca.* 800 ^{14}C years apart (Fig. 72). Other measurements are less frequent (Fig. 72). Diatom, carbon and mass lost on ignition accumulation rates were very low (Fig. 72). The dominant planktonic diatom was *Melosira italica* subsp. *subarctica*, an alkaliphilous diatom widely distributed in lakes. Smaller amounts of *Tabellaria* spp., some of which are planktonic and which occur in a wide range of environments, and *Cyclotella stelligera*, pH indifferent and occasionally planktonic, were found (Figs. 62 and 72). There was evidence of corrosion of diatoms, especially *Cyclotella stelligera*. The most important non - planktonic diatoms were alkaliphilous *Fragilaria* spp. and the acidophilous *Eunotia pectinalis* var. *minor* (Fig. 59), although the latter is more tolerant of lime than many other *Eunotia* spp. (Patrick in Hutchinson *et al.* 1970). The pH spectrum (Fig. 73) shows that the majority of the individuals were alkaliphilous with occasional pH indifferent and acidophilous contributions. There was a predominance of pH indifferent and alkaliphilous taxa, with smaller numbers of acidophilous taxa. This data suggests that during phase 1 Ellesmere was considerably poorer in nutrients than at the present day and was rather poor in diatoms. The pH of the lake was a little above 7, compared to the present day range of pH 7.5 - 9.5 (Reynolds 1979).

Phase 2 (Fig. 72), ca. 8000 - 4500bp. The diatom, carbon and mass lost on ignition accumulation rates were still low, although rather higher than from 10,000 - 8000bp (Fig. 72). The diatom accumulation rate started to rise irregularly after ca. 5000bp. The dominant planktonic diatom was Melosira italica subsp. subarctica, with smaller amounts of Tabellaria spp. (Figs. 62 and 72). The small non - planktonic input to the sediment consisted chiefly of alkaliphilous Fragilaria spp., pH indifferent Gomphonema gracile and acidophilus Eunotia pectinalis var. minor (Fig. 59). The pH spectrum (Fig. 73) shows a dominance of alkaliphilous individuals, and indifferent taxa, with rather fewer alkaliphilous and acidophilous taxa. Ellesmere appears to have remained rather nutrient poor during phase 2 compared to the present day, although perhaps marginally more nutrient rich than during phase 1. The diatom flora was rather less impoverished than previously. The pH was, as before, rather above 7, though perhaps not as alkaline as at present.

Phase 3 (Fig. 72), ca. 4500 - 2500bp. The diatom, carbon and mass lost on ignition accumulation rates were rather higher than previously, especially the diatom accumulation rate (Fig. 72). The dominant planktonic diatom was Melosira italica subsp. subarctica with a considerable contribution from Tabellaria spp. Other planktonic species in smaller amounts included the occasionally planktonic Cyclotella stelligera and the alkaliphilous Asterionella formosa (Figs. 62 and 72). Asterionella formosa is found in a wide range of lakes, showing a preference for nutrient rich conditions. There was a dominance of alkaliphilous individuals (Fig. 73) and of indifferent taxa, with rather lower numbers of alkaliphilous and acidophilous taxa.

During phase 3 the lake appears to have been more eutrophic, and richer in diatoms than before, although not as nutrient and diatom rich as at present. The pH seems to have remained rather above 7.

Phase 4 (Fig. 72), ca 2500 - 2000bp. The diatom accumulation rate was low with a minimum at ca. 2100bp (Figs. 61c and 72). By 2000bp the organic carbon accumulation rate had increased (Figs. 71 and 72). After ca. 2200bp the accumulation rate for mass lost on ignition rose to a maximum at ca. 2000bp (Figs. 69 and 72). There was an abrupt increase in dry mass concentration at this level (Fig. 69a), and the appearance of abundant, amorphous, clay size material in diatom preparations. The mass lost on ignition cannot be relied upon to be proportional to organic material during this phase.

The dominant planktonic diatom was Melosira italica subsp. subarctica, with smaller amounts of Tabellaria spp. (some of which are planktonic) and Cyclotella stelligera (sometimes planktonic) (Figs. 62 and 72). The diatom accumulation rate was particularly low from ca. 2100 - 2000bp (2.3 and 2.2m). In the samples from 2.3 and 2.2m the frequency of acidophilous individuals was over 30% and the percentage of alkaliphilous individuals was depressed, although they still remained dominant (Fig. 73). Alkaliphilous and pH indifferent taxa were rather more abundant than acidophilous taxa. The main non - planktonic taxa were Eunotia pectinalis var. minor, Cocconeis placentula (alkaliphile) and Navicula viridula (pH indifferent) (Fig. 59).

During phase 4 Ellesmere appears to have been less nutrient rich than during phase 3 and considerably less eutrophic than at present. The planktonic diatom flora was particularly impoverished. The pH, particularly from

2100 - 2000bp may have been about 7, perhaps less alkaline than previously, and probably less alkaline than today's pH of 7.5 - 9.5.

Phase 5 (Fig. 72), ca. 2000 - 1000bp. The diatom accumulation rate during phase 5 was higher than during phase 4 although not as high as during phase 3 (Figs. 61 and 72). The organic carbon accumulation rate was higher than in any previous period (Figs. 71 and 72). The accumulation rate for mass lost on ignition declined from a maximum at 2000bp, to reach values higher than during phase 3 between 1700 and 1000bp (Figs. 69 and 72). The dominant planktonic diatom was the alkaliphilous Melosira italica subsp. subarctica with an increasing contribution from the occasionally planktonic pH indifferent Cyclotella stelligera, and with small amounts of Asterionella formosa and Fragilaria capucina (sometimes planktonic in eutrophic waters) (Figs. 62 and 72). Non - planktonic diatoms formed a much greater percentage of the diatom sum than previously, the majority being alkaliphilous Fragilaria spp. (Fig. 59). The bulk of both individuals and taxa were alkaliphilous, with smaller amounts of pH indifferent individuals and taxa (Fig. 73).

This data suggests that in phase 5 Ellesmere was rather more eutrophic than previously, although diatoms appear not to have formed such a large part of the phytoplankton as they did during phase 3. The lake water was distinctly alkaline, rather more so than previously, perhaps well within the present range from pH 7.5 - 9.5.

Phase 6 (Fig. 72), ca. 1000 - 600bp. The planktonic diatom volume accumulation rate was low during phase 6, reaching a minimum at ca. 800bp (Figs. 61c and 72). The most rapidly accumulating diatoms were Melosira italica subsp. subarctica and Cyclotella comta, a pH indifferent planktonic species found in a wide range of lakes. Small quantities of Cyclotella stelligera were also present

(Figs, 62 and 72). The organic carbon accumulation rate at *ca.* 600bp was slightly lower than during phase 5 (Figs. 70 and 72). The mass lost on ignition accumulation rate was higher than previously from *ca.* 1000 - 650bp (Figs. 69 and 72). During this period the dry material accumulation rate showed a considerable maximum (Figs. 69 and 72), the sediment was visually clayey (Fig. 49), and considerable amounts of amorphous clay sized material was found in diatom preparations. Loss of structural water on ignition of this clay material may have caused the anomalous raising of the mass lost on ignition. The most frequent non - planktonic diatom was *Fragilaria elliptica* (Fig. 59). The pH spectrum shows alkaliphilous diatoms dominant, with a smaller contribution from pH indifferent taxa.

The evidence suggests that during phase 6 the lake was rather less nutrient rich than during phase 5 or today, and that diatoms were rather poorly represented. The pH was above 7, possibly as much as today.

Phase 7 (Fig. 72), ca. 600bp - 1950AD. There are problems with the interpretation of this period because the Ellesmere core 6 and 'Mini'core were taken at different sites, and have markedly different sedimentation rates. The absence of dates above 600bp in core 6 has resulted in a rather crude estimate of sedimentation rate which may have lost some detail near the top of the sediment core. Great caution must be observed in comparing the results from the 'Mini'core and core 6. After 600bp the planktonic diatoms (Fig. 62) consisted mainly of *Stephanodiscus astraea*, *Stephanodiscus astraea* var. *minutula* and *Stephanodiscus dubius*, all diatom species preferring alkaline, nutrient rich waters, and *Cyclotella comta*, a pH indifferent, widely distributed species. Above 0.08m in core 6 (Fig. 58) and above 0.95m in the 'Mini'core (Fig. 63), *Stephanodiscus dubius* and *Cyclotella comta* became infrequent, and *Stephanodiscus hantzschii* and

Melosira granulata var. angustissima increased in abundance (Fig. 63). Stephanodiscus astraea formed the bulk of the volume accumulation, with a contribution from Asterionella formosa (Fig. 66). After 600bp in core 6, the carbon accumulation rate was higher than it had been previously (Figs. 71 and 72). The accumulation rate from mass lost on ignition was about the same as from 1000 - 600bp (Figs. 69 and 72) but the sediment was not visually clayey, and diatom preparations contained little clay sized amorphous material, suggesting that mass lost on ignition is likely to be more or less proportional to organic material content.

The overall diatom, carbon and mass lost on ignition accumulation rates before ca. 1940 in the 'Mini'core were rather higher than those for the core 6 after 600bp (Fig. 72). This may be due to the poorly resolved rate of deposition used above 600bp in core 6, differences in environment of deposition, or a change in lake productivity. The diatom accumulation rate was rising near the top of core 6, suggesting the latter, but the carbon and ignitable material accumulation rates did not show this rise. The slower sediment accumulation rate at the site of Ellesmere core 6, compared to the site of the 'Mini'core, would have exposed organic material to decomposition, and silica to dissolution, for longer, perhaps contributing to the problem. The non - planktonic diatoms became infrequent in the upper sediments, particularly in the 'Mini'core (Figs. 59 and 63). The most common were alkaliphilous Fragilaria spp., with increasing contributions from the alkaliphilous Navicula cryptocephala, the pH indifferent Amphora perpusilla and the alkalibiontic Navicula scutelloides. The pH spectrum of samples from Ellesmere core 6 (Fig. 73) show dominance by alkaliphilous individuals and taxa, with a smaller contribution from pH indifferent individuals and taxa. Acidophilous species were infrequent.

This data suggests that the lake was much more nutrient rich during phase 7 than before. It is not clear whether there was any major rise in nutrient status during this phase, but the high carbon accumulation rate, and dominance of the planktonic diatoms by Stephanodiscus spp. precludes any marked return to the previous lower nutrient levels. The lake water was distinctly alkaline, probably in its present range from pH 7.5 - 9.5.

Phase 8 (Fig. 72), ca. 1950 - 1980AD. The planktonic diatoms were generally dominated by Stephanodiscus hantzschii and Asterionella formosa (Fig. 66), largely replacing the previous Stephanodiscus astraea dominated flora by ca. 1955AD, except for an isolated maximum of the latter in the mid - 1970's AD. Stephanodiscus hantzschii is thought to characterise very nutrient rich situations, and Stephanodiscus astraea is found in eutrophic waters, but is generally uncommon in the most eutrophic conditions (Hustedt 1959). The carbon (Figs. 71b and 72) and mass lost on ignition (Figs. 70d and 72) accumulation rates both rose considerably between ca. 1940 and 1960AD, remaining at rather variable, high levels thereafter. Non - planktonic diatoms were very infrequent from ca. 1940AD (Fig. 60), mainly represented by Fragilaria spp. and Navicula scutelloides. The lake productivity appears to have risen to its present high level between ca. 1940 and 1960AD. The water remained distinctly alkaline, supporting a diverse planktonic diatom flora

The diatom and carbon histories of Ellesmere suggest that the eutrophication of the lake occurred in a series of oscillations. A slight increase in nutrient status occurred ca. 4500 ^{14}C years bp (phase 3), followed by a larger increase at ca. 2000bp (phase 5). There was a third, much more significant period commencing at ca. 600bp (phase 7) and a considerable recent eutrophication between 1940 and 1960AD (phase 8).

CHAPTER V.

GENERAL DISCUSSION.

GENERAL DISCUSSION.

Diatom studies of lake sediment cores have been interpreted in terms of specific taxonomic problems (e.g. Haworth 1972) and have also been used for investigating the past history of individual diatom taxa (e.g Haworth 1979) or successions of diatom communities (e.g. Evans 1970). These interpretations have sometimes thrown light on aspects of the past history of the lake (e.g. Battarbee 1978, Walker 1978). It has been shown that diatom communities are influenced by lake water pH and trophic status (e.g. Cholnoky 1968, Patrick 1977). Such factors are likely to be affected by changes in the catchment (e.g. soil disturbance, reafforestation or use of synthetic fertilizers). A relationship might be expected to exist between major local vegetation / land use changes (reconstructed from pollen diagrams) and major alterations in lake productivity (reflected in diatom and organic chemical accumulation rates).

Detailed discussion of the individual diatom histories of Rostherne Mere and Ellesmere, and interpretation of these, and organic chemical analyses, in terms of lake history have already been given (page 72 , page 102). This general discussion will review this information, in addition considering the timing and sequence of local vegetational changes. This is not intended to be a rigorous test of the hypothesis that catchment vegetation is related to the history of lake productivity. On the other hand the hypothesis is strengthened by the fact that variations in productivity, inferred from diatom and other studies, can be shown, in different lakes, to be related to catchment events such as human settlement, deforestation and agriculture.

The Late - Devensian clays at the base of Ellesmere core 6 contained no recognisable diatom remains, although the presence of sponge spicules suggests an aquatic origin. The absence of diatoms may be due in part to mechanical attrition, and in part to the suspected impoverished nature of the flora. Late - Devensian lake clays are frequently characterised by few diatoms (e.g. Round 1961, Crabtree 1969, Walker 1978). Other Late - Devensian clays have contained assemblages characteristic of alkaline conditions (e.g. Evans 1970, Pennington *et al* 1972, Evans and Walker 1977).

During the first half of the Flandrian, from *ca*. 10,000 - 5,000bp Ellesmere (phases 1 and 2) remained rather alkaline (Figs 73 and 74) and nutrient poor (Figs 72 and 74). The dominant diatom was the planktonic *Melosira italica* subsp. *subarctica*, an alkaliphile found in a wide range of lake types. During the early post - glacial, alkaliphilous diatoms were improtant in many temperate European lakes. *Melosira italica* subsp. *subarctica* was dominant in Lake Trummen, Sweden (Digerfeldt 1972), non - planktonic *Fragilaria* spp. were dominant from lakes from the English Lake District (Round 1957, Evans 1970), North Wales (Crabtree 1969, Evans and Walker 1977, Walker 1978), North Scotland (Pennington *et al* 1972, Haworth 1976) and Bolling So in Denmark (Fjedingstadt 1954), and non - planktonic *Melosira arenaria* was characteristic at Windermere (Pennington 1943) and Esthwaite (Round 1961). At Ellesmere the base - demanding diatoms remained dominant throughout the first half of the Flandrian, but at the other sites mentioned above, the floras of alkaliphilous diatoms were replaced, at varying times, by pH indifferent or acid tolerant floras, the assemblages generally achieving stability by mid - Flandrian times. A similar sequence was found by Andersen (1964) in an interglacial lake at Herning. At Ellesmere the surface inflows are insignificant, and the surrounding topography makes it unlikely that they have achieved importance in the past. It is possible that a groundwater feed, similar to that proposed for Crose Mere (Reynolds 1979) operates at Ellesmere. This groundwater would be in intimate contact with the enormous base reservoir of the 100m deep glacial drift in which Ellesmere lies. The first evidence of disturbance of the alkaline, rather nutrient poor conditions characteristic of Ellesmere during the first part of the Flandrian occurs at ca. 4,500bp (Figs 72 and 74, Phase 3). Between ca. 4,500bp and 3,800bp, at the start of Phase 3, the diatom accumulation rate showed a variable, slight increase suggesting that lake productivity was increasing. The first signs of forest clearance in the pollen diagram for Crose Mere (Beales 1976, 1980) 4km to the south - east of Ellesmere, are found after 5,300bp and increasingly towards 3,700bp. This may be the first evidence of the impact of man in the area.

After 3,800bp at Ellesmere, and until 2,500bp the accumulation rates of Melosira italica subsp. subarctica and Tabellaria spp. are considerably raised, and that for carbon is also slightly increased (Figs 72 and 74, Phase 3). A similar Melosira italica subsp. subarctica and Tabellaria floculosa flora was found during the early stages of the eutrophication of Lough Neagh (Battarbee 1978) preceded, as at Ellesmere, by a slowly accumulating Melosira italica subsp. subarctica flora. A rather similar flora was also found, with the addition of Stephanodiscus astraea, at Loch Leven (Zone 1, Haworth 1972). During almost the same period at Crose Mere (Beales 1980) from ca. 3,700 - 2,300bp, there was very strong evidence of extensive forest clearance and pastoral agriculture. At Whixall Moss, 10km to the east of Ellesmere the clearance does not appear to commence until ca. 3,200bp (Turner 1964, 1965). At Chat, Holcroft and Lindow Mosses, near Rostherne Mere, Birks (1964, 1965) found a similar clearance phase, C2. This was immediately below a major recurrence surface dated ca. 3,100 - 2,650bp (Godwin and Switsur 1966).

This suggests that major forest clearance around Ellesmere and Crose Mere began ca. 3,800bp, perhaps rather earlier than other sites in the region. This bronze age forest clearance (Beales 1980) may have caused the considerable increase in nutrient status of Ellesmere, perhaps due to the release of nutrients from disturbed soils in the catchment.

From ca. 2,500 - 2,000bp at Ellesmere (Figs 72 and 74, Phase 4), ca. 2,700BP (2,500bp) - 2,000BP (2,000bp) at Rostherne Mere (Figs 47 and 74, Phase 1) there were rather low planktonic diatom accumulation rates, non - planktonic diatoms were quite frequent, and, especially at Rostherne Mere, rather low organic chemical accumulation rates. At Ellesmere there is some evidence for a decline in pH, perhaps indicating incipient exhaustion of local base sources, perhaps a drop in water level, partially isolating the lake from its groundwater base supply. At Crose Mere (Beales 1980) there seems to have been a considerable reafforestation at ca. 2,300 - 2,100bp (Zone CMCP 8 - 9), a similar forest regeneration being noted at Whixall Moss at ca. 2,300bp (Zones F and G). These appear to be similar to the regeneration phase R4 at Holcroft, Lindow and Chat Mosses (Birks 1964, 1965) near Rostherne Mere. The iron age was a time of forest clearance in many parts of the country (Turner 1970) and the iron age forest regeneration phase in the Shropshire/Cheshire plain appears rather unusual. It is possible that rather wetter conditions thought to have prevailed in north west Britain after ca. 2,800bp (Pennington 1970) made the heavy soiled lowlands of the plain less suitable for agriculture than the surrounding well drained sandy ridges.

From ca. 2,000 to 1,000bp at Ellesmere (Figs 72 and 74, Phase 5) and ca. 2,000 - 1,400bp at Rostherne Mere (Figs 47 and 74, Phase 2) the organic chemical and diatom accumulation rates were raised. Melosira italica subsp. subarctica and Cyclotella spp. were the dominant planktonic diatoms, and both lakes appear to have been alkaline. A similar Melosira italica subsp. subarctica/ Cyclotella spp. diatom flora was found during the first phase of the cultural eutrophication of Esthwaite by Round (1961), and during colonial deforestation of the area around Granite and Seymour Lakes, New England, USA by Davis and Norton (1978). The pollen diagram from Crose Mere (Zone CMCP 10, Beales 1980) shows increasing evidence of wide scale deforestation and human agricultural activity, with a continuous cereal pollen curve after ca. 2,100bp. At Whixall Moss, Turner (1965) found a similar major clearance phase after 2,000bp (Zones I and J). This seems to be correlated with the major clearance (C5, Birks 1964, 1965) found at Holcroft, Lindow and Chat Mosses, near Rostherne Mere. This phase may also be located in the Chat Moss pollen diagram of Erdtman (1928), by means of the simultaneous Tilia decline. This evidence suggests that there was a well developed Romano - British agricultural society in the Shropshire/Cheshire plain. The forest clearance, soil disturbance and increased population pressure may have released considerable amounts of nutrients into the catchments of Ellesmere and Rostherne Mere, enriching the lake waters. Roman age eutrophication of lakes has been reported for Lago di Monterosi, Italy, by Hutchinson et al (1970) and Llangorse Lake, Wales, by Jones et al (1978). In both cases the building of major roads was implicated and the previous sparse non - planktonic diatom flora was replaced by a planktonic flora dominated by Melosira granulata var. angustissima (Lago di Monterosi) or Melosira granulata (Llangorse

Lake). The A556, an important Roman Road, passes within 500m of the western margin of Rostherne Mere, (Fig 2a). South Shropshire appears to have been more important during Roman times than historical records suggest (Beales 1980).

During the period from *ca.* 1,000 - 600bp in Ellesmere (Figs 72 and 74, *Phase 6*) and *ca.* 1,400 - 600bp in Rostherne Mere (Figs 47 and 74, *Phase 3*) the diatom and organic chemical accumulation rates were generally rather less than during the previous phase. In Ellesmere, *Melosira italica* subsp. *subarctica* was the most abundant planktonic diatom; in Rostherne Mere *Cyclotella comta* was the most frequent. Both lakes remained rather alkaline. *Cyclotella* spp. have been regarded as indicative of oligotrophic conditions (e.g. Digerfeldt 1972), but *Cyclotella comta* is widespread in many lake types including the recent sediments of the eutrophic Lough Neagh (Battarbee 1978) and Loch Leven (Haworth 1972). The ^{14}C dating of Crose Mere pollen diagram above *ca.* 2,000bp appears unreliable (Beales 1980), but it seems possible that the slight forest regeneration seen during Zone CMCP 10a represents this period. The phases R5, C6 and R6 of Birks (1964, 1965) in Holcroft Moss, Lindow Moss and Chat Moss seem to have occurred at about this time, representing a fluctuating reafforestation lasting until after the devastation of the Norman Conquest (Birks 1965). This suggests that the disorder which prevailed through the 'Dark Ages' enabled re-establishment of forests through much of the region, with subsequent stabilization of soils, and nutrient depletion of Ellesmere and Rostherne Mere. It is possible that the irregular diatom accumulation peak rates between 1,200 and 1,000bp may be correlated with the minor clearance phase C6 of Birks (1965) from Holcroft Moss and Lindow Moss.

After *ca.* 600bp, *Phase 7* in Ellesmere (Figs 72 and 74), *Phase 4* in Rostherne Mere (Figs 47 and 74), the organic chemical and diatom accumulation rates were increased. The planktonic diatom floras were dominated by *Stephanodiscus* spp., with *Asterionella formosa*. The lakes were alkaline and eutrophic. In other lake sediments, similar assemblages have been interpreted as indicating severe cultural eutrophication, e.g. at Lough Neagh, Ulster, since *ca.* 1915AD (Battarbee 1978) and at Lake Trummen, Sweden, since *ca.* 1900AD (Digerfeldt 1972). Evidence of cultural eutrophication of lakes in Britain during the last *ca.* 1000 years is, in general, rather poorly dated. There is evidence of oscillating eutrophication at Esthwaite in pollen zone VIIb (Round 1961). Diatom evidence from Blelham Tarn (Evans 1970) suggested recent eutrophication, perhaps preceded by oscillations in trophic status, in pollen zone VIIb. Carbon and Nitrogen accumulation rates in Blelham Tarn (Pennington *et al* 1977) have shown an oscillating increase, with major phases ^{14}C dated to *ca.* 950bp and 500bp (Pennington *et al* 1976). Palaeomagnetic evidence suggests that these ^{14}C dates may be erroneously old (Thompson 1979, Thompson and Wain - Hobson 1979). The man made broads, dating from *ca.* 500bp appear to have been oligotrophic through their early history (Osborne and Moss 1977, Moss 1978). Isolated, upland tarns have generally shown little or no evidence of cultural eutrophication (e.g. Pennington *et al* 1972, Evans and Walker 1977).

The phase of eutrophication starting *ca.* 600BP in Rostherne Mere (Phases 4 and 5) and Ellesmere (Phase 7) may possibly be correlated with Zone CMCP 10b of Beales (1980) at Crose Mere, and may also be represented by Zone C7a of Birks (1964, 1965) for mosses near Rostherne Mere. It appears that further forest clearance and agricultural development around the two lakes after *ca.* 600bp may have led to their eutrophication.

After 280bp at Rostherne Mere (Figs 47 and 74, *Phase 5*), there was a slight decrease in diatom and organic chemical accumulation rates, although the diatom flora remained largely unchanged.

Since 1955AD at both Ellesmere (Figs 72 and 74, *Phase 8*) and Rostherne Mere (Figs 47 and 74, *Phase 6*), organic chemical accumulation rates have dramatically increased, and there has been some replacement of *Stephanodiscus astraea* with *Stephanodiscus hantzschii*. At Ellesmere, the diatom accumulation rate has increased, but at Rostherne Mere it has remained rather variable. A similar change from *Stephanodiscus astraea* to *Stephanodiscus hantzschii* was noted in recent sediments in Loch Leven, Scotland by Haworth (Zone 1 - 2, 1972). The recent sediments of sewage polluted Lake Trummen contained a mixed *Stephanodiscus astraea*/*Stephanodiscus hantzschii* diatom flora (Digerfeldt 1972).

In the sediments of other British lakes similarly timed changes in accumulation rates of organic chemicals and diatoms have been recorded. Battarbee (1973b, 1978) reported a dramatic increase in accumulation rate of diatoms, especially *Stephanodiscus astraea*, just before 1960AD in Lough Neagh. At Blelham Tarn, in the English Lake District, Pennington *et al* (1977) found an abrupt increase in accumulation rate of carbon and nitrogen between 1950 and 1963AD. Osborne and Moss (1977) showed, from diatom and phosphorus accumulation rates, a major increase in nutrient status of Barton Broad between 1950 and 1960AD. Hickling Broad showed a similar increase in diatom accumulation rate (Moss 1978) between 1950 and 1960AD.

This suggests that there may have been a major increase in the trophic status of lakes in several parts of the British Isles since *ca.* 1950 - 1960AD. This may be due to the increasing use of synthetic fertilizers since

1950 - 1955AD (Lund 1971). Brinkhurst and Walsh (1967) have proposed that the extreme eutrophication of Rostherne Mere is partly caused by the large overwintering gull roost and wildfowl population. They suggested that direct contribution of faeces has caused 'guanotrophy'. The calculations of Livingstone (1979) show that bird faeces contribute about 10% of the total phosphorus to the lake, and that direct input of human sewage appears to be of the same order. Much of the catchment is grazing land, on which the current nitrogen loading as inorganic fertiliser is ca. 300kg $Ha^{-1}a^{-1}$(T. Wall pers. comm.).

This study has produced evidence of similar oscillating increases in trophic status of Rostherne Mere and Ellesmere, which may be correlated with local vegetation history (Birks 1964,1965, Turner 1964,1965, Beales 1980). It provides confirmation of the suggestions of Goulden (1964) and Evans (1970), and the evidence of Pennington et al. (1977) that the eutrophication of lakes may proceed in a series of oscillations. This research lends support to the idea that reconstructions of past lake productivity from chemical analyses and from diatom analyses yield largely consistent results (Digerfeldt 1972,1975). Cultural eutrophication of these once alkaline, but rather nutrient poor meres has lead to development into their current alkaline, very eutrophic condition.

TABLES.

TABLE 1 - Rostherne Mere Core 5 and Extension Core deposition rates used to calculate accumulation rates.

Rostherne Core 5.

Depth m	Rate of deposition $m\ a^{-1}$
0.1	0.0043
0.2	0.0043
0.3	0.0043
0.4	0.0043
0.5	0.0043
0.6	0.0043
0.7	0.0035
0.8	0.0035
0.9	0.0035
1.0	0.0035
1.1	0.0054
1.2	0.0054
1.3	0.0054
1.4	0.0054
1.5	0.0054
1.6	0.0054
1.7	0.0054
1.8	0.0054
1.9	0.0054
2.0	0.0054
2.1	0.0054
2.2	0.0054
2.3	0.0054
2.4	0.0054
2.5	0.0054
2.6	0.0054
2.7	0.0054
2.8	0.0054
2.9	0.0035
3.0	0.0025
3.1	0.0017
3.2	0.0017
3.3	0.0017
3.4	0.0017
3.5	0.0017
3.6	0.0017
3.7	0.0017
3.8	0.0017
3.9	0.0017
4.0	0.0017
4.1	0.0017
4.2	0.0017
4.3	0.0017
4.4	0.0017
4.5	0.0023
4.6	0.0023
4.7	0.0023

Rostherne Extension Core.

Depth m	Rate of deposition $m\ a^{-1}$
4.0	0.0017
4.2	0.0017
4.3	0.0017
4.4	0.0017
4.5	0.0023
4.6	0.0023
4.7	0.0023
4.8	0.0023
4.9	0.0023
5.0	0.0023
5.1	0.0023
5.2	0.0023
5.3	0.0023
5.4	0.0023
5.5	0.0023
5.6	0.0015
5.7	0.0015
5.8	0.0015
5.9	0.0015
6.0	0.0015
6.1	0.0015
6.2	0.0015
6.3	0.0015
6.4	0.0015
6.5	0.0015
6.6	0.0015
6.7	0.0015
6.8	0.0015
6.9	0.0015

TABLE 1 continued.

Rostherne Core 5.

Depth m	Rate of deposition m a^{-1}
4.8	0.0023
4.9	0.0023
5.0	0.0023
5.1	0.0023
5.2	0.0023
5.3	0.0023
5.4	0.0023
5.5	0.0023

TABLE 2 - Rostherne Mere 'Mini'core ^{210}Pb and ^{226}Ra results and calculated chronologies.

Depth cm	^{226}Ra pCi g^{-1}	Total ^{210}Pb pCi g^{-1}	Unsupported ^{210}Pb pCi g^{-1}
0-3	1.71±0.17	3.58±0.25	1.87
4-7		3.04±0.23	1.36
8-10		2.95±0.24	1.31
13-15		3.18±0.19	1.59
18-20		2.86±0.22	1.30
23-25		2.76±0.23	1.23
28-30	1.52±0.15	2.80±0.18	1.28
38-40		2.40±0.13	0.83
48-50		2.18±0.12	0.45
63-65	2.21±0.22	2.20±0.15	0.00

Depth cm	Accumulated dry mass gcm^{-1}	CIC date years AD	CRS date years AD
0-3	0.10	1984	1978
4-7	0.34	1974	1976
8-10	0.69	1972	1973
13-15	1.16	1979	1968
18-20	1.66	1972	1963
23-25	2.17	1970	1957
28-30	2.81	1972	1949

TABLE 2 continued.

Depth cm	Accumulated dry mass gcm^{-1}	CIC date years AD	CRS date years AD
38-40	4.33	1958	1926
48-50	5.76	1938	1902
63-65	8.23	-	-

TABLE 3 - Comparison of ^{137}Cs related factors in Rostherne Mere 'Mini'core and Core B, Livingstone and Cambray (1978).

	Rostherne 'Mini'core	Core B Livingstone and Cambray 1978
Total ^{137}Cs since peak, pCi cm^{-2}	3.1	8.2
Total ^{137}Cs since 1963, pCi cm^{-2}(^{210}Pb dated)	7.7	8.2

TABLE 4 - Ecological preferences of diatoms.

Abbreviations:-
Akp - Alkaliphilous or Alkalibiont.
Acp - Acidophilous or Acidobiont.
I - Circum neutral or indifferent.
? - Unknown.
P - Planktonic.
S - Sometimes or occasionally Planktonic.
- Non Planktonic

Diatom Taxon.	pH Preference	Habitat
Melosira distans	Acp	
Melosira granulata	Akp	P
Melosira granulata var. angustissima	Akp	P
Melosira italica subsp. subarctica	Akp	P
Melosira varians	Akp	
Cyclotella comensis	I	P
Cyclotella comta	I	P
Cyclotella kutzingiana	I	
Cyclotella meneghiniana	Akp	
Cyclotella ocellata	I	S
Cyclotella stelligera	I	S
Stephanodiscus astraea	Akp	P
Stephanodiscus astraea var. minutula	Akp	P
Stephanodiscus dubius	Akp	P
Stephanodiscus hantzschii	Akp	P
Stephanodiscus tenuis	Akp	P

TABLE 4 continued.

Diatom taxon	pH preference	Habitat
Tabellaria spp	?	S
Meridion circulare	Akp	
Fragilaria brevistriata	Akp	
Fragilaria capucina	?	S
Fragilaria capucina var. mesolepta	?	
Fragilaria constricta	Acp	
Fragilaria construens	Akp	
Fragilaria construens var. binodis	Akp	
Fragilaria construens var. pumila	?	
Fragilaria construens var. venter	Akp	
Fragilaria crotonensis	Akp	P
Fragilaria elliptica	Akp	
Fragilaria lapponica	?	
Fragilaria pinnata	Akp	
Fragilaria pinnata var. intercedens	Akp	
Fragilaria undata	?	
Fragilaria undata var. quadrata	?	
Fragilaria vaucheriae	Akp	
Fragilaria virescens	I	
Asterionella formosa	Akp	P
Synedra acus	Akp	
Synedra minuscula	I	
Synedra parasitica var. constricta	Akp	
Synedra rumpens	I	
Synedra tenera	I	
Synedra ulna	Akp	
Synedra ulna var. danica	Akp	
Eunotia alpina	Acp	
Eunotia flexuosa	Acp	
Eunotia formica	I	
Eunotia microcephala		
Eunotia monodon	Acp	
Eunotia monodon var. bidens	Acp	
Eunotia naegli	P	
Eunotia pectinalis	Acp	
Eunotia pectinalis var. minor	Acp	
Eunotia pectinalis var. undulata	Acp	
Eunotia serra	Acp	
Eunotia serra var. diadema	Acp	
Eunotia valida	Acp	
Eunotia veneris	Acp	
Peronia fibula	Acp	
Cocconeis pediculus	I	
Cocconeis placentula	Akp	
Cocconeis placentula vars.	Akp	
Cocconeis thumensis	Akp	
Achnanthes clevei	Akp	
Achnanthes exigua	Akp	
Achnanthes hauckiana	?	
Achnanthes lanceolata	Akp	
Achnanthes lanceolata var apiculata	Akp	
Achnanthes lanceolata var elliptica	Akp	

TABLE 4 continued.

Diatom taxon	pH preference	Habitat
Achnanthes lanceolata var. rostrata	Akp	
Achnanthes linearis	I	
Achnanthes linearis var. pusilla	?	
Achnanthes microcephala	I	
Achnanthes minutissima	I	
Achnanthes oestrupii	?	
Achnanthes pinnata	?	
Rhoicosphaenia curvata	Akp	
Frustulia rhomboides	Acp	
Frustulia rhomboides var. saxonica	Acp	
Gyrosigma attenuatum	Akp	
Gyrosigma obtusatum	?	
Gyrosigma sp.	?	
Caloneis bacillum	Akp	
Caloneis limosa	?	
Caloneis ventricosa	Akp	
Neidium dubium	?	
Neidium iridis	I	
Diploneis elliptica	Akp	
Diploneis oculata	?	
Diploneis puella	?	
Stauroneis anceps	I	
Stauroneis kriegeri	?	
Stauroneis phoenicenteron	I	
Stauroneis smithii	I	
Anomoeneis serians var. brachysira	Acp	
Anomoeneis sphaerophorum	Akp	
Anomoeneis vitraea	?	
Navicula acceptata	?	
Navicula arvensis	?	
Navicula atomus	?	
Navicula capitata	Akp	
Navicula cari	I	
Navicula cincta	?	
Navicula cryptocephala	Akp	
Navicula cuspidata	Akp	
Navicula dicephala	Akp	
Navicula disjuncta	?	
Navicula fossalis	?	
Navicula gastrum	I	
Navicula gottlandia	?	
Navicula gracilis	?	
Navicula graciloides	Akp	
Navicula jentzschii	?	
Navicula lanceolata	Akp	
Navicula minima	Akp	
Navicula muralis	?	
Navicula oblonga	?	
Navicula pelliculosa	?	
Navicula pseudoventralis	?	
Navicula pseudoscutiformis	I	
Navicula pupula	I	

TABLE 4 continued.

Diatom taxon	pH preference	Habitat
Navicula pupula var. mutata	?	
Navicula radiosa	I	
Navicula rotunda	Akp	
Navicula rhynchocephala	Akp	
Navicula scutelloides	Akp	
Navicula schonfeldii	Akp	
Navicula seminulum	I	
Navicula cf. sohrensis	?	
Navicula suchlandtii	I	
Navicula utermohlii	?	
Navicula viridula	I	
Navicula vitabunda	?	
Pinnularia appendiculata	I	
Pinnularia biceps	I	
Pinnularia borealis	I	
Pinnularia dactylis	I	
Pinnularia divergens	I	
Pinnularia gibba	I	
Pinnularia hilseana	?	
Pinnularia interrupta	Acp	
Pinnularia maior	I	
Pinnularia mesolepta	I	
Pinnularia microstauron	I	
Pinnularia rupestris	?	
Pinnularia cf. socialis	?	
Pinnularia stomatophora	?	
Pinnularia subcapita	Acp	
Pinnularia subsolaris	?	
Pinnularia viridis	I	
Pinnularia undulata	Acp	
Amphora ovalis var. pediculus	Akp	
Amphora perpusilla	I	
Cymbella cistula	Akp	
Cymbella ehrenbergii	Akp	
Cymbella lunata	I	
Cymbella microcephala	Akp	
Cymbella minuta	I	
Cymbella muelleri	?	
Cymbella prostrata var. auerswaldii	Akp	
Cymbella proxima	?	
Cymbella sinuata	I	
Cymbella turgida	Akp	
Gomphonema acuminatum	Akp	
Gomphonema acuminatum var. brebissonii	Akp	
Gomphonema angustatum	Akp	
Gomphonema constrictum	Akp	
Gomphonema dichotomum	?	
Gomphonema gracile	I	
Gomphonema intricatum	Akp	
Gomphonema longiceps	I	
Gomphonema olivaceum	Akp	
Epithemia sorex	Akp	
Epithemia turgida	Akp	

TABLE 4 continued.

Diatom taxon	pH preference	Habitat
Epithemia zebra	Akp	
Rhopalopodia gibba	Akp	
Hantzschia amphyoxis	I	
Nitzschia acuta	Akp	
Nitzschia dissipata	Akp	
Nitzschia fonticola	Akp	
Nitzschia frustulum	Akp	
Nitzschia kutzingiana	Akp	
Nitzschia palea	I	
Nitzschia paleacea	?	
Nitzschia recta	Akp	
Nitzschia sigmoidea	?	
Nitzschia tryblionella	I	
Cymatopleura elliptica	Akp	
Cymatopleura solea	?	
Surirella linearis	I	
Surirella robusta	I	

TABLE 5 - Rostherne Mere, Extension Core, list of diatoms found at a maximum frequency of less than 2%.

Melosira arenaria, M. distans, Stephanodiscus dubius, S. hantzschii, Tabellaria spp., Fragilaria capucina var. lanceolata, F. capucina var. mesolepta, F. crotonensis, F. inflata, F. leptostauron, F. pinnata var. intercedens, Asterionella formosa, Synedra acus, S. capitata, S. minuscula, S. parasitica, S. radians, S. tenera, S. ulna, S. ulna var. danica, Eunotia flexuosa, E. formica, E. monodon, E. pectinalis var. minor, E. veneris, Cocconeis pediculus, C. thumensis, Achnanthes clevei, A. clevei var. rostrata, A. exigua, A. hauckiana, A. lanceolata, Mastogloia smithii var. lacustris, Frustulia rhomboides, Gyrosigma attenuatum, G. obtusatum, Caloneis bacillum, C. limosa, Neidium dubium, N. iridis, Diploneis elliptica, D. oculata, D. puella, Navicula atomus, N. cicta, N. cryptocephala, N. cryptocephala var. veneta, N. gastrum, N. gottlandica, N. graciloides, N. capitata, N. capitata var. hungarica, N. capitata var. lunebergensis, N. jentzschii, N. menisculus, N. oblonga, N. pseudoventralis, N. pupula, N. radiosa, N. reinhardtii, N.rhynchocephala, N. tuscula, N. viridula, N. vulpina, Pinnularia borealis, P. hemiptera, P. maior, P. mesolepta, P. microstauron, Amphora ovalis var. pediculus, Cymbella aspera, C. cistula, C. helvetica, C. lata, C. lunata, C. microcephala, C. minuta, C. muelleri, C. proxima, Gomphonema abbreviatum, G. acuminatum G. angustatum var. obtusatum, G. gracile, G. olivaceum, Epithemia sorex, E. zebra, Denticula elegans, D. tenuis, Rhopalopodia gibba, Hantzschii amphyoxis, Nitzschia

TABLE 5 continued.

amphibia, N. fonticola, N. recta, N. sinuata var. tabellaria, N. tryblionella, Surirella robusta, Campylodiscus noricus.

TABLE 6 - Rostherne Mere, Core 5, list of diatoms found at a maximum frequency of less than 2%.

Melosira distans, Cyclotella pseudostelligera, C. stelligera, Stephanodiscus dubius, Diatoma elongatum, D. hiemale, D. tenue, D. vulgare, Fragilaria brevistriata var. inflata, F. capucina var. lanceolata, F. capucina var. mesolepta, F. construens var. pumila, F. lapponica, F. leptostauron, Synedra acus, S. affinis, S. amphicephala, S. capitata, S. delicatissima, S. minuscula, S. nana, S. parasitica, S. parasitica var. constricta, S. pulchella, S. rumpens, S. tenera, S. ulna, S. ulna var. danica, Eunotia flexuosa, E. formica, E. maior, E. monodon, E. parallela, E. pectinalis var. minor, E. veneris, Cocconeis disculus, C. pediculus, C. thumensis, Achnanthes affinis, A. clevei, A. clevei var. rostrata, A. exigua, A. hauckiana, A. lanceolata, A. oestrupii, A. pinnata, Rhoicosphaenia curvata, Meridion circulare, M. circulare var. constricta, Mastogloia smithii, M. smithii var. lacustris, Amphipleura pellucida, Frustulia vulgaris, Gyrosigma attenuatum, G. obtusatum, G. spencerii, Caloneis alpestris, C. bacillum, C. limosa, C. pediculus, Neidium iridis, N. productum, Diploneis marginestriata, D. oculata, D. puella, Stauroneis acuta, S. anceps, S. phoenicenteron, Anomoeneis serians var. brachysira, A. vitrea, Navicula arvensis, N. bacillum, N. cincta, N. cryptocephala var. veneta, N. dicephala var. neglecta, N. elginensis, N. exigua, N. gastrum, N. gottlandica, N. gracilis, N. cf. halophila, N. heufleri, N. capitata , N. capitata var. hungarica N. capitata var. lunebergensis, N. menisculus, N. oblonga, N. pelliculosa, N. protracta, N. pupula, N. pupula var. elliptica, N. pupula var. rectangularis, N. radiosa, N. radiosa var. parva, N. radiosa var. tenella, N. reinhardtii, N. rhynchocephala, N. seminulum, N. tuscula N. verecunda, N. viridula, N. vulpina, Pinnularia leptosoma, P. microstauron, P. subcapitata, P. subcapitata var. paucistriata, P. subsolaris, Amphora ovalis, A. ovalis var. pediculus, Cymbella aspera, C. cistula, C. cuspidata, C. ehrenbergii, C. helvetica, C. lata, C. muelleri, C. muelleri var. ventricosa, C. naviculiformis, C. prostrata, C. prostrata var. auerswaldii, C. proxima, C. sinuata, Gomphonema abbreviatum, G. acuminatum , G. angustatum, G. apiculatum, G. constrictum, G. intricatum, G. obtusatum, G. olivaceum, G. parvulum, Epithemia sorex, E. sorex var. gracilis, E. turgida, E. zebra, Denticula elegans, D. tenuis, Rhopalopodia gibba, R. parallela, Hantzschia amphioxys, Nitzschia amphibia, N. angustata var. acuta, N. dissipata, N. fonticola, N. palea, N. recta, N. romana, N. sigmoidea, N. sinuata var tabellaria, N. tryblionella,

TABLE 6 continued.

Cymatopleura solea, Surirella birostrata, S. ovalis, S. ovata, S. robusta.

TABLE 7 - Rostherne Mere, 'Mini'core, list of diatoms found at a maximum frequency of less than 2%.

Melosira cf. binderana, M. italica subsp. subarctica, M. varians, Cyclotella comta, C. meneghiniana, C. ocellata, C. pseudostelligera, Stephanodiscus astraea var. minutula, S. tenuis, Diatoma vulgare, Fragilaria brevistriata, F. capucina var. mesolepta, F. construens, F. construens var. binodis, F. construens var. pumila, F. elliptica, F. pinnata var. intercedens, Synedra affinis, S. radians, S. rumpens, S. parasitica, S. tenera, S. ulna, S. ulna var, danica, Eunotia maior, Cocconeis pediculus, C. placentula var. euglypta, C. thumensis, Achnanthes clevei, A. exigua, A. hauckiana, A. lanceolata, A. minutissima, A. oestrupii, Rhoicosphaenia curvata, Frustulia vulgaris, Gyrosigma attenuatum, Diploneis elliptica, D. oculata, Stauroneis phoenicenteron, Navicula cryptocephala, N. cryptocephala var. veneta, N. gottlandica, N. gracilis, N. graciloides, N. capitata var. hungarica, N. capitata var. lunebergensis, N. menisculus, N. pupula, N. radiosa, N. reinhardtii, N. rhynchocephala, N. scutelloides, N. tuscula, N. viridula, Pinnularia microstauron, P. subcapitata, Amphora ovalis var. pediculus, A. perpusilla, Cymbella cymbiformis var. non-punctata, C. microcephala, C. minuta, C. muelleri, Gomphonema abbreviatum, G. acuminatum, G. angustatum, G. dichotomum, G. gracile, G. olivaceum, Epithemia zebra, Denticula tenuis, Hantzschii amphioxys, Nitzschia acuta, N. dissipata, N. fonticola, N. gracilis, N. hungarica, N. recta, N. sigmoidea, N. tryblionella, Cymatopleura elliptica, C. solea, Surirella birostrata, S. ovata, S. robusta.

TABLE 8 - Rostherne Mere, Core 3, list of diatoms found at a maximum frequency of less than 2%.

Melosira arenaria, Cyclotella kutzingiana, C. meneghiniana, C. operculata, C. stelligera, Stephanodiscus dubius, S. tenuis, Diatoma anceps, D. tenue, D. vulgare, Fragilaria capucina var. lanceolata, F. capucina var mesolepta, F. construens var. pumila, F. construens var. venter, F. leptostauron, F. pinnata, F. virescens, Synedra acus, S, affinis, S. capitata, S. parasitica, S. parasitica var. subconstricta, S. tenera, S. ulna, S. ulna var. danica, Eunotia exigua, E. flexuosa, E. pectinalis var. minor, E. veneris, Cocconeis diminuta, C. pediculus, C. placentula, C. placentula var. euglypta,

TABLE 8 continued.

C. thumensis, Achnanthes clevei, A. exigua, A. hauckiana, A. lanceolata, A. lanceolata var. elliptica, A. oestrupii, Mastogloia smithii var. lacustris, Amphipleura pellucida, Gyrosigma attenuatum, G. kutzingii, Caloneis alpestris, C. bacillum, C. limosa, Neidium affine, N. binode, N. productum, Diploneis elliptica, D. domblittensis, D. oculata, D. ovalis var. oblongella, D. pseudovalis, D. puella, Stauroneis smithii, Navicula bacillum, N. capitata, N. capitata var. hungarica, N. cincta, N. cryptocephala, N. dicephala, N. gastrum, N. gracilis, N. graciloides, N. menisculus, N. protracta, N. pupula, N. radiosa, N. reinhardtii, N. sublitissima, N. tuscula, N. verecunda, N. viridula, Pinnularia divergens, P. interrupta, P. legumen, P. maior, P. microstauron, P. molaris, P. stomatophora, Amphora ovalis, Amphora ovalis var. pediculus, Cymbella amphicephala, C. aspera, C. cistula, C. ehrenbergii, C. helvetica, C. naviculiformis, C. prostrata, C. sinuata, Gomphonema abbreviatum, G. acuminatum, G. acuminatum var. brebissonii, G. constrictum, G. intricatum, G. olivaceum, Denticula elegans, D. tenuis var. crassula, Epithemia sorex, Epithemia turgida, Epithemia zebra, Rhopalopodia gibba, Hantzschia amphyoxis, Nitzschia amphibia, N. hantzschiana, N. recta, N. romana, N. sigmoidea, N. sinuata var. tabellaria, N. tryblionella, Cymatopleura elliptica, C. solea, Surirella ovata, S. ovata var. elliptica, S. robusta, Campylodisans noricus, C. noricus var. hibernica.

TABLE 9 - Rostherne Mere, Core 10.5, list of diatoms found at a maximum frequency of less than 2%.

Melosira arenaria, M. distans, Stephanodiscus hantzschii, Fragilaria capucina var. mesolepta, F. crotonensis, F. lapponica, F. virescens, Asterionella formosa, Synedra affinis, S. parasitica, S. rumpens, S. tenera, S. ulna var. danica, Eunotia flexuosa, E. maior, E. monodon, E. veneris, Cocconeis pediculus, C. thumensis, Achnanthes clevei, A. hauckiana, A. lanceolata, A. oestrupii, Rhoicosphaenia curvata, Frustulia vulgaris, Gyrosigma attenuatum, G. obtusatum, Caloneis bacillum, Diploneis elliptica, D. oculata, Stauroneis acuta, S. phoenicenteron, Navicula cincta, N. contenta, N. cryptocephala, N. gastrum, N. menisculus, N. pupula, N. reinhardtii, N. vulpina, Amphora ovalis var. pediculus, Cymbella aspera, C. ehrenbergii, C. microcephala, C. naviculiformis, Gomphonema acuminatum, G. angustatum, G. gracile, Epithemia turgida, Denticula tenue, Rhopalopodia gibba, Hantzschia amphyoxis, Nitzschia amphibia, N. angustatum, N. angustatum var. acuta, N. fonticola, N. tryblionella, Cymatopleura elliptica, C. solea, Campylodiscus noricus.

TABLE 10 - Rostherne Mere, Russian Core G, list of diatoms found at a maximum frequency of less than 2%.

Melosira arenaria, Cyclotella kutzingiana, Diatoma anceps, D. elongatum, Fragilaria capucina var. mesolepta, F. leptostauron, F. vaucheriae, Asterionella formosa, Synedra acus, S. capitata, S. nana, S. parasitica, S. parasitica var. subconstricta, S. rumpens, Eunotia flexuosa, E. formica, E. pectinalis var. minor, E. valida, E. veneris, Achnanthes lapponica, Rhoicosphaenia curvata, Mastogloia smithii, Amphipleura pellucida, Frustulia vulgaris, Gyrosigma attenuatum, G. kutzingii, Caloneis bacillum, C. limosa, Neidium iridis, N. productum, Diploneis elliptica, D. oculata, D. puella, Stauroneis acuta, S. phoenicenteron, S. smithii, Anomoeneis vitrae, Navicula americana, N. angelica, N. bacilliformis, N. bacillum, N. cf. bicapitella, N. capitata, N. capitata var. hungarica, N. cari, N. cryptocephala var. veneta, N. cuspidata, N. dicephala, N. exlissima, N. falaisensis, N. gastrum, N. gottlandica, N. menisculus, N. minima, N. oblonga, N. protracta, N. pupula, N. pupula var. rectangularis, N. radiosa, N. radiosa var. tenella, N. reinhardtii, N. cf. schonfeldii N. seminulum, N. similis, N. tuscula, N. viridula, N. cf. verecunda, Pinnularia cardinalis, P. dactylus, P. gibba, P. maior, P. mesolepta, P. microstauron, P. molaris, P. viridis, Amphora ovalis, Cymbella affinis, C. amphicephala, C. aspera, C. ehrenbergii, C. helvetica, C. laevis, C. minuta var. silesiaca, C. muelleri, C. naviculiformis, Gomphonema acuminatum, G. acuminatum var. coronata, G. angustatum, G. augur, G. intricatum, Epithemia sorex, E. turgida, Rhopalopochia gibba, R. parallela, Hantzschia amphyoxis, Nitzschia acuta, N. amphibia, N. angustatum, N. denticula, N. frustulum, N. hantzschiana, N. linearis, N. recta, N. sigmoidea, N. sinuata var. tabellaria, N. stagnorum, Cymatopleura elliptica, c solea, Surirella biseriata, S. robusta.

TABLE 11 - Volumes of planktonic and occasionally planktonic diatoms from Rostherne Mere and Ellesmere, mean of 100 individuals.

Taxon	Rostherne Mere μm^3	Ellesmere μm^3
Melosira italica subsp. subarctica	520	305
Melosira granulata	1262 (1.5-2.5m)	-
	650 (0-1m)	-
Melosira granulata var. angustissima	597 (1.5-2.5m)	216
	351 (0-1m)	
Cyclotella comta	1854	917

TABLE 11 continued.

Taxon	Rostherne Mere μm^3	Ellesmere μm^3
Cyclotella comensis	93	-
Cyclotella ocellata	353	-
Cyclotella stelligera	-	346
Stephanodiscus astraea	9543	5630
Stephanodiscus astraea var. minutula	1445	1085
Stephanodiscus hantzschii	108	95
Stephanodiscus dubius	-	798
Tabellaria spp.	682	580
Fragilaria crotonensis	469	523
Fragilaria capucina	285	300
Asterionella formosa	304	449
Nitzschia palea	90	-

TABLE 12 - Magnetic measurements on empty core tube used for Rostherne Core 6.

Distance from top of tube in m	NRM intensity in mA m^{-1}	Susceptibility in μSI units
2.250	0.1	1
2.275	-	2
2.300	0.1	2
2.325	-	2
2.350	0.6	17
2.375	-	71
2.400	15.8	126
2.425	-	111
2.450	88.2	129
2.475	-	134
2.500	14.6	62
2.525	-	14
2.550	0.2	0
2.575	-	2
2.600	0.1	2

TABLE 13 - Rostherne Mere, Core 10.5, Susceptibility.

Depth m	Susceptibility μSI units
20	168
60	140
90	172
120	100
150	172
180	140
210	190

TABLE 13 continued.

Depth m	Susceptibility /µSI units
240	174
270	158
300	158
330	190
360	164
390	148
420	148
450	104
480	108
510	156
540	184
570	184
600	184
630	184
660	176
690	192
720	196
750	196
780	176
810	176
840	152
870	132
900	132
930	152
960	132
990	200
1020	224

TABLE 14 - Rostherne Mere 'Mini'core and Core 5 susceptibility and SIRM.

Depth in 'Mini'core m	Suscept. (µSI units)	SIRM (mAm^{-1})	Depth in Core 5 m	Suscept. (µSI units)	SIRM (mAm^{-1})
0.40	97	2000	0.01	66	2800
0.41	91	2150			
0.42	72	1800			
0.43	73	1750			
0.44	42	900	0.04	57	2500
0.45	50	800			
0.46	40	850			
0.47	42	950	0.07	51	2300
0.48	50	1050			
0.49	63	1300			
0.50	65	1450	0.10	46	1950
0.51	72	1800			
0.52	75	1750	0.12	48	2050
0.53	80	1850			
0.54	85	1900			
0.55	88	2100	0.15	47	2000

TABLE 14 continued.

Depth in 'Mini'core m	Suscept. (µSI units)	SIRM (mAm^{-1})	Depth in Core 5 m	Suscept. (µSI units)	SIRM (mAm^{-1})
0.56	93	1950			
0.57	98	2200	0.17	43	1900
0.58	83	1950			
0.59	87	1950			
0.60	91	2100	0.20	44	2000
0.61	82	2050			
0.62	80	2050			
0.63	78	2100	0.23	39	1800
0.64	77	2050			
0.65	78	2050			
0.66	73	1950	0.26	33	1800
0.67	80	2050			
0.68	83	2050	0.28	35	1700
0.69	87	2000			
0.70	92	2050			
0.71	83	1800	0.31	40	1750
0.72	87	2000			

TABLE 15 - Rostherne Mere correlations between 'Mini'core and Core 5.

Depth in 'Mini'core m	Depth in Core 5 m	Feature
0.70	0.30	Decline in frequency of Stephanodiscus hantzschii.
0.35 - 0.45	0.02 - 0.10	Correspondence analysis of diatom percentages.
0.72 - 0.50	0.30 - 0.10	Susceptibility and SIRM.

TABLE 16 - Rostherne Mere correlations between Core 5 and Russian Core G.

Depth in Russian Core G m	Depth in Core 5 m	Feature
0.10	1.5	Occurrence of Stephanodiscus hantzschii and Fragilaria crotonensis.
0.25	2.0 - 3.0	Occurrence of Stephanodiscus astraea and Asterionella formosa.

TABLE 16 continued.

Depth in Russian Core G m	Depth in Core 5 m	Feature
0.37	1.9	Occurrence of the non-planktonic diatom Navicula scutelloides.

TABLE 17 - Rostherne Mere, Russian Core G, Susceptibility.

Depth m	Susceptibility μSI units
0.16	-3.5
0.25	-3.1
0.31	10.6
0.40	-3.0
0.51	-0.1
0.60	-0.4
0.69	-2.8
0.81	-1.3
0.90	-1.0
0.99	-1.3
1.10	-4.8
1.19	-1.6
1.31	-3.7
1.40	-2.0
1.51	-5.6
1.60	-4.9
1.69	-4.4
1.81	-3.2
1.90	-5.2
2.01	-1.6
2.10	-4.0
2.19	-4.5
2.31	-4.1
2.40	-3.2
2.51	-2.4
2.60	-1.4
2.69	-0.6
2.81	5.1
2.90	5.5
2.99	0.0
3.10	-4.5
3.19	-0.4
3.31	10.5
3.40	11.3
3.49	21.9

Zero test for susceptibility bridge in μSI units
0.10
-0.02
0.29
-0.16
-0.43
-0.70
0.43
0.40
0.19
0.22

Susceptibility of a random sample of 10 empty plastic cuboids. μSI units
-3.7
-4.5
-3.9
-3.3
-5.9
-4.8
-4.7
-2.9
-3.2
-3.8

TABLE 18 - Rostherne Mere, Core 5 and Extension Core, $\delta^{13}C$ data.

Core	Depth m	NERC code	Date yrs bp	$\delta^{13}C$ (‰)
5	2.075-2.125	SRR 1886	1030±70	-28.6
5	2.80 -2.85	SRR 1887	480±80	-26.7
5	3.525-3.575	SRR 1888	580±100	-28.0
Ext	3.575-3.625	SRR 1889	1120±70	-28.5
Ext	4.275-4.325	SRR 1890	2620±70	-31.7
Ext	4.975-5.025	SRR 1891	2090±70	-28.6
Ext	5.575-5.625	SRR 1892	1070±140	-26.4
Ext	6.075-6.125	SRR 1893	2250±70	-28.8
Ext	6.575-6.625	SRR 1894	2190±80	-27.8

TABLE 19 - Ellesmere, Long Cores, Stratigraphy.

	Depth in CORE (m) 1	2	3
Dark brown lake mud	0.0 -1.0	0.0 -1.3	0.0 -0.95
Transition	1.0 -2.0	1.3 -2.0	0.95-1.5
Pale brown clayey mud	2.0 -3.9	2.0 -4.0	1.5 -3.3
Transition	-	-	3.3 -3.4
Dark brown lake mud	3.9 -4.12	4.0 -4.26	3.4 -3.61
Fine textured dark brown lake mud	-	-	-
Pink clay	-	-	3.61-3.76

	Depth in CORE (m) 6	4	5
Dark brown lake mud	0.0 -0.5	0.0 -0.4	0.0 -0.5
Transition	0.5 -0.7	0.4 -0.5	0.5 -0.8
Pale brown clayey mud	0.7 -2.05	0.5 -1.7	0.8 -2.2
Transition	2.05-2.15	1.7 -1.9	2.2 -2.3
Dark brown lake mud	2.15-3.1	1.9 -3.4	2.3 -3.7
Fine textured dark brown lake mud	3.1 -3.315	3.4 -3.72	-
Pink clay	3.315-4.1	3.72-4.2	-

TABLE 20 - Ellesmere, correlations between Core 6 and 'Mini'core.

Depth in Core 6(m)	Depth in 'Mini'core(m)	Feature
0.08-0.01	0.90-0.95	Decline in percentage of Stephanodiscus dubius.

TABLE 20 continued.

Depth in Core 6(m)	Depth in 'Mini'core(m)	Feature
0.08-0.01	0.90-0.95	Decline in percentage of Cyclotella comta.
0.225	1.10	Susceptibility feature 1.

TABLE 21 - Ellesmere, Core 6, rate of deposition, used to calculate accumulation rates.

Depth m	Deposition rate m a^{-1}
0.10	0.0016
0.20	0.0016
0.30	0.0016
0.40	0.0016
0.50	0.0016
0.60	0.0016
0.70	0.0016
0.80	0.0016
0.90	0.0016
1.00	0.00125
1.10	0.00125
1.20	0.00125
1.30	0.00125
1.40	0.00125
1.50	0.00075
1.60	0.00075
1.70	0.00075
1.80	0.00075
1.90	0.00075
2.00	0.00075
2.10	0.00075
2.20	0.00075
2.30	0.00075
2.40	0.00025
2.50	0.00025
2.60	0.00025
2.70	0.00025
2.80	0.0001
2.90	0.0001
3.00	0.0001
3.10	0.0001
3.20	0.00004
3.30	0.00004

TABLE 22 - Ellesmere, 'Mini'core, ^{210}Pb, CIC and CRS Chronologies.

Depth cm	^{226}Ra pCi g^{-1}	Total ^{210}Pb pCi g^{-1}	Unsupported ^{210}Pb pCi g^{-1}
0 -3	0.82±0.08	5.52±0.42	4.70
7 -9		5.38±0.35	4.53
15-17		3.91±0.28	3.03
23-25		3.27±0.23	2.35
31-33	0.96±0.10	2.73±0.20	1.77
38-40		2.63±0.21	1.64
45-47		2.14±0.17	1.12
52-54		1.78±0.14	0.73
59-61		1.27±0.21	0.20
66-68	1.10±0.10	1.27±0.16	0.17

Depth cm	Accumulated dry mass g cm^{-2}	CIC date years AD	CRS date years AD
0 -3	0.05	1978	1979
7 -9	0.55	1977	1973
15-17	1.26	1964	1964
23-25	2.10	1955	1954
31-33	3.00	1946	1942
38-40	3.82	1944	1928
45-47	4.59	1932	1912
52-54	5.49	1918	1889
59-61	6.36	1876	1866
66-68	7.27	1871	1848

TABLE 23 - Ellesmere 'Mini'core preferred ^{210}Pb Chronology.

CIC date Years AD	CRS date years AD	Difference between CIC & CRS dates %	CRS dates used years AD	Interpolated dates used * years AD	Preferred ^{210}Pb chronol.
1978	1979	50		1979	1979
1977	1973	57		1973	1973
1964	1964	0	1964		1964
1955	1954	4	1954		1954
1946	1942	10	1942		1942
1944	1928	31		1926	1926

TABLE 23 continued.

CIC date years AD	CRS date years AD	Difference between CIC & CRS dates %	CRS dates used years AD	Interpolated dates used years AD	Preferred ^{210}Pb chronol.
1932	1912	29		1909	1909
1918	1889	32		1890	1890
1876	1866	9	1866		1866
1871	1848	16			-

TABLE 24 - Ellesmere, 'Mini'core, list of diatoms found at a maximum frequency of less than 2%.

Melosira distans, M. granulata, M. italica subsp. subarctica, M. varians, Cyclotella kutzingiana, C. meneghiniana, C. pseudostelligera, C. stelligera, Stephanodiscus tenuis, Tabellaria spp., Diatoma tenue, Fragilaria capucina var. mesolepta, F. construens var. pumila, F. pinnata, F. vaucheriae, Synedra parasitica var. constricta, S. radians, S. rumpens, S. ulna, Eunotia pectinalis var. minor, E. serra, Cocconeis pediculus, C. placentula vars., C. thumensis, Achnanthes clevei, A. exigua, A. hauckiana, A. lanceolata, A. lanceolata var. elliptica, A. microcephala, A. pinnata, Rhoicosphaenia curvata, Amphipleura pellucida, Frustulia rhomboides var. saxonica, Gyrosigma attenuatum, G. sp., Caloneis bacillum, C. limosa, Neidium dubium, N. iridis, Diploneis elliptica, D. oculata, D. puella , Stauroneis anceps, S. kriegeri, S. phoenicenteron, Anomoeneis sphaerophora, Navicula atomus, N. bacillum, N. capitata, N. cincta, N. cuspidata var. ambigua, N. gastrum, N. gottlandica, N. gracilis, N. graciloides, N. jentzschii, N. menisculus, N. minima, N. muralis, N. pseudoventralis, N. pupula, N. pupula var. capitata, N. pupula var. rostrata, N. radiosa, N. rotunda, N. rhynchocephala, N. sp., N. utermohlii,N. viridula, Pinnularia dactylus, P. divergens, P. interrupta fo. minutissima, P. maior, P. viridis, Amphora ovalis var. pediculus, Cymbella cistula, C. ehrenbergii, C. lata, C. lunata, C. microcephala, C. prostrata var. auerswaldii, Gomphonema angustatum, G. constrictum, G. dichotomum, G. gracile, G. olivaceum, Epithemia sorex, E. zebra, Rhopalopodia gibba, Hantzschia amphyoxis, Nitzschia acuicularis, N. acuta, N. amphibia, N. dissipata, N. fonticola, N. linearis, N. recta, N. sigmoidea, N. tryblionella, Cymatopleura solea, Surirella linearis var. constricta, S. ovata, S. ovata var. pinnata, S. robusta, Campylodiscus noricus.

TABLE 25 - Ellesmere, Core 6, list of diatoms found at a maximum frequency of less than 2%.

Melosira varians, Cyclotella comensis, C. kutzingiana, C. meneghiniana, Stephanodiscus tenuis, Fragilaria brevistriata, F. capucina, F. capucina var. mesolepta, F. constricta var. stricta, F. construens var. venter, F. crotonensis, F. lapponica, F. undata, F. undata var. quadrata, F. virescens, Synedra acus, S. parasitica var. constricta, S. rumpens, S. tenera, S. ulna var danica, Eunotia alpina, E. exigua, E. flexuosa, E. formica, E. microcephala, E. monodon, E. monodon var. bidus, E. naegeli, E. pectinalis, E. pectinalis var. undulata, E. serra, E. serra var. diadema, E. valida, Peronia fibula, Cocconeis diminuta, C. pediculus, C. thumensis, Achnanthes clevei, A. clevei var. rostrata, A. hauckiana, A. lanceolata var. rostrata, A. linearis var. pusilla, A. microcephala, A. oestrupii, A. pinnata, Rhoicosphaenia curvata, Meridion circulare, Frustulia rhomboides, Gyrosigma attenuatum, G. obtusatum, Caloneis limosa, C. ventricosa, Neidium dubium, N. iridis, Diploneis elliptica, D. oculata, D. puella, Stauroneis anceps, S. anceps fo. gracilis, S. kriegeri, S. phoenicenteron, S. smithii, Anomoeneis serians var. brachysira, A. sphaerophora, A. vitrea, Navicula acceptata, N. arvensis, N. capitata, N. cari, N. cincta, N. cuspidata, N. dicephala, N. gracilis, N. jentzschii, N. lanceolata, N. muralis, N. oblonga, N. pelliculosa, N. placentula, N. pseudoscutiformis, N. pupula, N. pupula var. mutata, N. pupula var. rectangularis, N. radiosa, N. rhynchocephala, N. schonfeldii, N. suchlandtii, N. vitabunda, Pinnularia appendiculata, P. biceps, P. borealis, P. dactylus, P. divergens, P. gibba, P. hilseana, P. interrupta, P. interupta fo. minutissima, P. maior, P. mesolepta, P. microstauron, P. rupestris, P. cf. socialis, Amphora ovalis var. pediculus, Cymbella cistula, C. cymbiformis, C. ehrenbergii, C. microcephala, C. muelleri, C. prostrata, C. proxima var. auerswaldii, C. turgida, Gomphonema acuminatum, G. acuminatum var. coronata, G. angustatum, G. constrictum, G. dichotomum, G. gracile, G. intricatum, G. olivaceum, G. olivaceum var. calcareae, Epithemia sorex, E. turgida, E. zebra, Rhopalopodia gibba, Hantzschia amphyoxis, Nitzschia acuta, N. dissipata, N. fonticola, N. frustulum, N. kutzingiana, N. palea, N. paleacea, N. recta, N. sigmoidea, N. tryblionella, Cymatopleura elliptica, Surirella linearis, S. robusta.

TABLE 26 - Ellesmere Core 4, list of diatoms found at a maximum frequency of less than 2%.

Melosira granulata, Cyclotella meneghiniana, Stephanodiscus astraea, S. dubius, S. tenuis, Fragilaria brevistriata, F. construens var. binodis, F. crotonensis, F. pinnata var. intercedens, Synedra rumpens, S. tenera,

TABLE 26 continued.

Eunotia diodon, E. exigua, E. flexuosa, E. parallela, E. serra var. diadema, E. veneris, Cocconeis placentula vars., C. thumensis, Achnanthes clevei, A. exigua, A. lanceolata, A. lanceolata var. apiculata, A. linearis, A. minutissima, Frustulia rhomboides, Gyrosigma attenuatum, Caloneis bacillum, C. ventricosa, Neidium dubius, Stauroneis anceps, S. kriegeri, S. phoenicenteron, Anomoeneis vitrea, Navicula capitata, N. cryptocephala, N. gastrum, N. gottlandica, N. graciloides, N. jentzschii, N. minima, N. muralis, N. mutica, N. protracta, N. pseudoscutelloides, N. pseudoventralis, N. pupula, N. radiosa, N. radiosa var. parva, N. rotunda, N. sublitissima, Pinnularia appendiculata, P. borealis, P. braunii, P. clevei, P. divergens, P. maior, P. microstauron, P. subcapitata, P. subsolaris, Amphora ovalis var. pediculus, A. perpusilla, Cymbella cistula, C. lata, C. lunata, C. prostrata var. auerswaldii, C. proxima, C. turgida, Gomphonema acuminatum, G. acuminatum var. brebissonii, G. angustatum, G. constrictum, Epithemia sorex, E. zebra, Rhopalopodia gibba, Hantzschia amphyoxis, Nitzschia sigmoidea, N. tryblionella, Surirella robusta var. splendida.

TABLE 27 - Ellesmere, Russian Core R, results of attempted diatom analysis.

Depth m.	
0.25	Few diatoms, mainly Melosira granulata var. angustissima.
0.49	Few diatoms, mainly Melosira granulata var. angustissima.
0.75	Very few diatoms, mainly Asterionella formosa.
0.99	Very few diatoms, mainly Melosira granulata var. angustissima.
1.25	No diatoms found.
1.49	No diatoms found.
1.75	No diatoms found.

TABLE 28 - Ellesmere, Core 6, Calibration of ^{14}C dates using the dendrochronological calibration curve of Clarke, 1975.

Depth m	Date ^{14}C years bp	Calibrated date dendrochronological years BP
1.45 -1.55	940±50	850-950
1.975-2.025	1670±60	1550-1700
2.375-2.425	2160±50	2090-2340
2.775-2.825	3780±50	4050-4430
3.175-3.225	7640±60	Beyond calibration curve.

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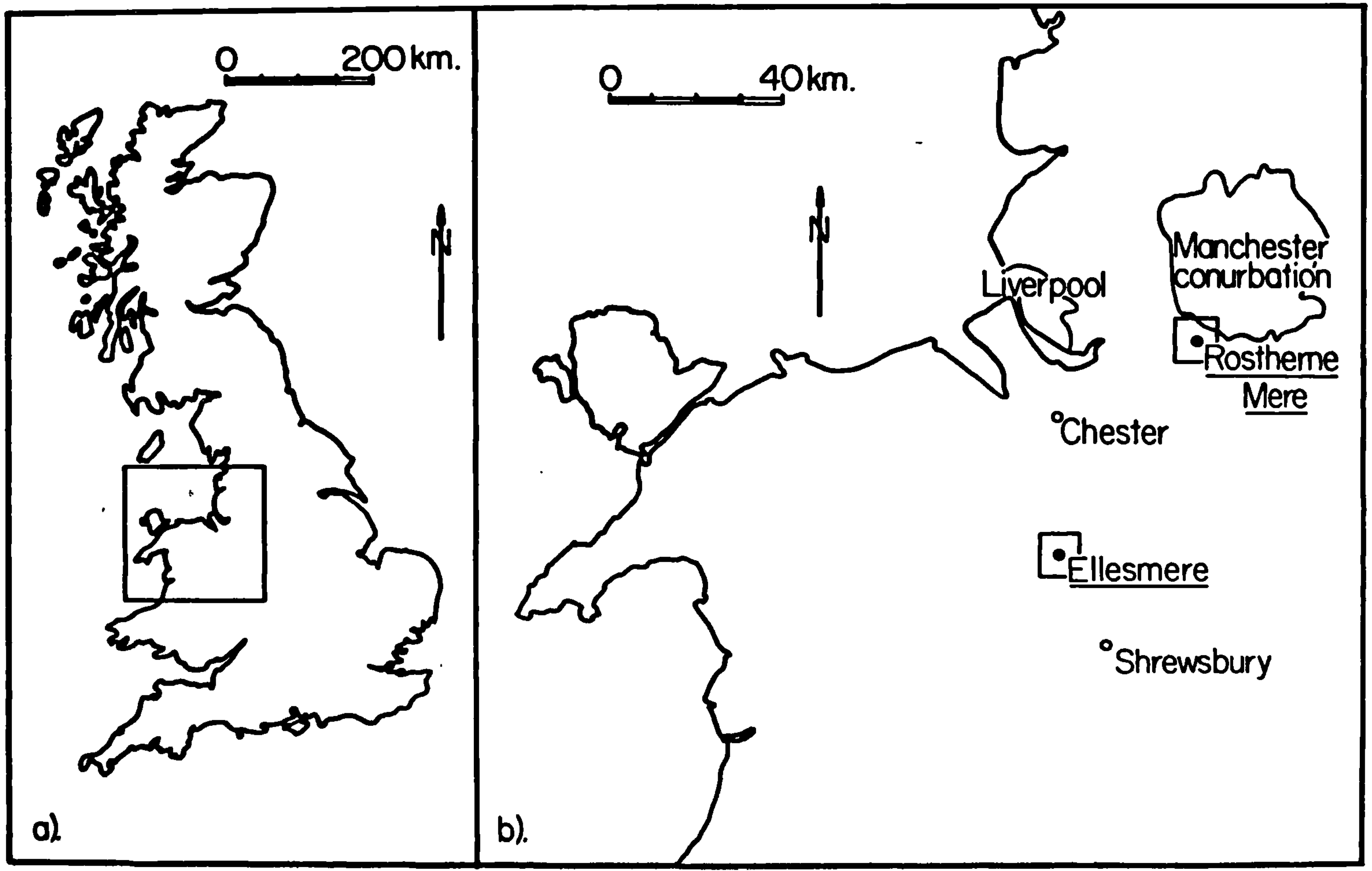
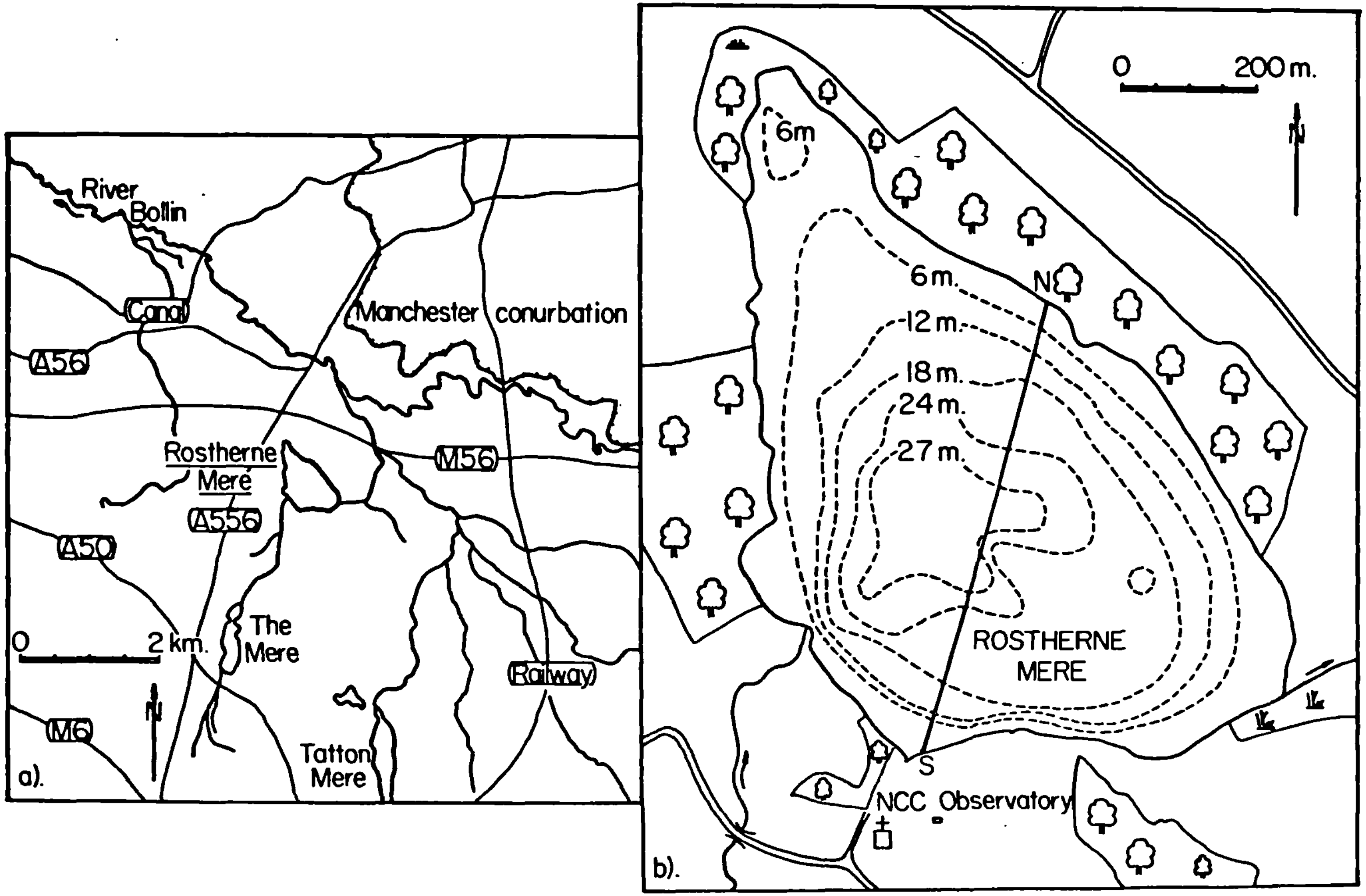
FIGURES.



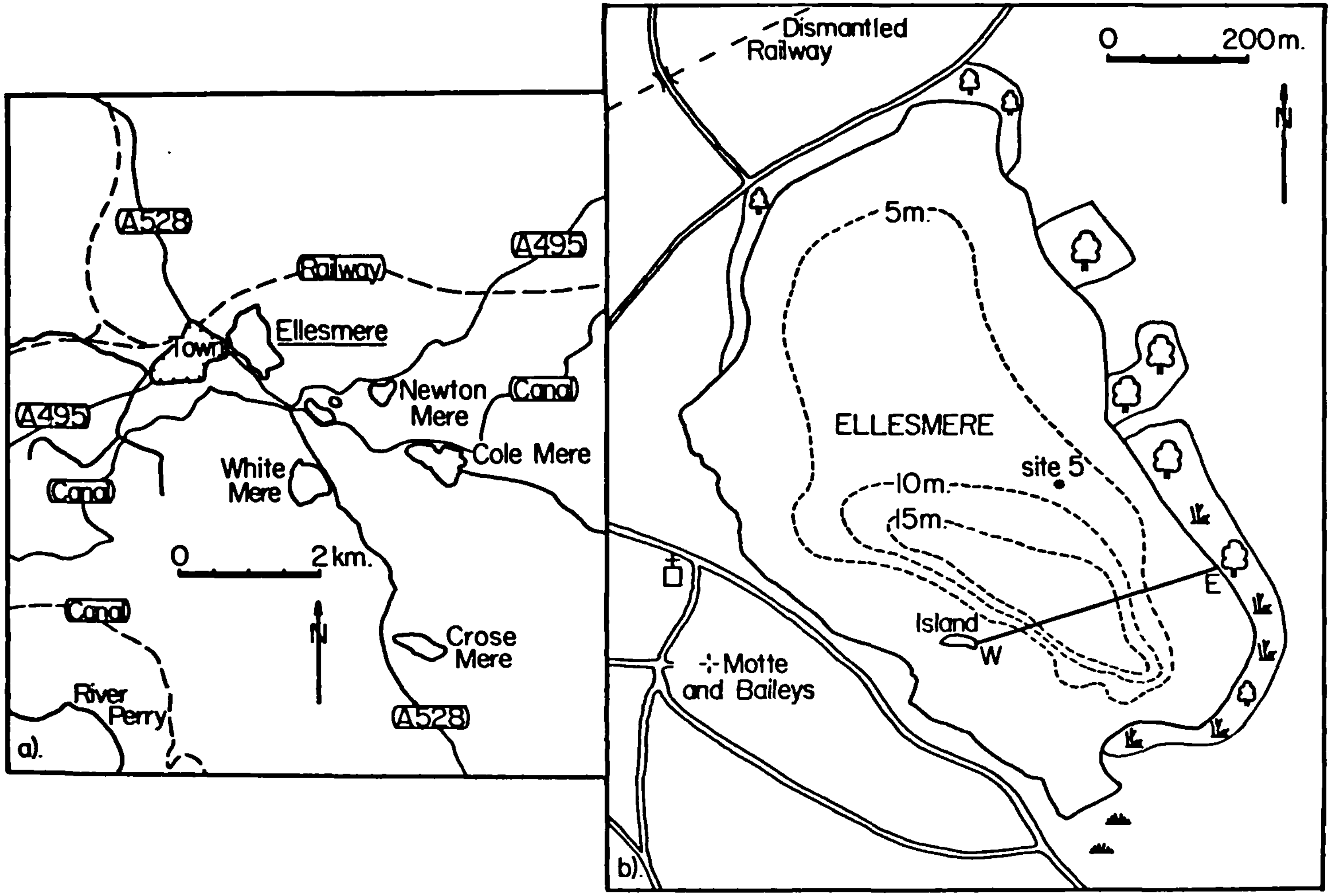
a). Map of Britain showing location of study area (enlarged in Fig 1b).
b). Map of NW Britain showing location of Rostherne Mere (enlarged in Fig 2a) and Ellesmere (enlarged in Fig 3a).

Fig. 1



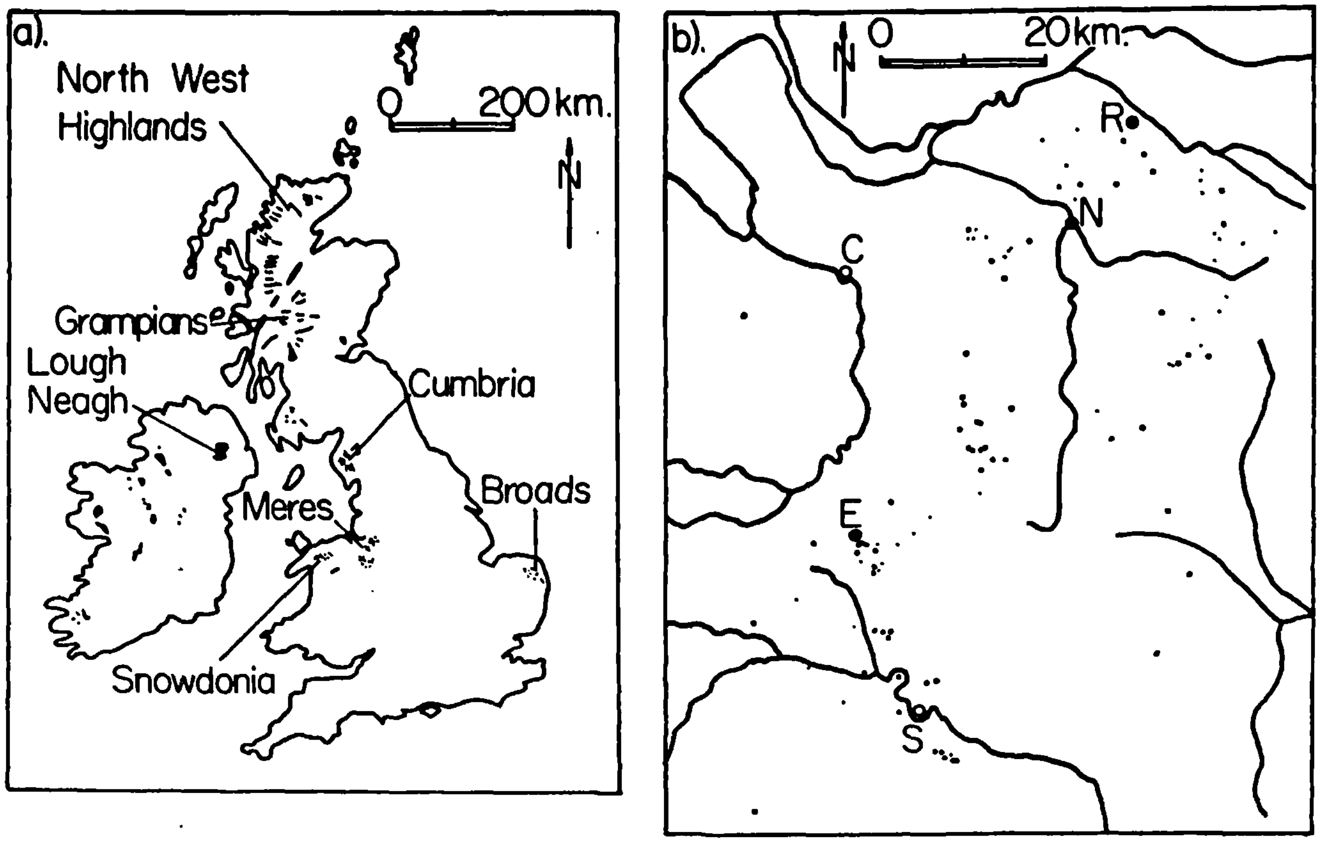
a). Map of northern Cheshire showing Rostherne Mere.
b). Map of Rostherne Mere showing transect S-N.

Fig. 2



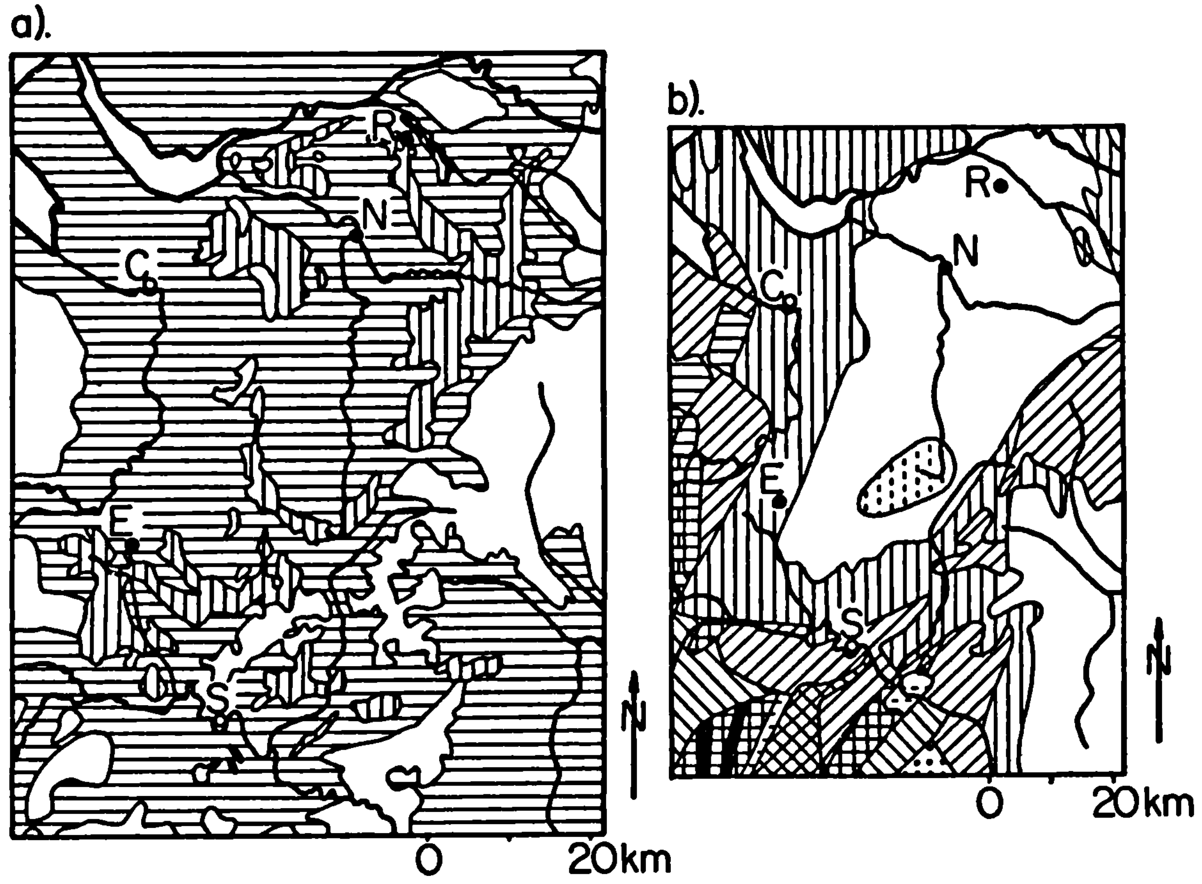
a). Map of north-western Shropshire (Salop) showing Ellesmere.
b). Map of Ellesmere showing transect W-E, and core site 5.

Fig. 3



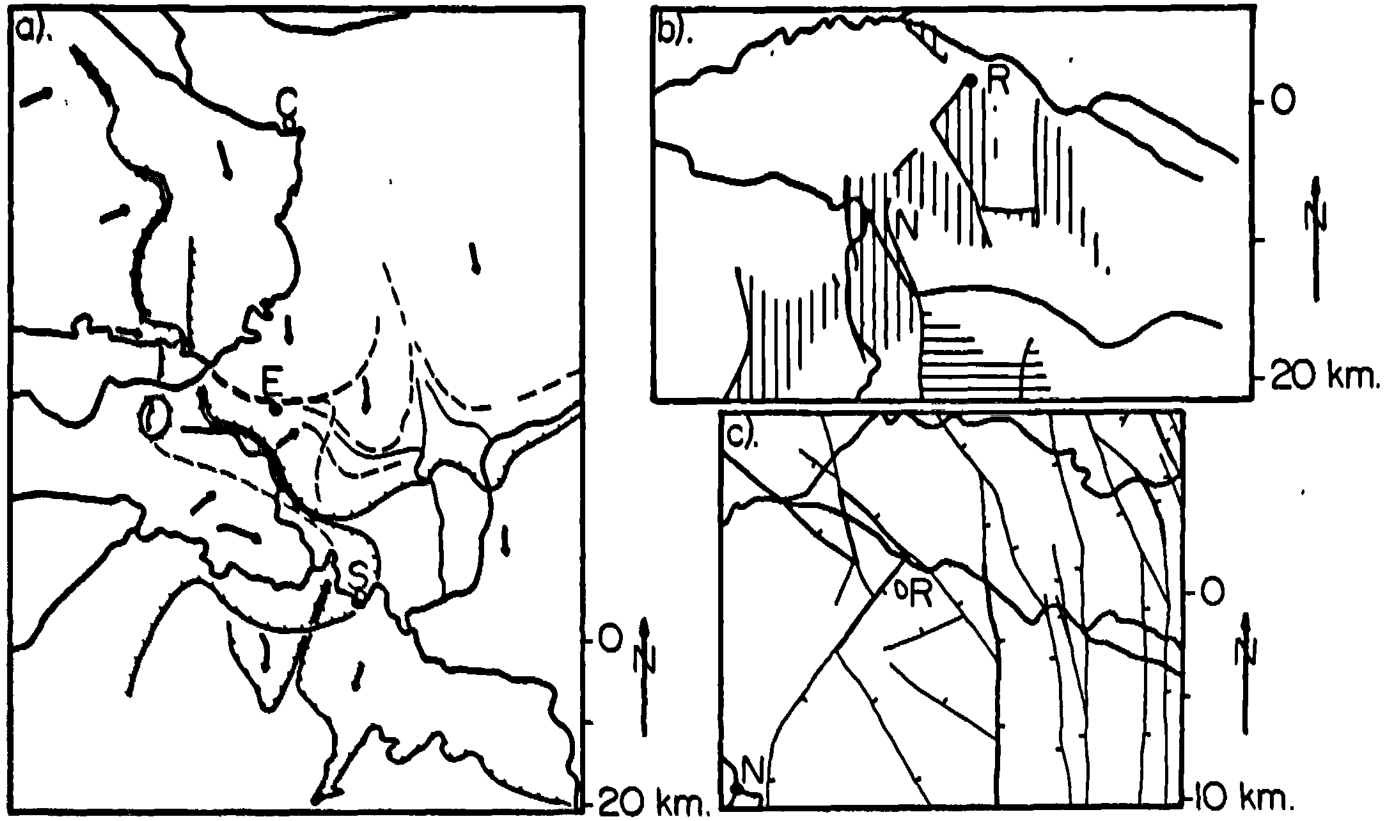
Map showing a), distribution of major lake sites in the British Isles.
b), distribution of main Meres (•) and Mosses (·) in the area around Rostherne Mere (R), Ellesmere (E), Chester (C), Northwich (N) and Shrewsbury (S).

Fig. 4



Maps showing geology around Rostherne Mere (R), Ellesmere (E), Northwich (N), Chester (C) and Shrewsbury (S).
a), Surface drift, boulder clay ▤, sand and gravel ▥, drift free □.
b), Solid geology, Liassic ░, Bunter Sandstones ▥, Keuper Marls and Sandstones □,
Coal measures ▨, Millstone grit ▤, Carboniferous Limestone ▦,
Old Red Sandstone ░, Silurian ▧, Ordovician ▦, Cambrian ░,
Pre-Cambrian ▩, Volcanic ■.

Fig. 5



a), Map showing some features of the Devensian glaciation of the area around Ellesmere (E), Chester (C) and Shrewsbury (S), maximum extent of Devensian ice sheet ▨, Welsh and Ellesmere readvances ▨, direction of ice advances ➡, moraines ▨.

b), c), Maps showing selected structural features of the area around Rostherne Mere (R) and Northwich (N).

b), saliferous beds, Lower Keuper ▥, Upper Keuper ▤.

c), major faults, more than 300 m. throw ⊟, less than 300 m. throw ⊟, ticks on downthrow side.

Fig. 6

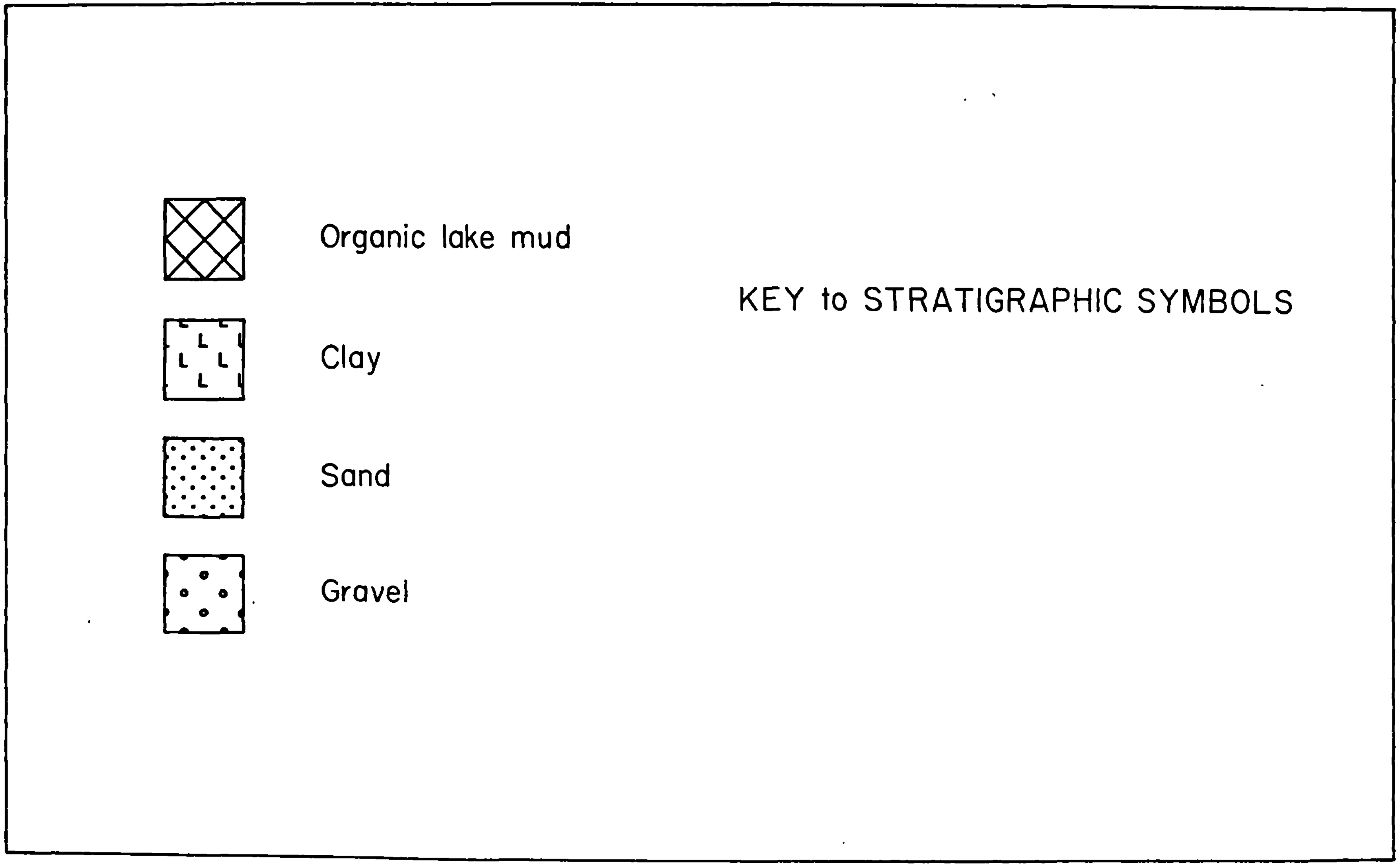
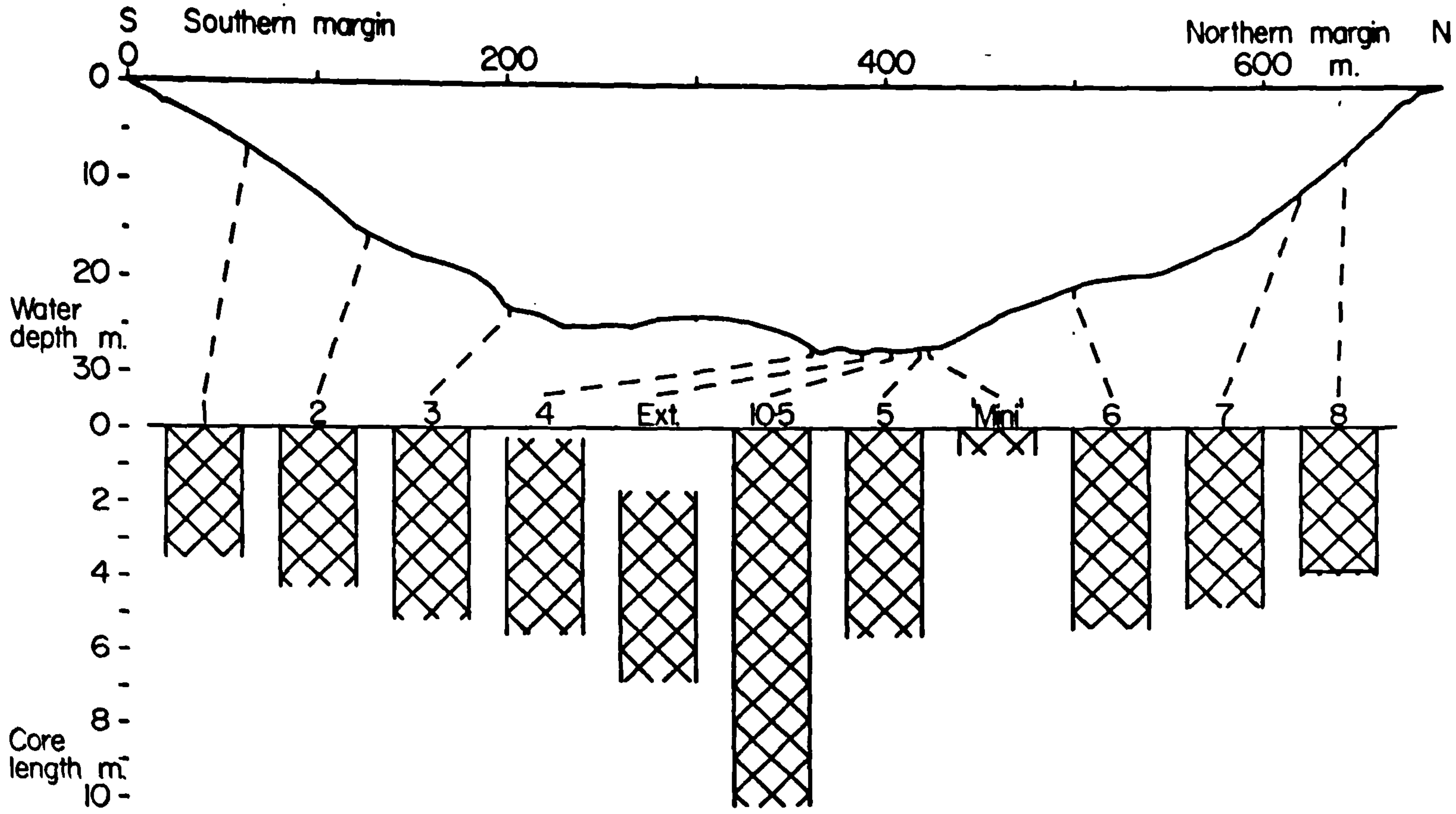
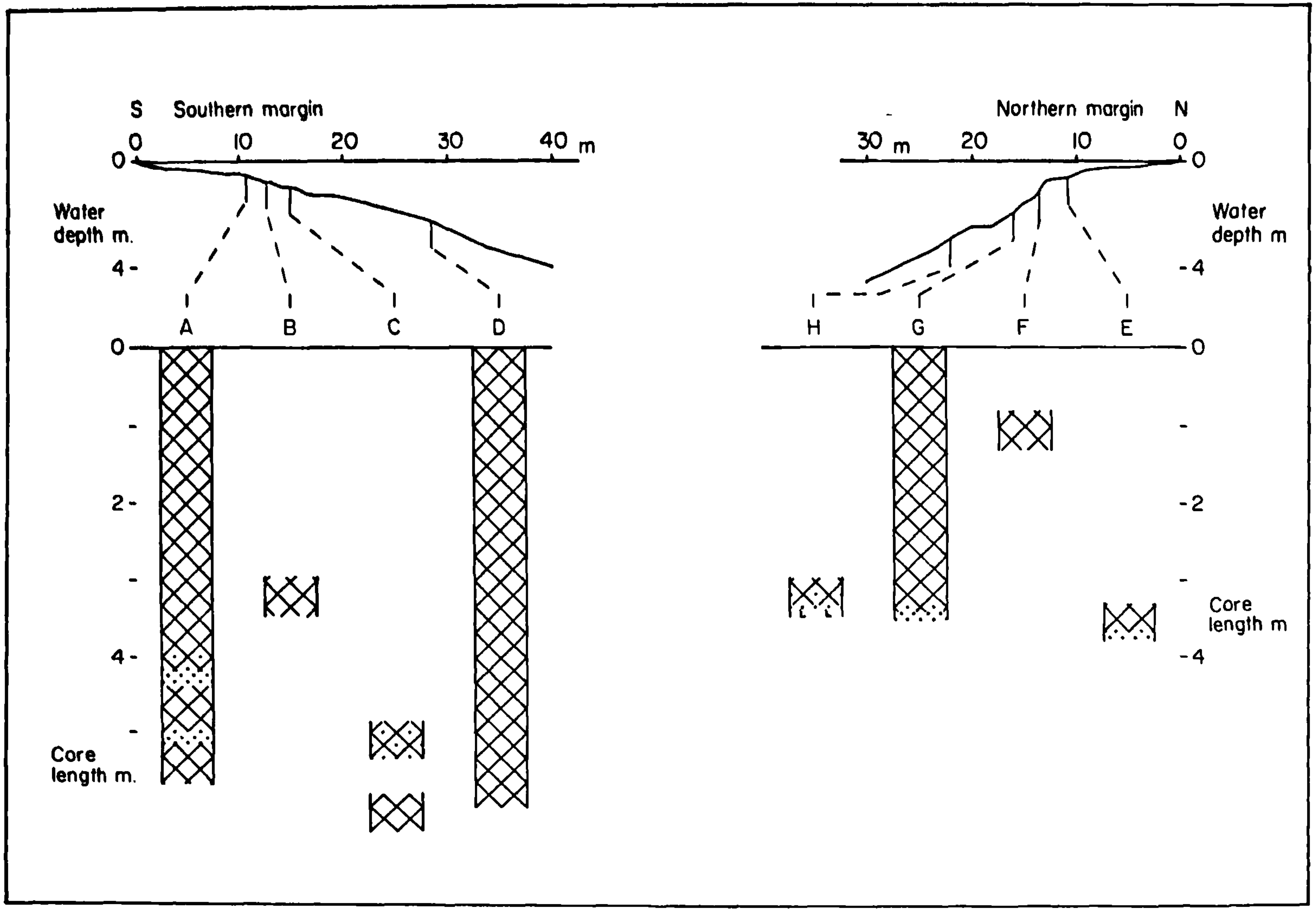

Organic lake mud
Clay
Sand
Gravel
KEY to STRATIGRAPHIC SYMBOLS

Fig. 7



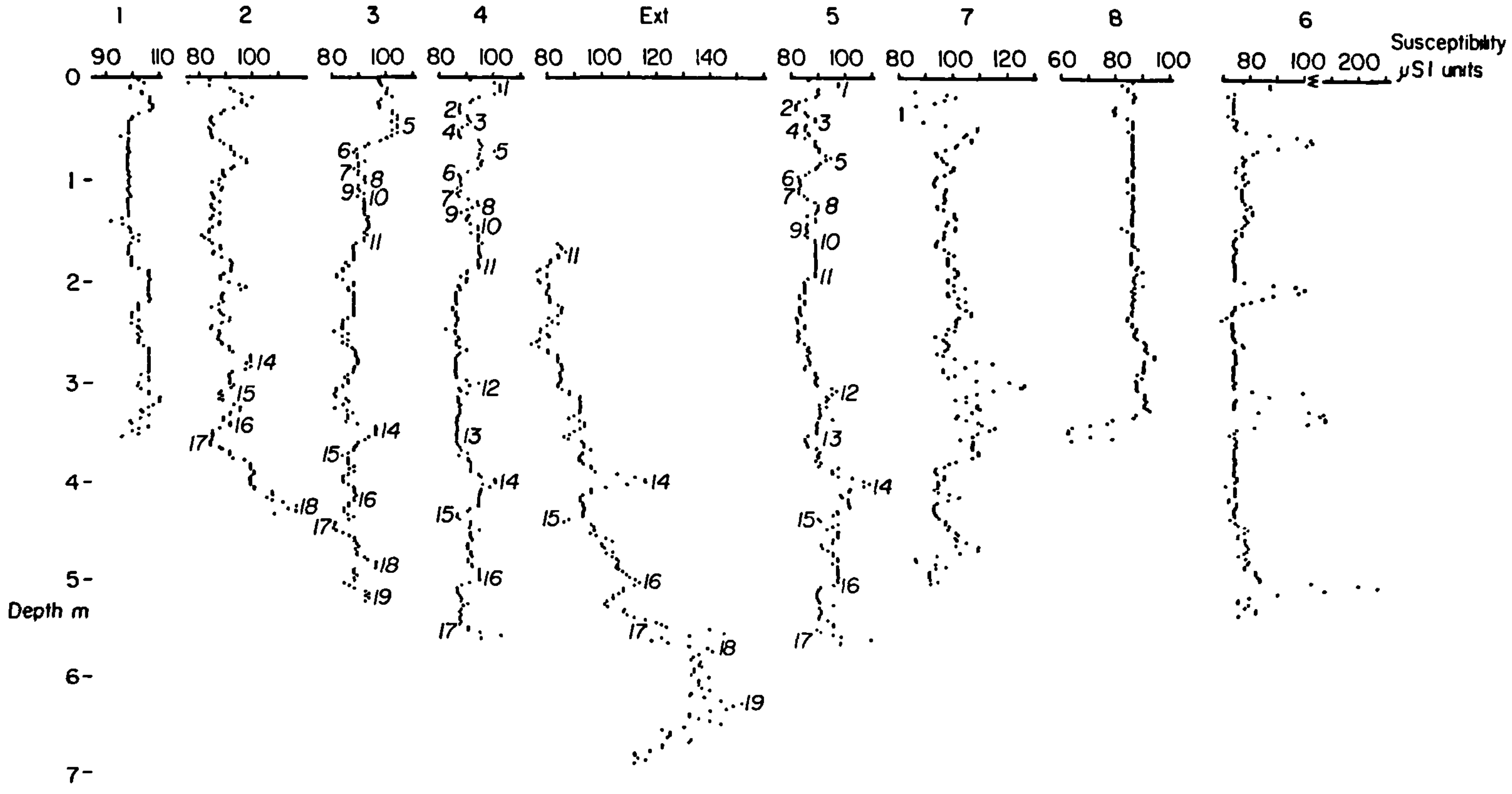
ROSTHERNE MERE, water depth, stratigraphy and position of Mackereth cores along transect S-N.

Fig. 8



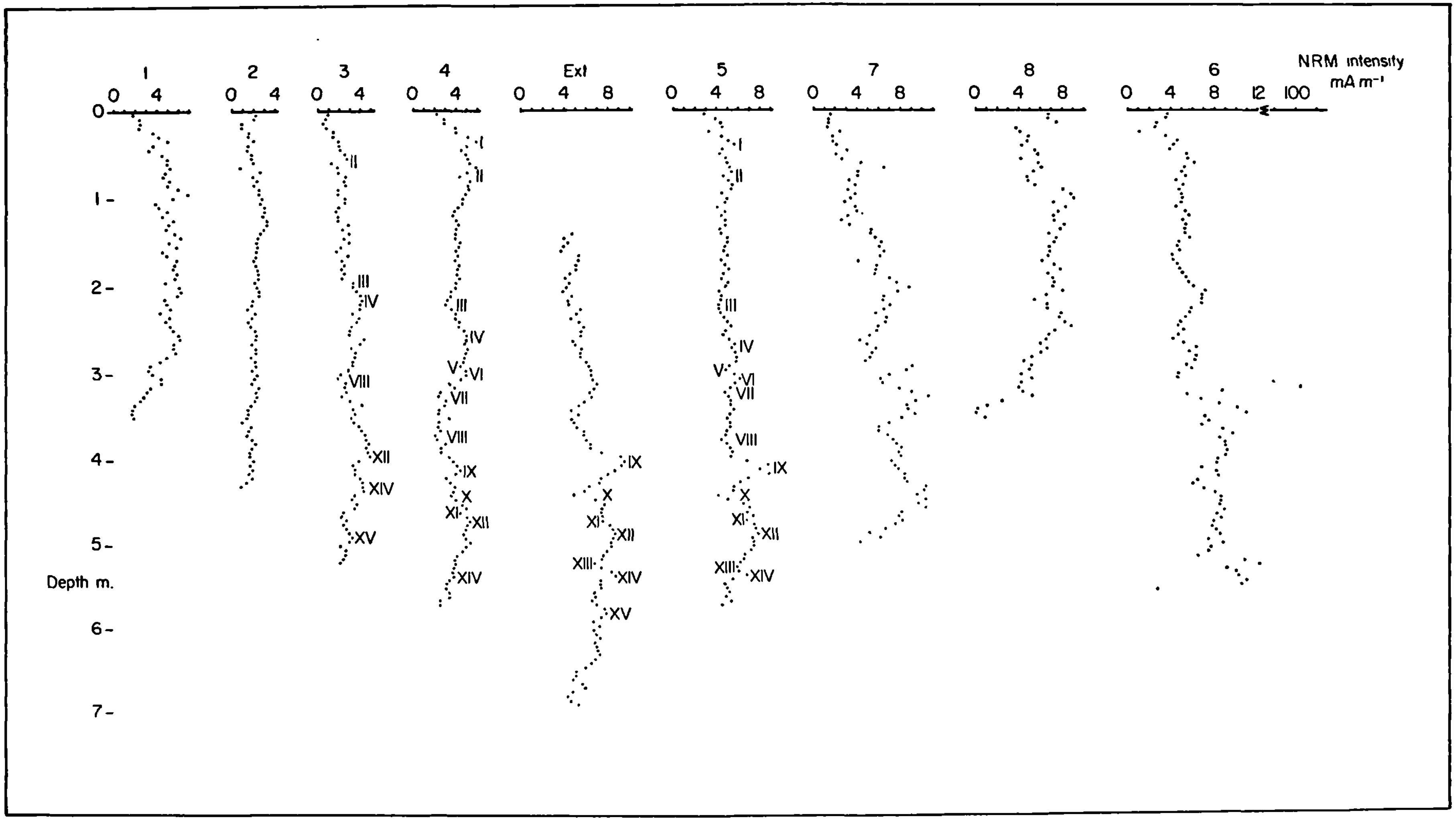
ROSTHERNE MERE, water depth, stratigraphy and position of Russian cores near the ends of transect S-N.

Fig. 9



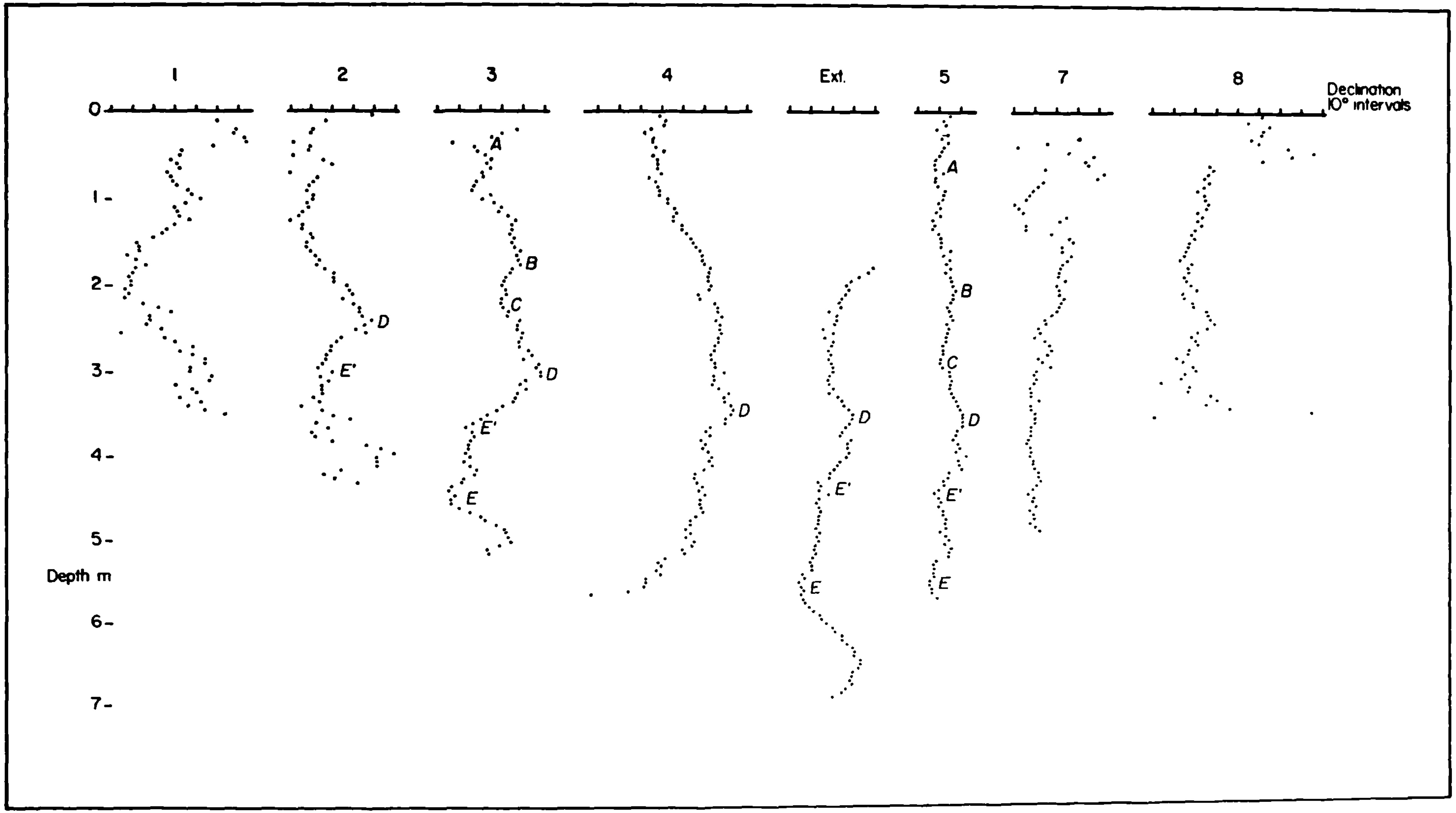
ROSTHERNE MERE, whole core susceptibility in μSI units vs. depth in metres in Mackereth cores 1 to 8, numerals *1* to *19* denote possible correlations

Fig. 10



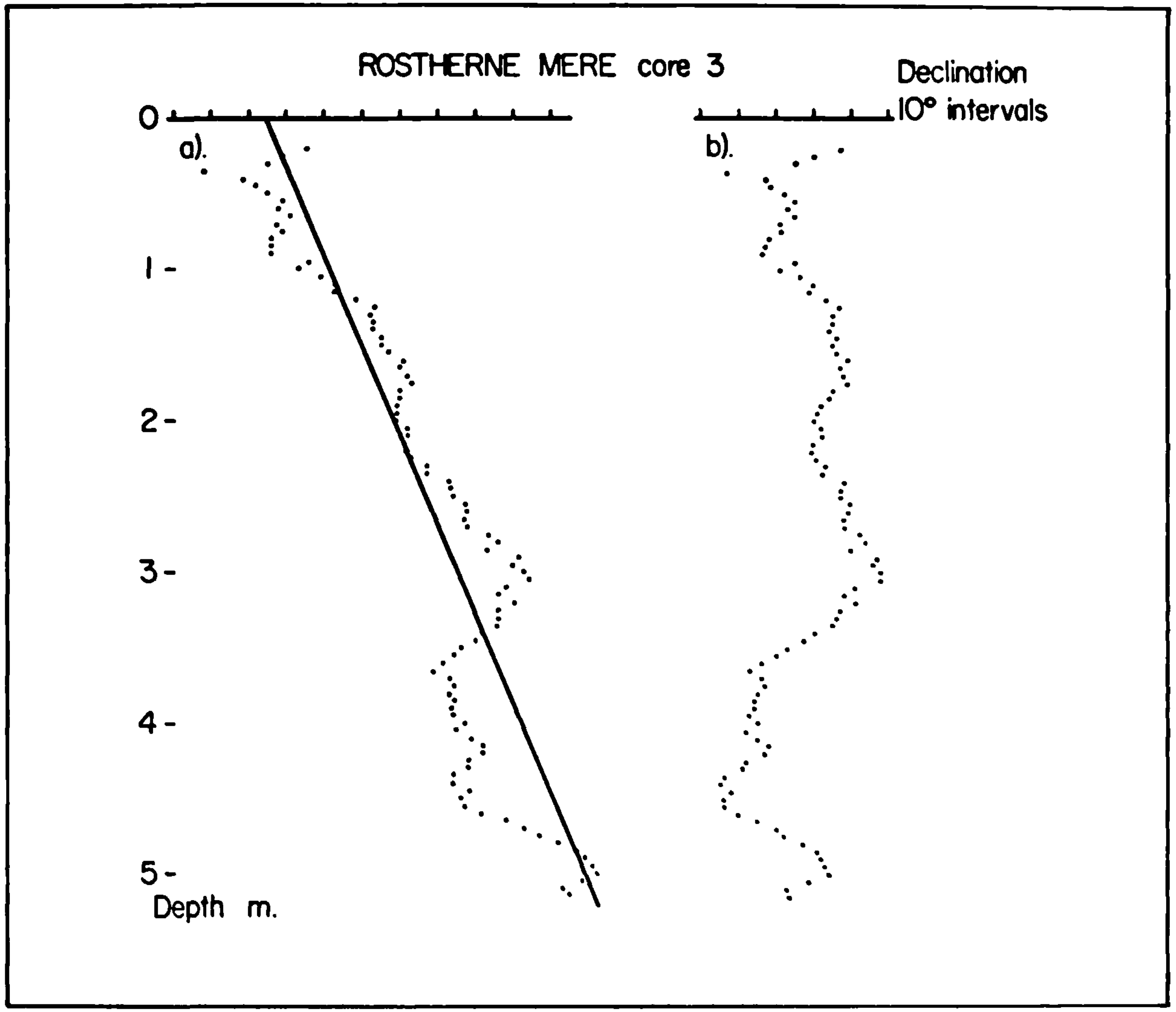
ROSTHERNE MERE, whole core intensity of natural remanent magnetization (NRM intensity) in mA m⁻¹ vs. depth in metres in Mackereth cores I to 8, Roman numerals I to XV denote possible correlations.

Fig. 11



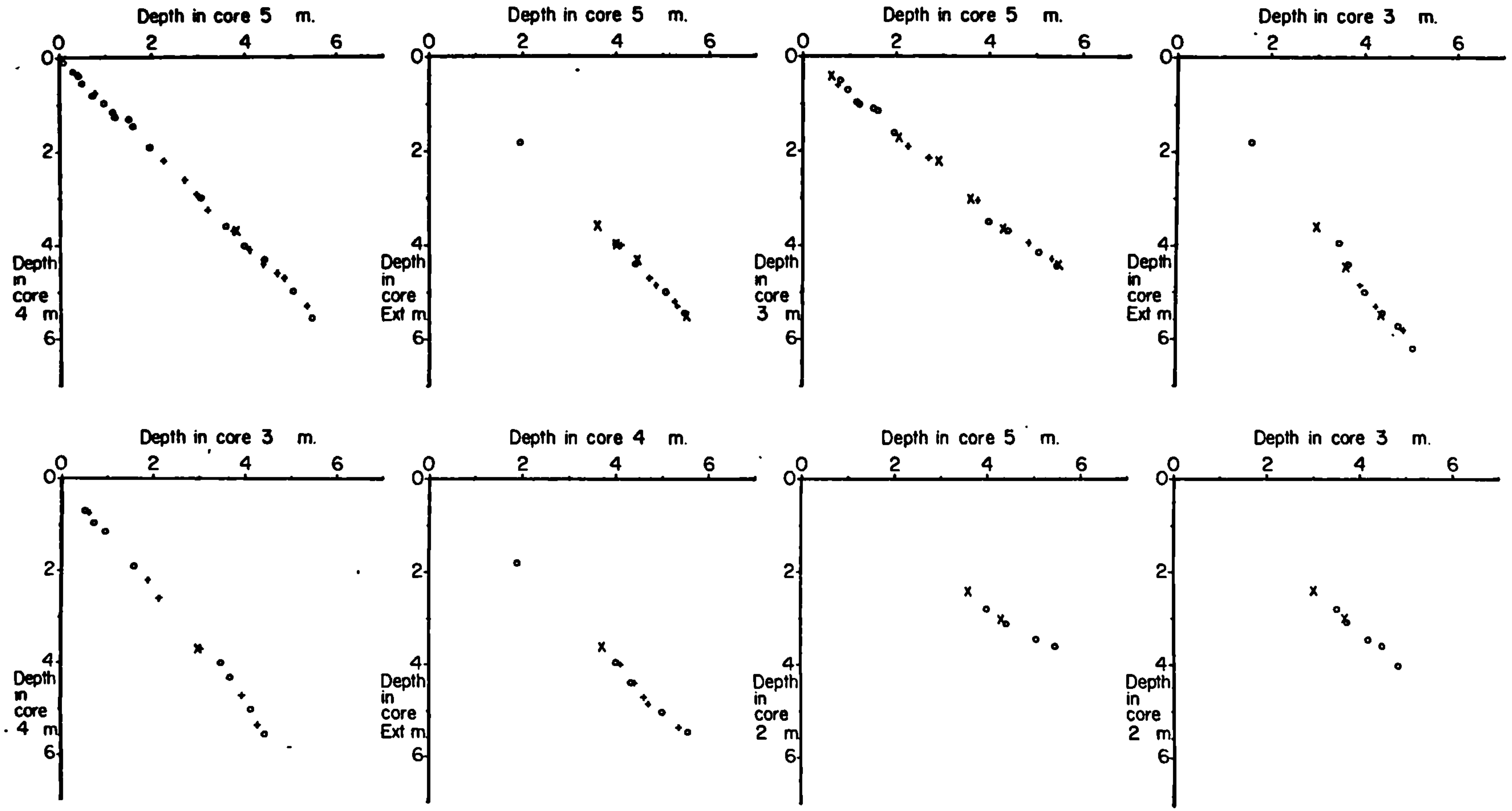
ROSTHERNE MERE, whole core relative declination, 10° intervals vs. depth in metres in Mackereth cores 1 to 8, letters *A* to *E* denote possible correlations

Fig. 12



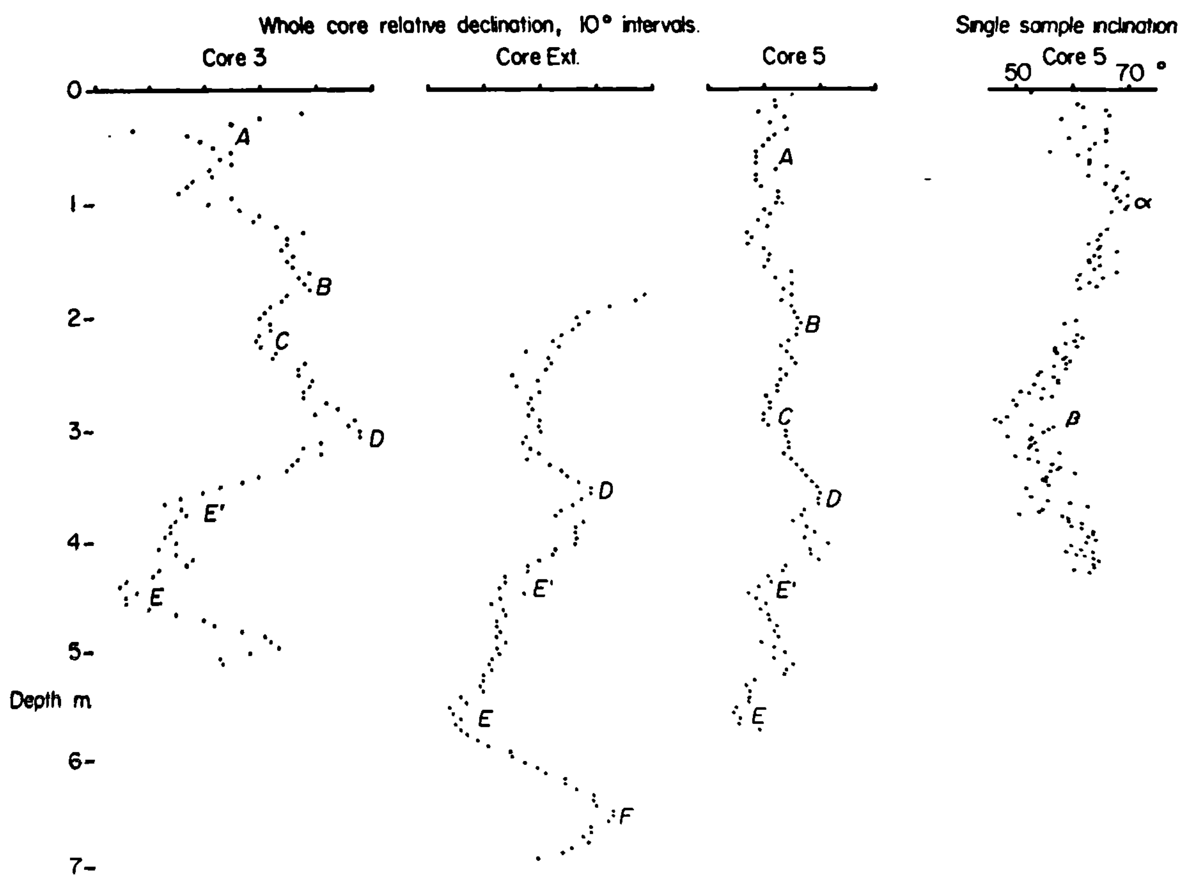
a), raw declination vs. depth data, trend due to rotation of core tube during coring.
b), declination vs. depth data with trend removed.

Fig. 13



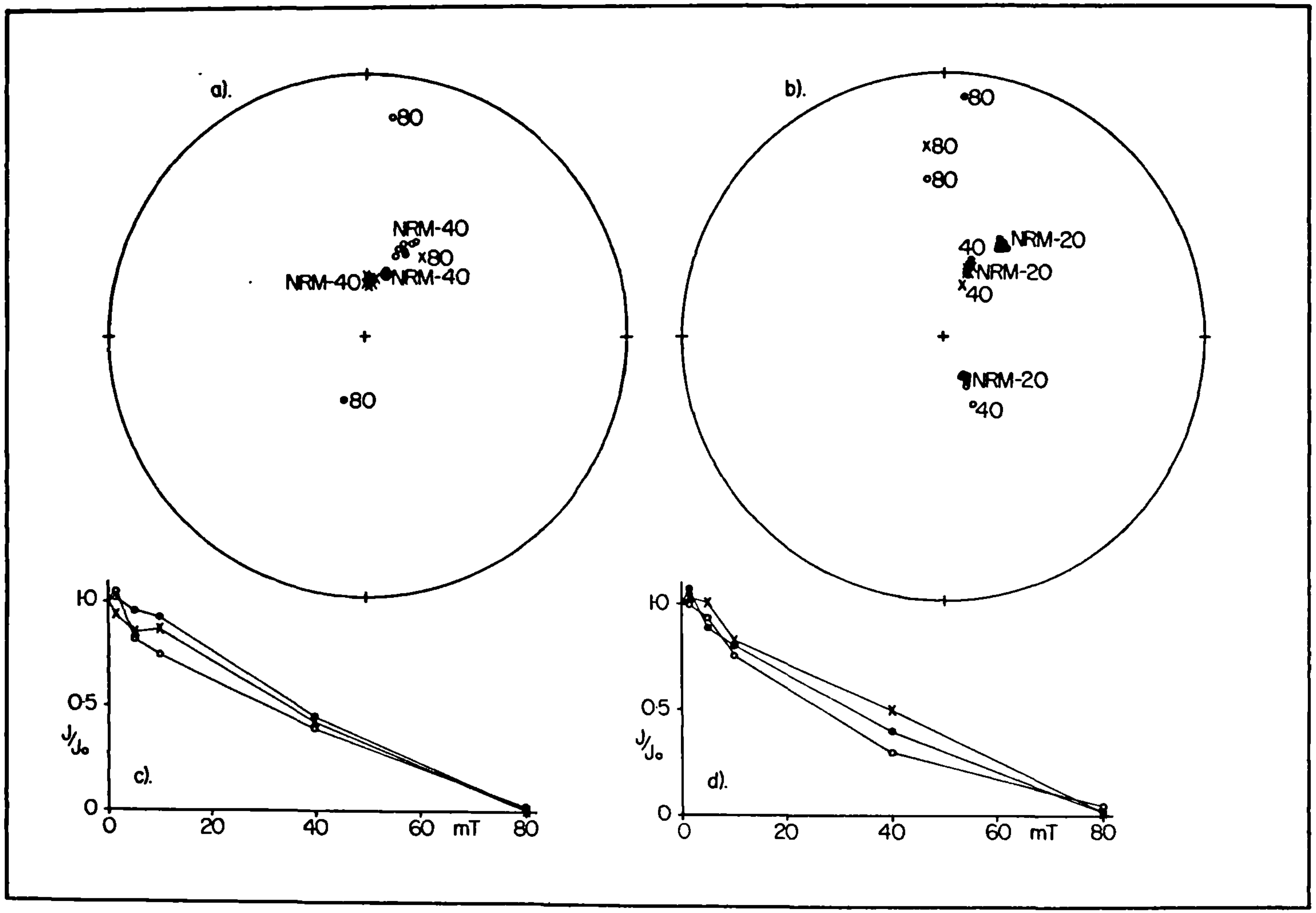
ROSTHERNE MERE, comparison of depth in metres of independant correlations derived from susceptibility (∘), NRM intensity (·) and declination (x) in cores 5 vs. 4, 5 vs. Ext, 5 vs. 3, 3 vs. Ext, 3 vs. 4, 4 vs. Ext, 5 vs. 2 and 3 vs. 2.

Fig. 14



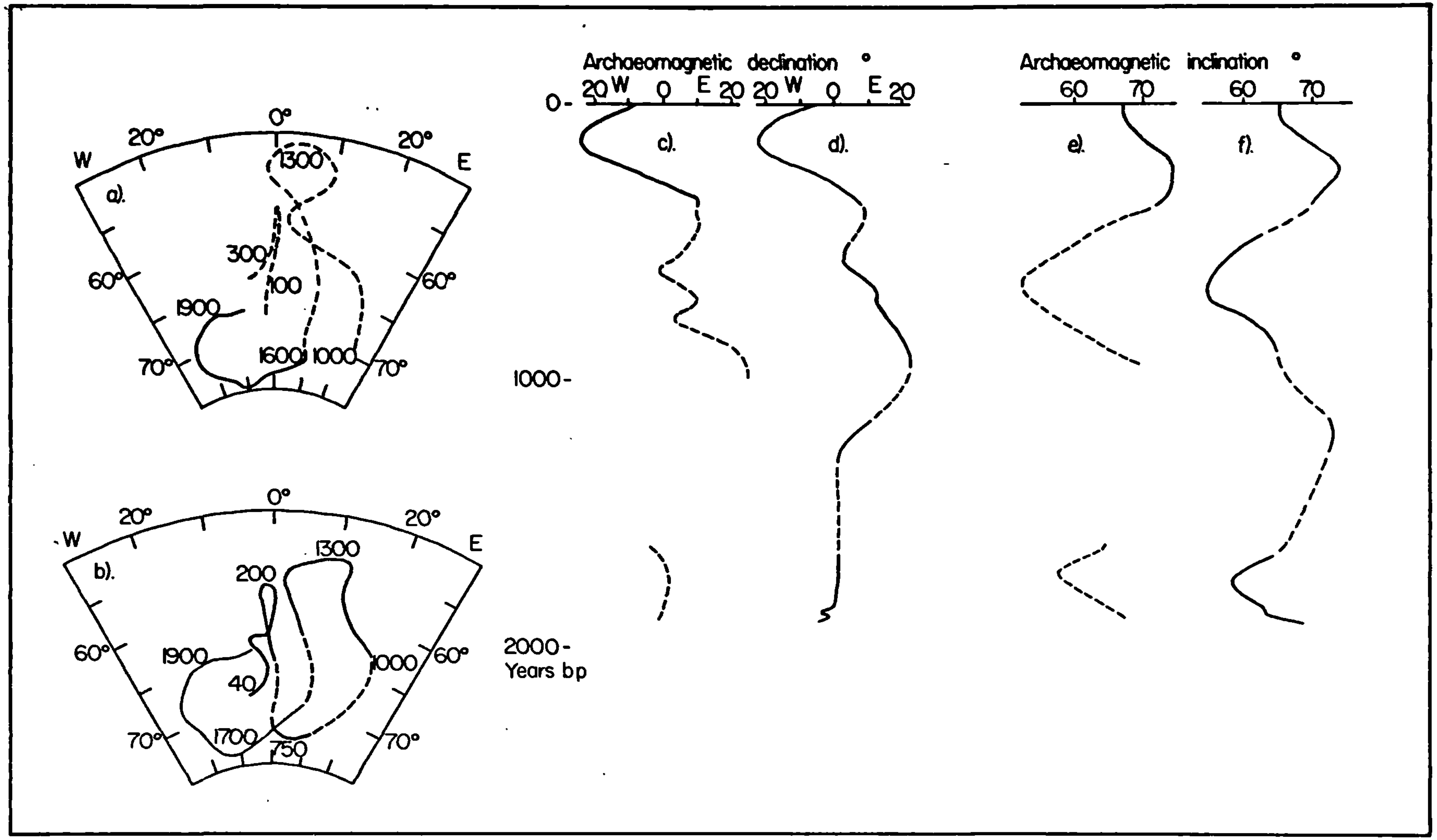
ROSTHERNE MERE, whole core relative declination, 10° intervals, vs. depth in metres in cores 3, Ext. and 5, and single sample inclination in degrees vs. depth in metres in core 5. Letters *A* to *F* denote palaeomagnetic declination features, and Greek letters α and β denote palaeomagnetic inclination feature

Fig. 15



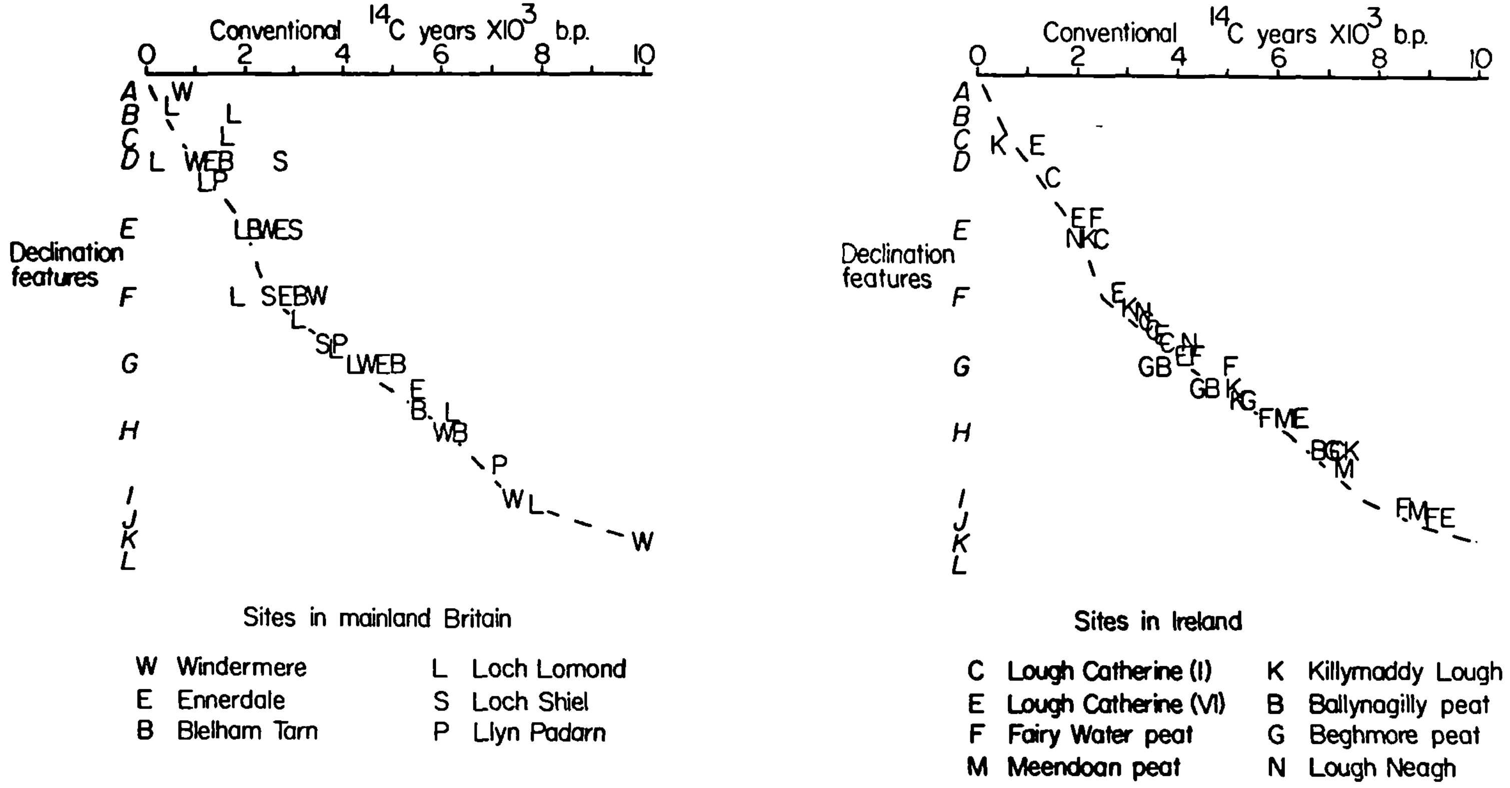
ROSTHERNE MERE, core 5, a), b), polar stereographic plots showing angular changes in direction of magnetization during alternating field demagnetization of six samples, a), 2·92m (∘), 4·23m (•), 5·46m (x), b), 0·72m (∘), 2·20m (•), 3·46m (x)
c), d), normalised remanent intensity of magnetization (J/J₀) vs. peak alternating demagnetizing field in milliTesla for six samples, c), symbols as a), d), symbols as b),

Fig. 16



Secular variation of declination and inclination; from ca. 1600 AD (350 bp) observatory records are used, earlier data are archaeomagnetic.
a), c), and e), for London, are redrawn from Aitken (1970); a), as originally presented (dates in years AD); c), and e), replotted for clearer comparison with palaeomagnetic data (dates in years bp).
b), d), and f), for Paris, are redrawn from Thellier (1981); b), as a), above; d), and f), as c), and e), above.

Fig. 17

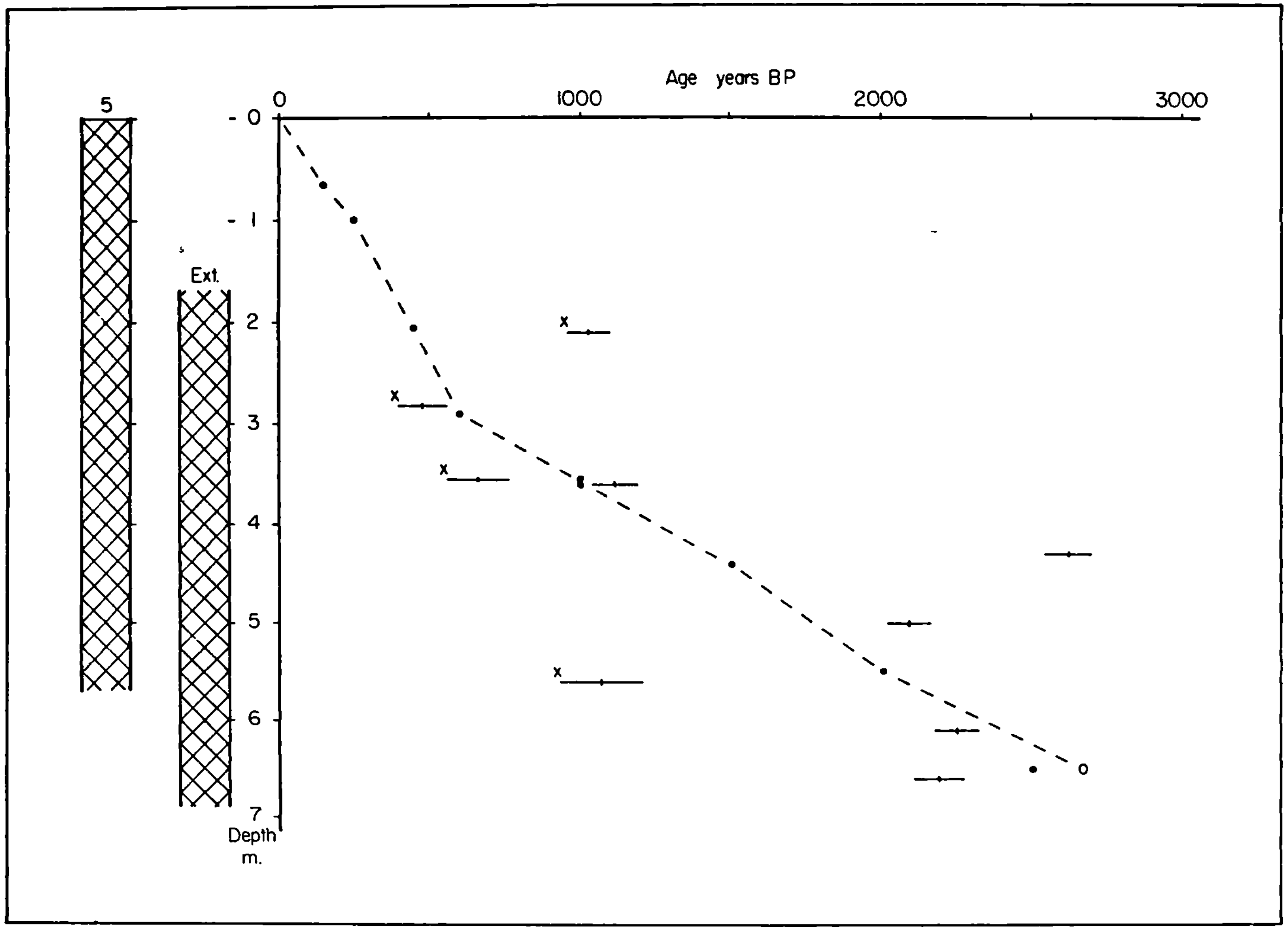


After Thompson (1979).

After Thompson and Edwards (in prep.).

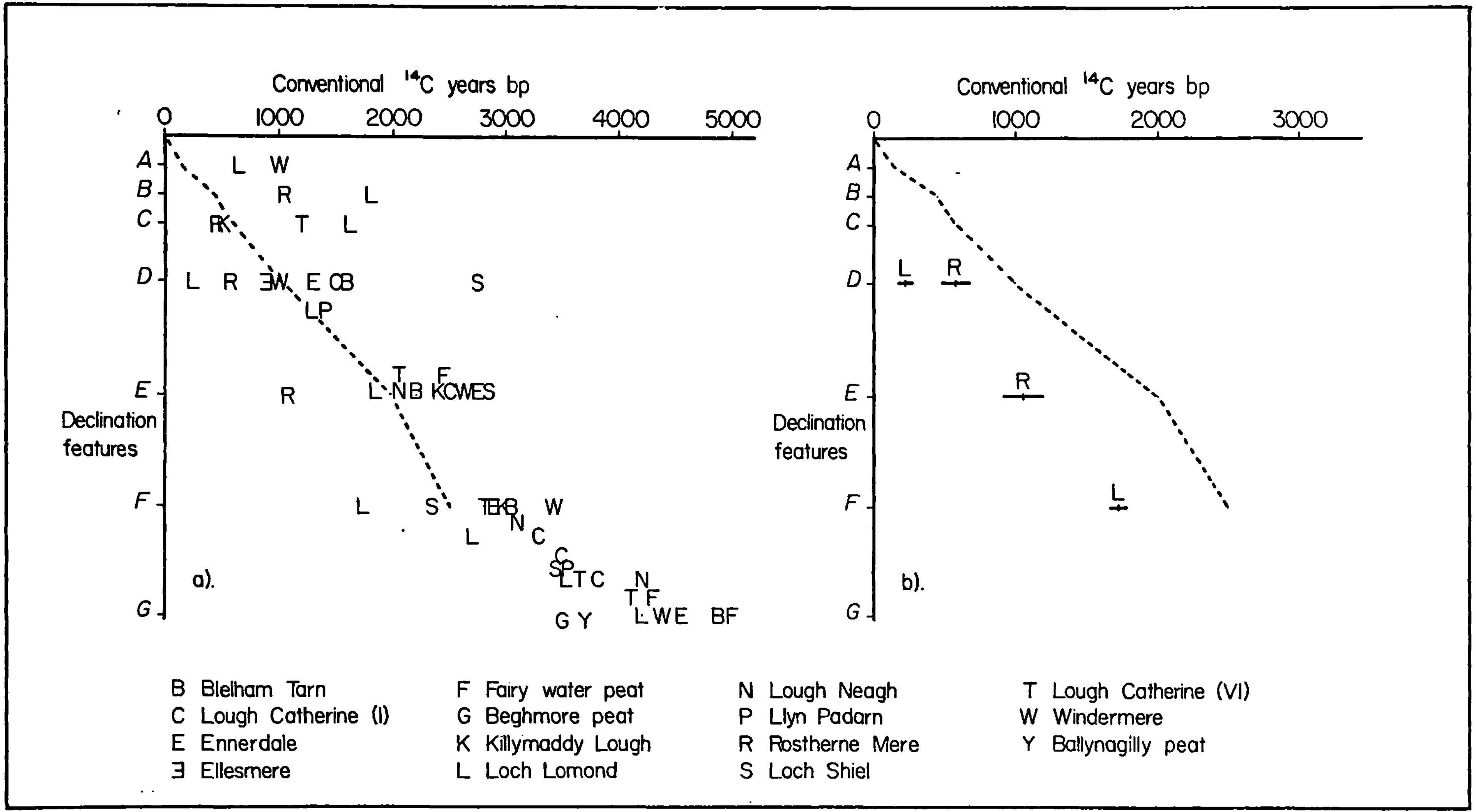
Comparison of ^{14}C age in years b.p. with declination records for sites in the British Isles.

Fig. 18



ROSTHERNE MERE, core 5 and Extension core , age in years BP vs depth in metres, comparing conventional ^{14}C age from ^{14}C analyses (-•-) and palaeomagnetic measurements (•). Age vs. depth curve (- -) constructed from palaeomagnetic dates, calibrated where necessary (o), using the dendrochronological calibration of Clark (1975). ^{14}C samples marked, x, contained 0·1 % or less inorganic carbon.

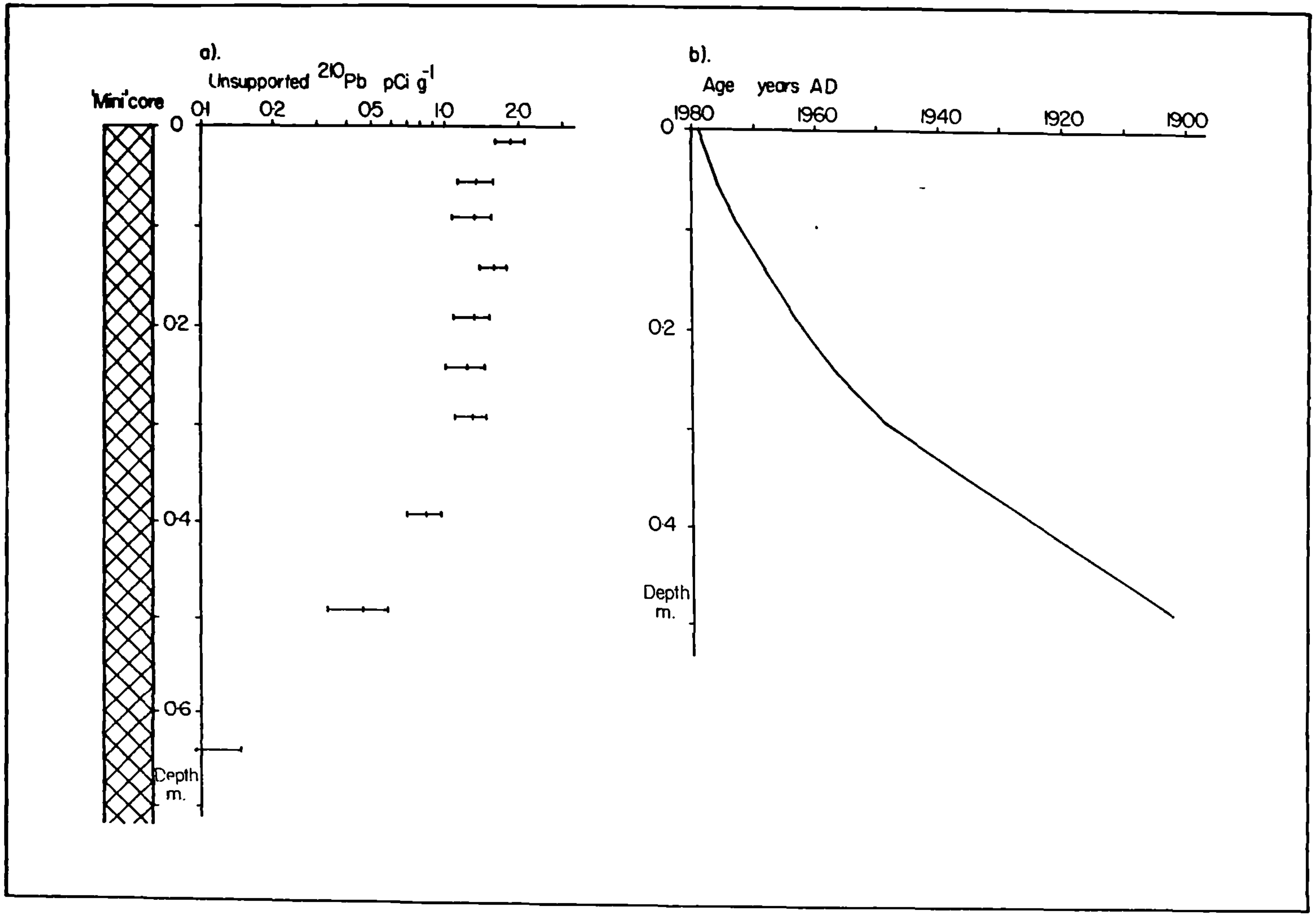
Fig. 19



a). Comparison of ^{14}C age in years bp. with declination records for 14 sites in the British Isles. The calibration curve of Thompson and Turner (1979) is shown (- - -).

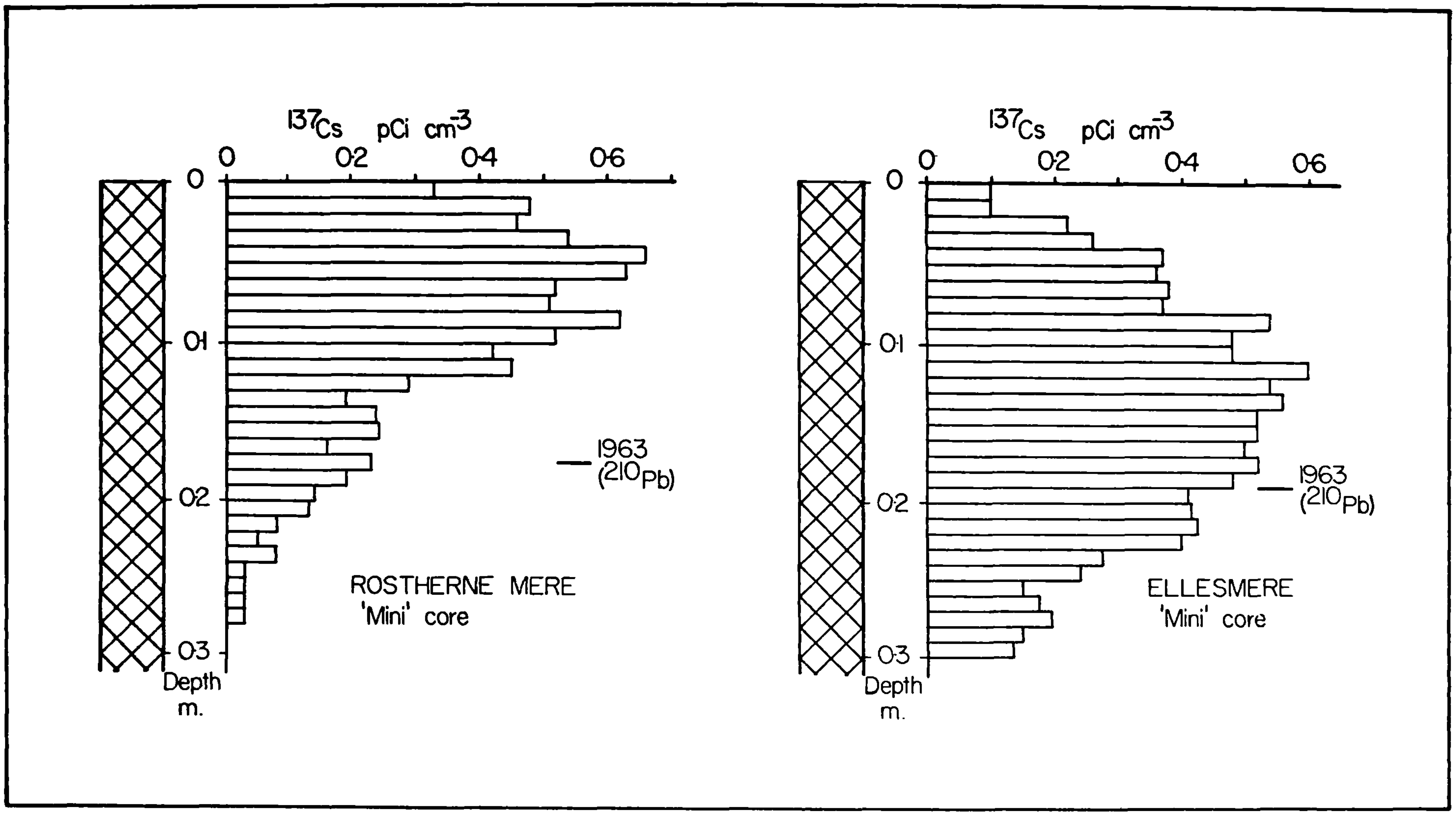
b). Significantly young ^{14}C ages of samples from Loch Lomond and Rostherne Mere, 95 % counting errors shown.

Fig. 20



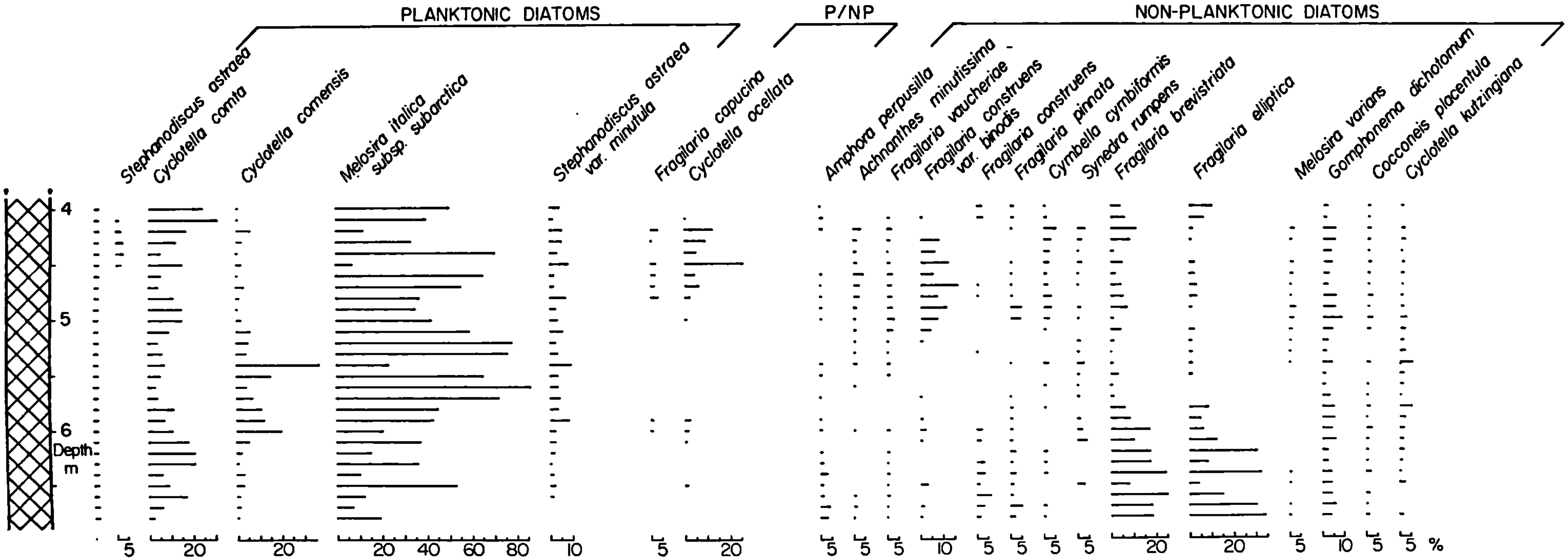
ROSTHERNE MERE, a), unsupported ^{210}Pb, showing 95 % counting error limits, in picoCuries per gram of dry sediment vs. depth in metres.
b), Age in years AD, calculated using the constant rate of supply' method, vs. depth in metres.

Fig. 21



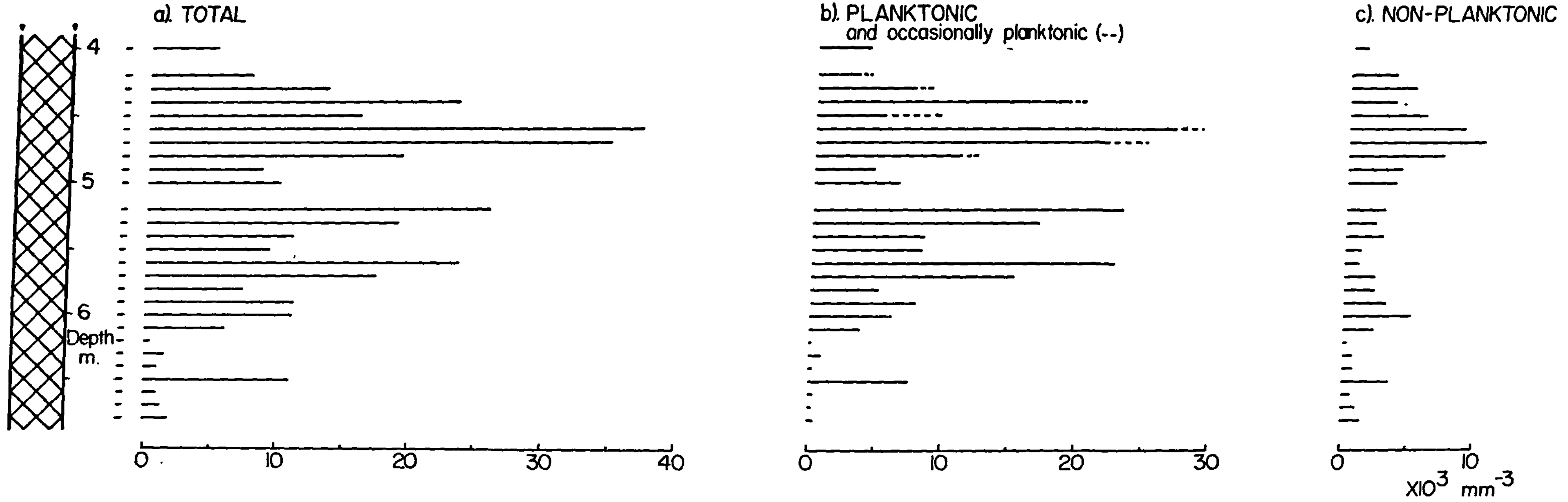
^{137}Cs in picoCuries per cubic centimetre of wet sediment vs. depth in metres

Fig. 22



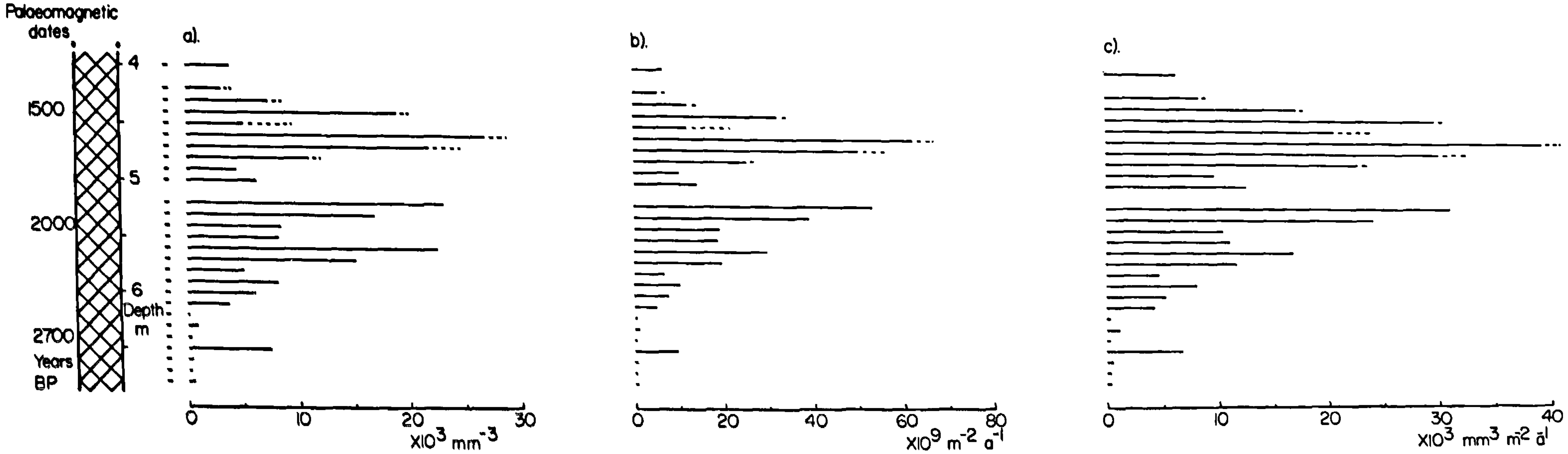
ROSTHERNE MERE, extension core, diatom diagram showing planktonic, occasionally planktonic (P/NP) and non-planktonic diatoms as a percentage of diatom sum vs depth in metres

Fig. 23



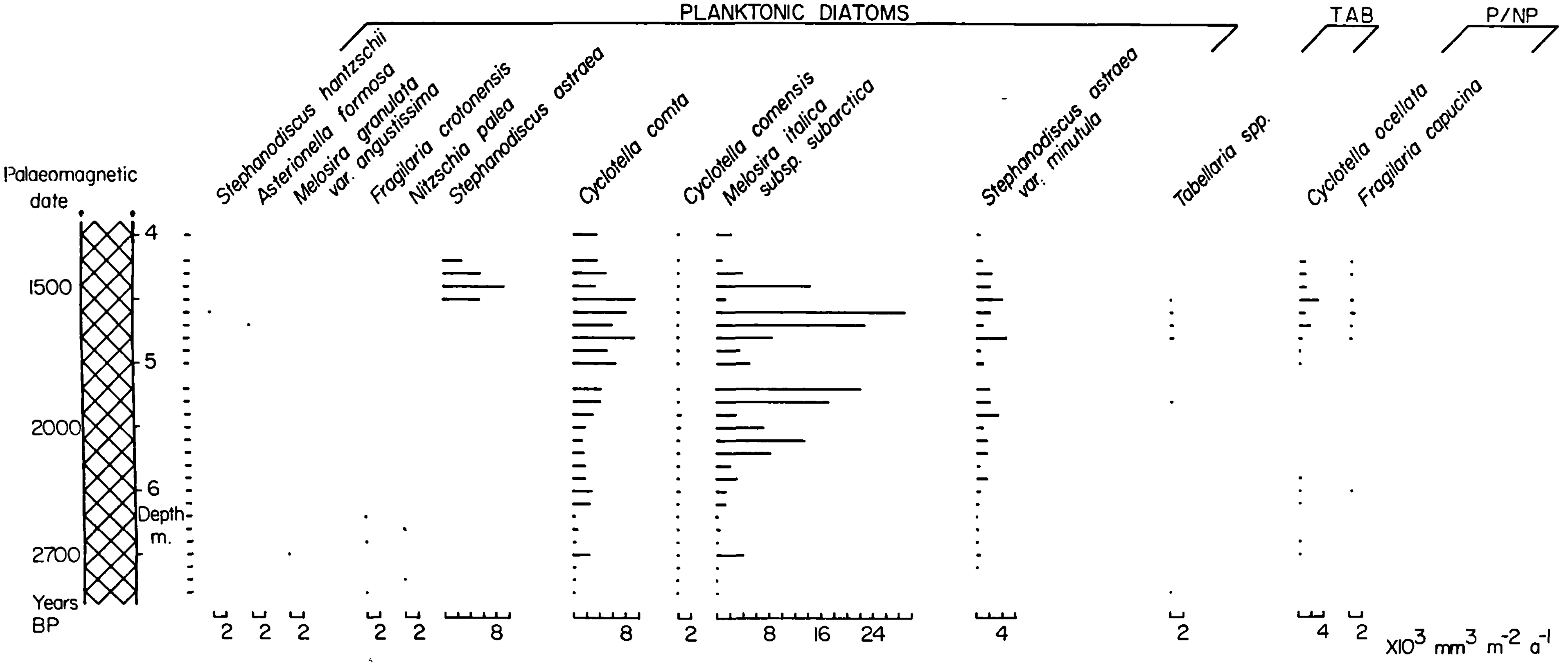
ROSTHERNE MERE, Extension core, numbers of diatoms per cubic millimetre of wet sediment vs. depth in metres.

Fig. 24



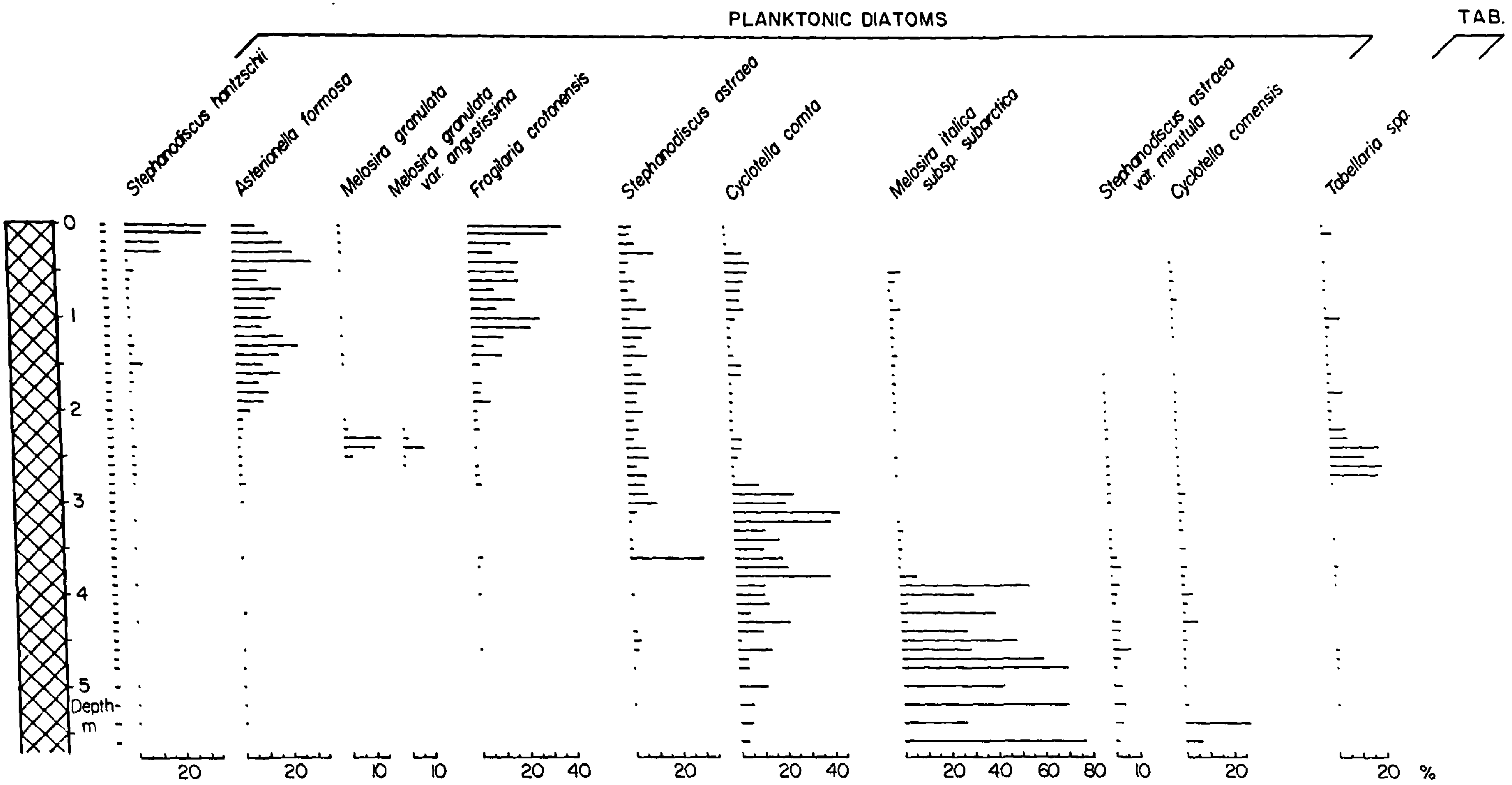
ROSTHERNE MERE, Extension core, planktonic (—) with *Tabellaria spp.* and other occasionally planktonic (···) diatoms a). numbers per cubic millimetre of wet sediment vs. depth in metres
b). numbers accumulating per square metre per annum vs. depth
c). volume in cubic millimetres accumulating per square metre per annum.

Fig. 25



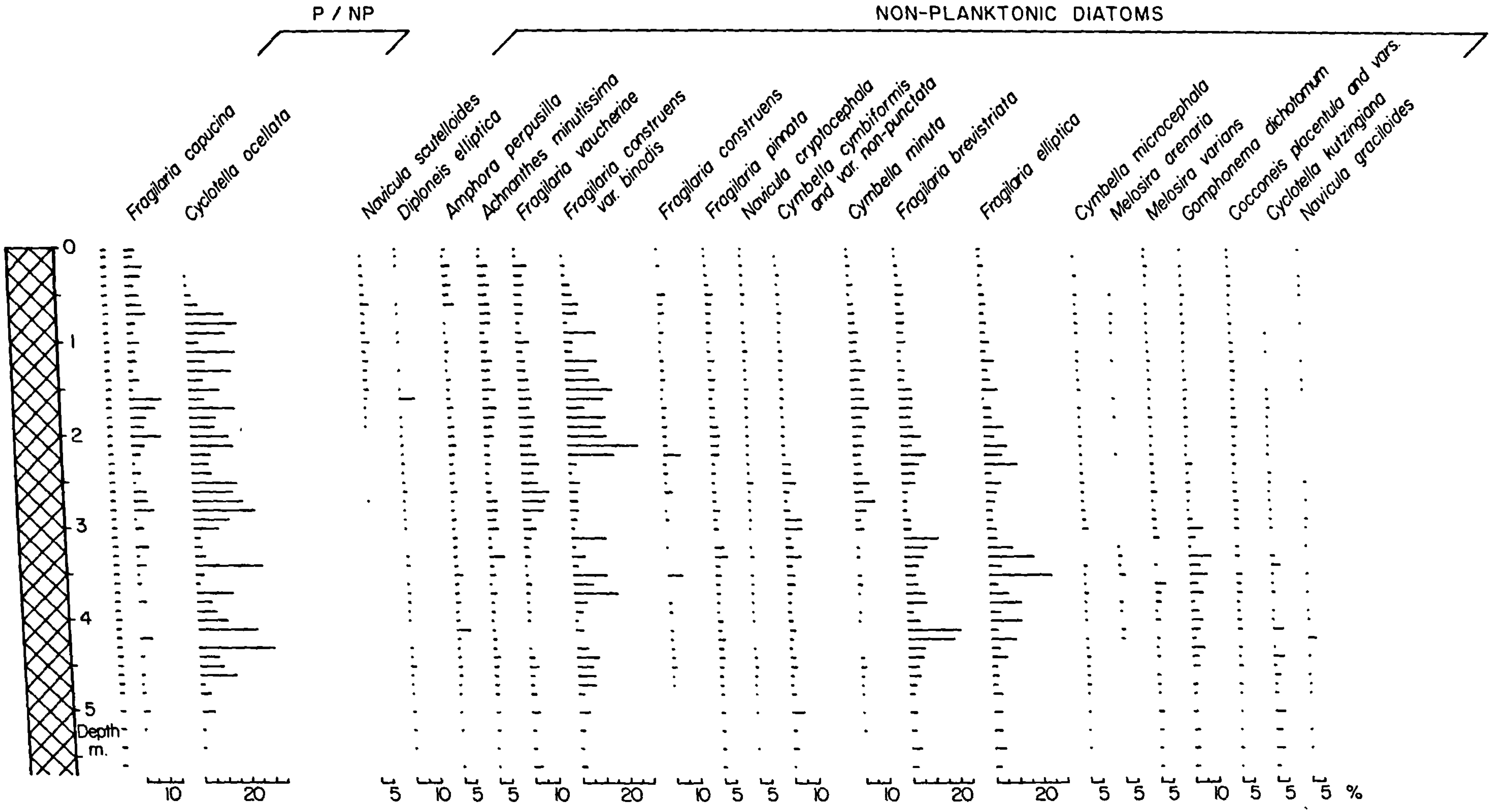
ROSTHERNE MERE, Extension core, diatom diagram, planktonic and occasionally planktonic (P/NP) diatoms and *Tabellaria spp.* (TAB) as volume, in cubic millimetres, accumulating per square metre per annum vs. depth in metres.

Fig. 26



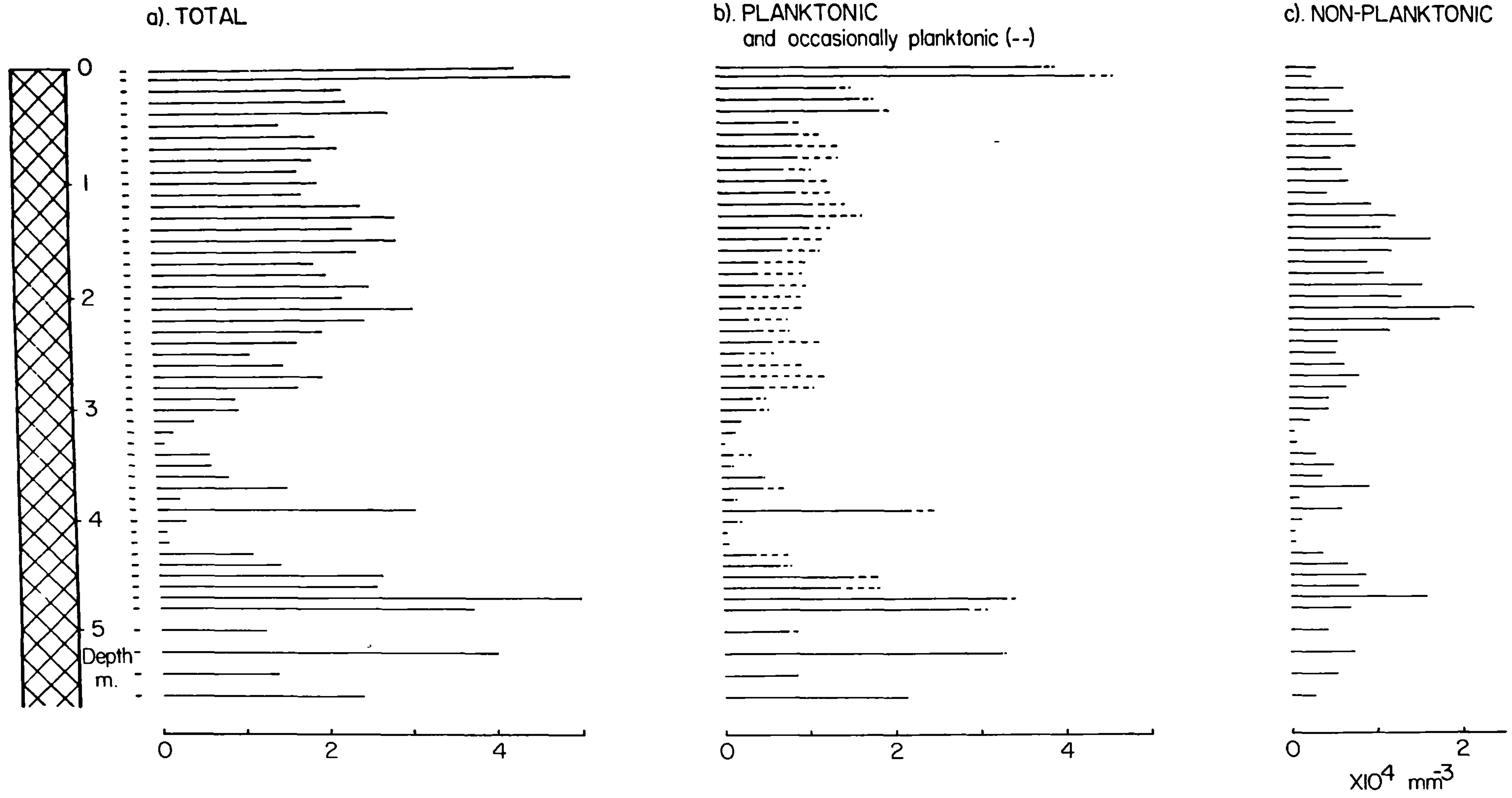
RCSTHERNE MERE, core 5, diatom diagram showing planktonic diatoms and *Tabellaria spp.* (TAB.) as a percentage of diatom total vs. depth in metres.

Fig. 27



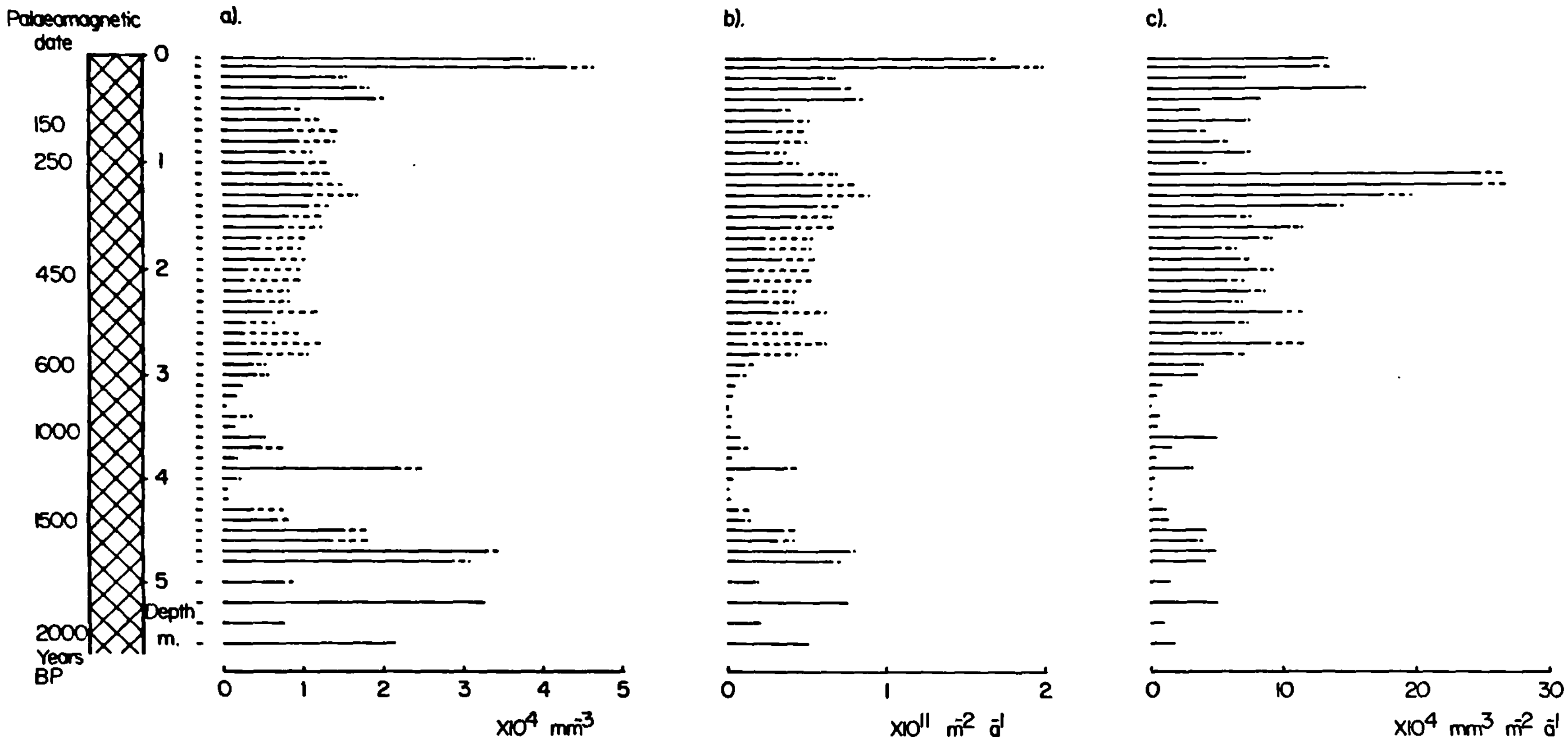
ROSTHERNE MERE, core 5, diatom diagram, occasionally planktonic (P/NP) and non-planktonic diatoms as a percentage of total diatoms vs. depth in metres.

Fig. 28



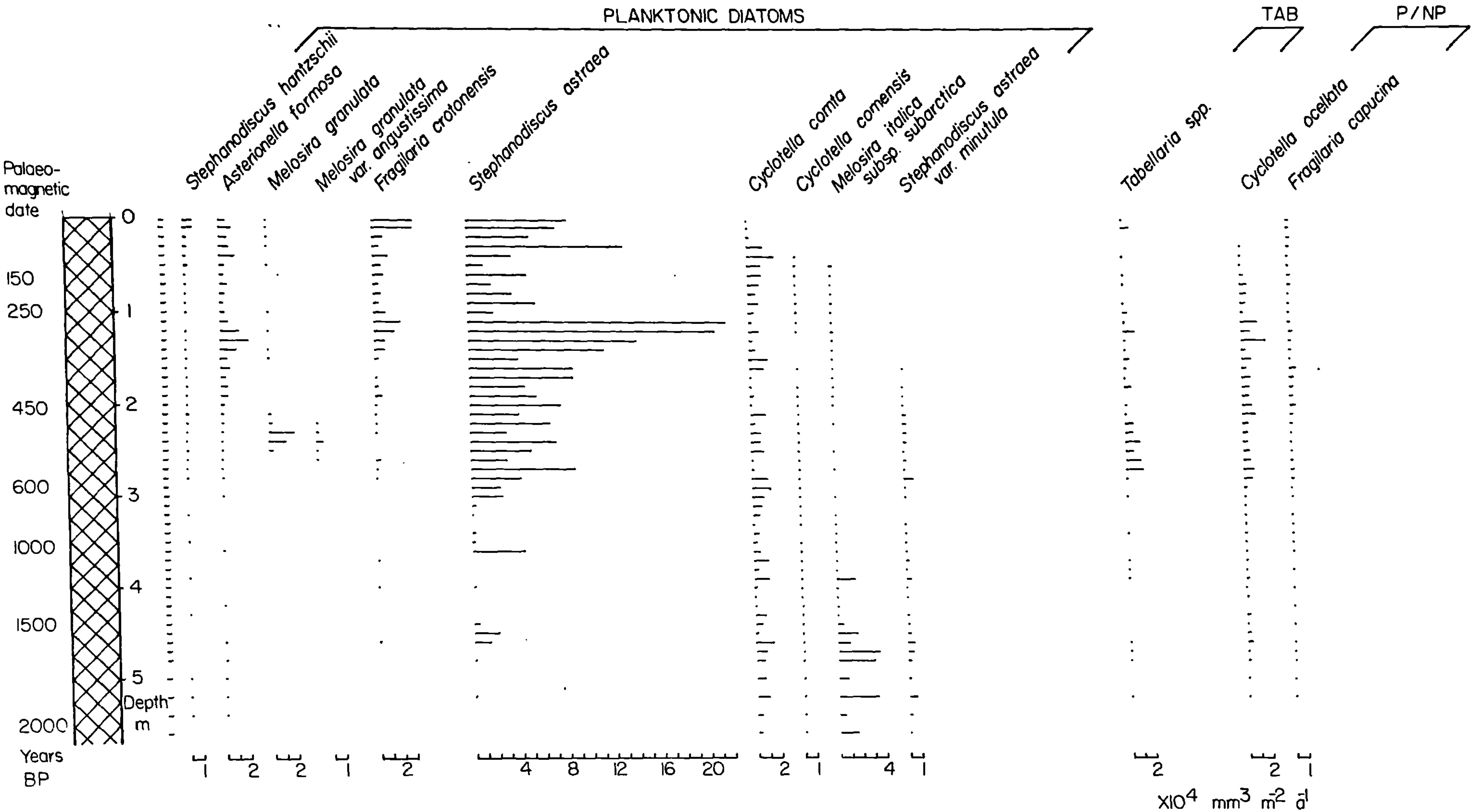
ROSTHERNE MERE, core 5, numbers of diatom cells per cubic millimetre of wet sediment vs. depth in metres.

Fig. 29



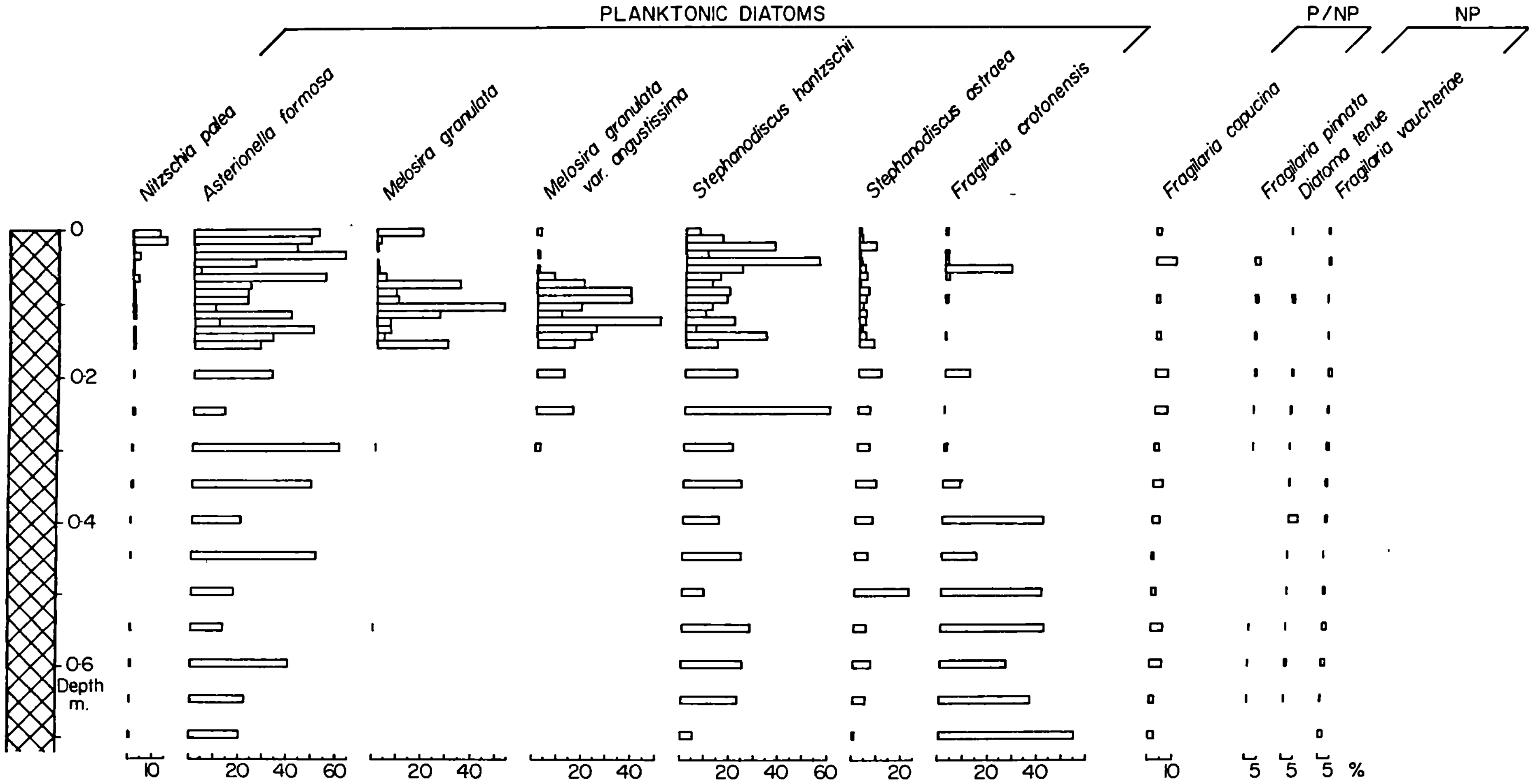
ROSTHERNE MERE, core 5, planktonic (—) with *Tabellaria spp.* and other occasionally planktonic (- -) diatoms, a), numbers per cubic millimetre of wet sediment vs. depth in metres.
b), numbers accumulating per square metre per annum vs. depth in metres.
c), volume in cubic millimetres accumulating per square metre per annum vs. depth.

Fig. 30



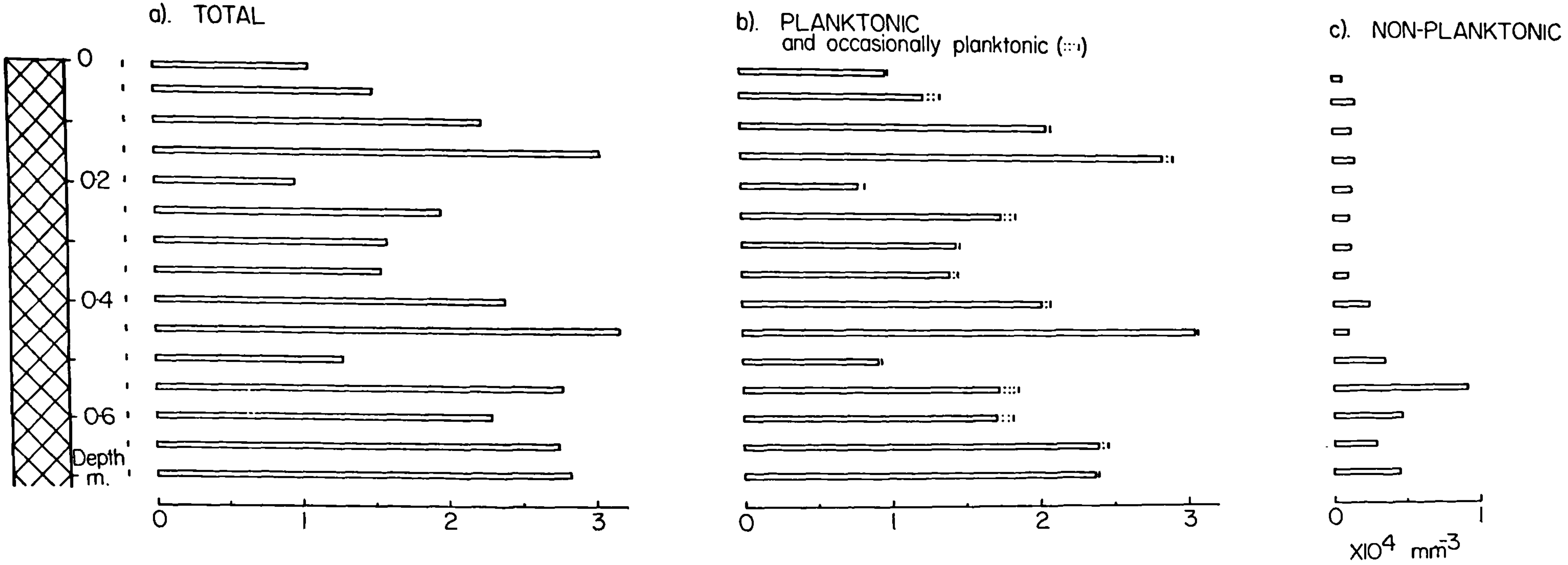
ROSTHERNE MERE, core 5, diatom diagram, planktonic and occasionally planktonic (P/NP) diatoms and *Tabellaria spp.* (TAB) as volume in cubic millimetres accumulating per square metre per annum vs. depth in metres.

Fig. 31



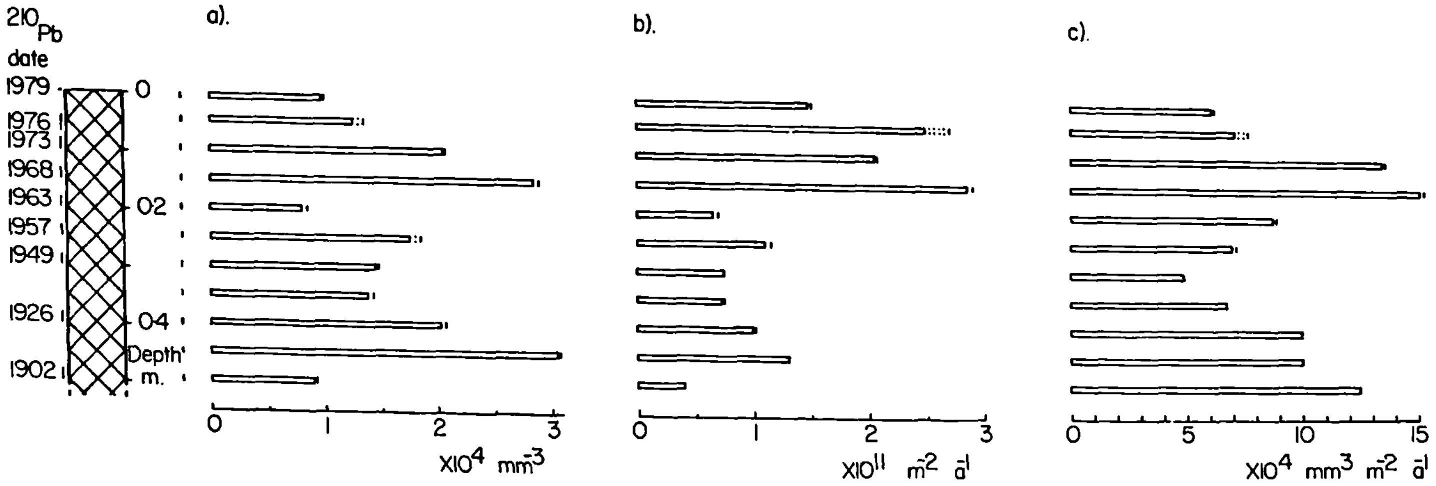
ROSTHERNE MERE, 'Mini'core, diatom diagram showing planktonic, occasionally planktonic (P/NP) and non-planktonic (NP) diatoms as a percentage of diatom sum vs depth in metres P NP and NP not recorded individually for samples 0·01-0·04m, 0·05-0·09m, 0·10-0·14m and 0·15-0·16m.

Fig. 32



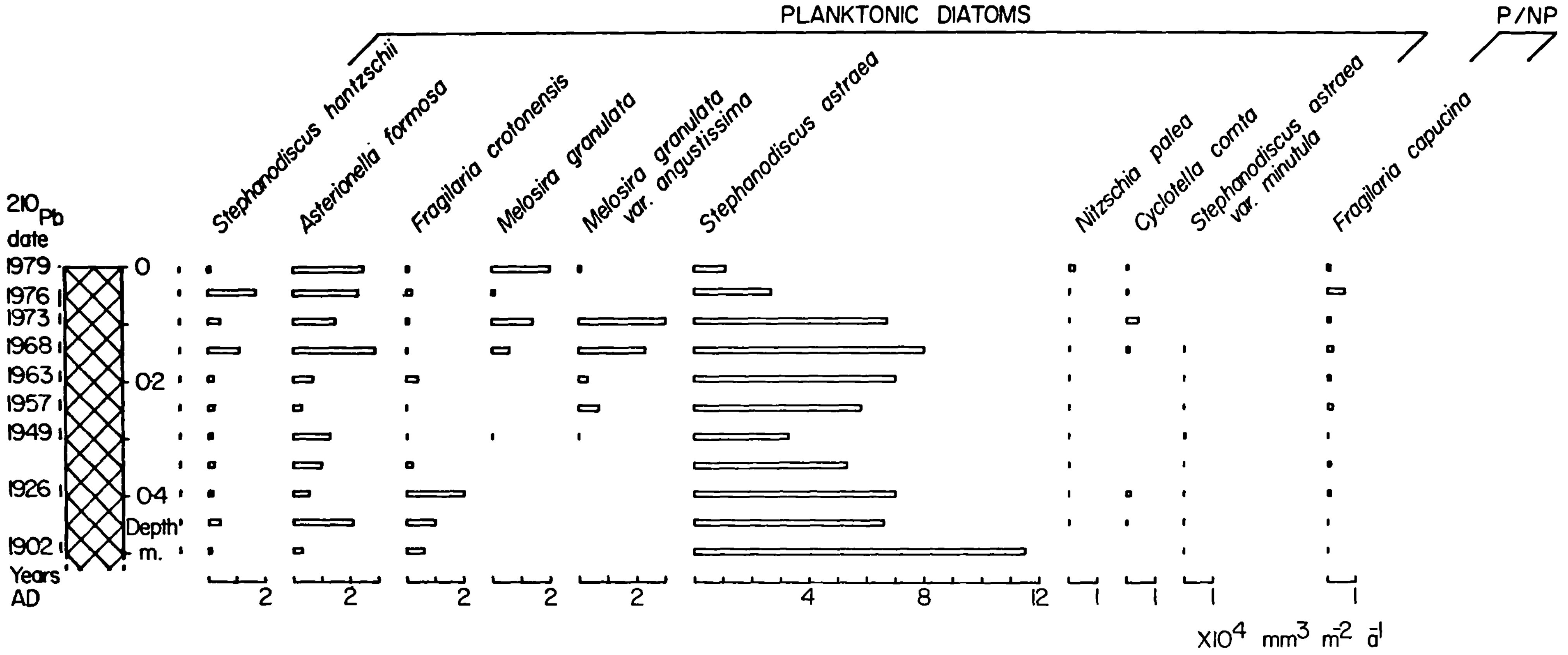
ROSTHERNE MERE, 'Mini' core, numbers of diatoms per cubic millimetre of wet sediment vs. depth in metres.

Fig. 33



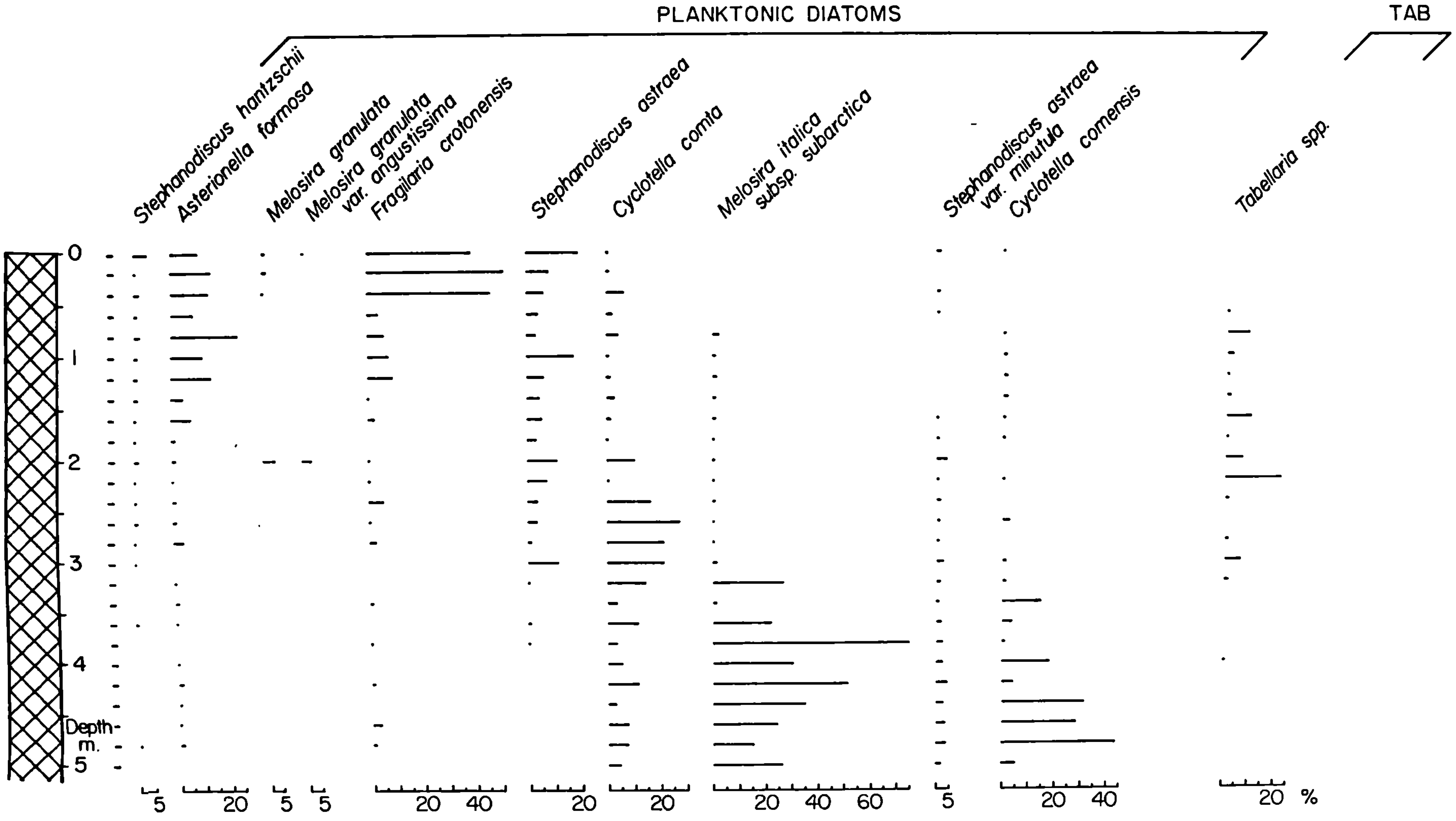
ROSTHERNE MERE, 'Mini'core, planktonic (=) with *Tabellaria spp.* and other occasionally planktonic (: :) diatoms a), numbers per cubic millimetre of wet sediment vs. depth in metres.
b), numbers accumulating per square metre per annum vs. depth.
c), volume in cubic millimetres accumulating per square metre per annum.

Fig. 34



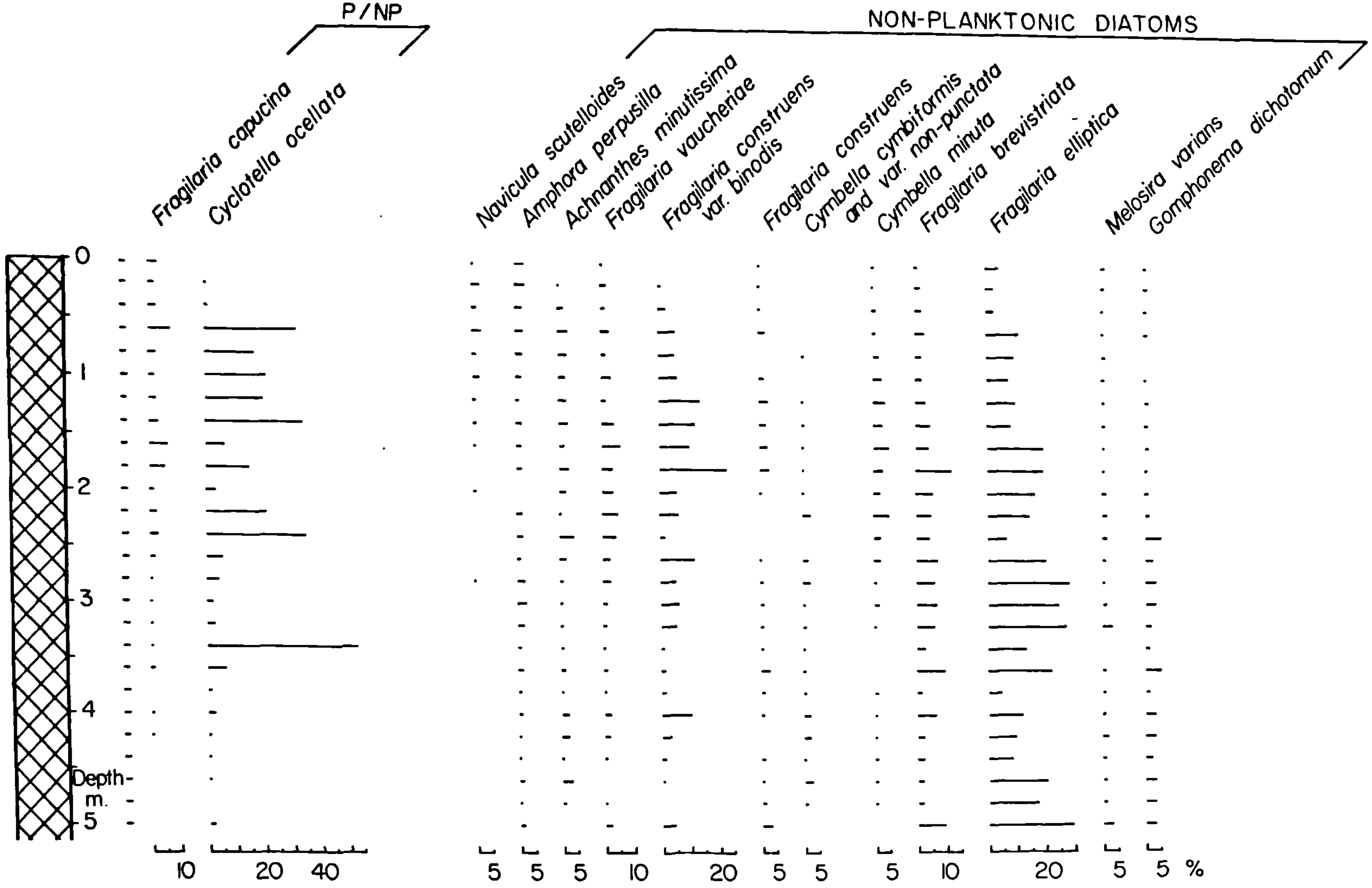
ROSTHERNE MERE, 'Mini' core, diatom diagram showing volume, in cubic millimetres, of planktonic and occasionally planktonic (P/NP) diatoms accumulating per square metre per annum. vs. depth in metres.

Fig. 35



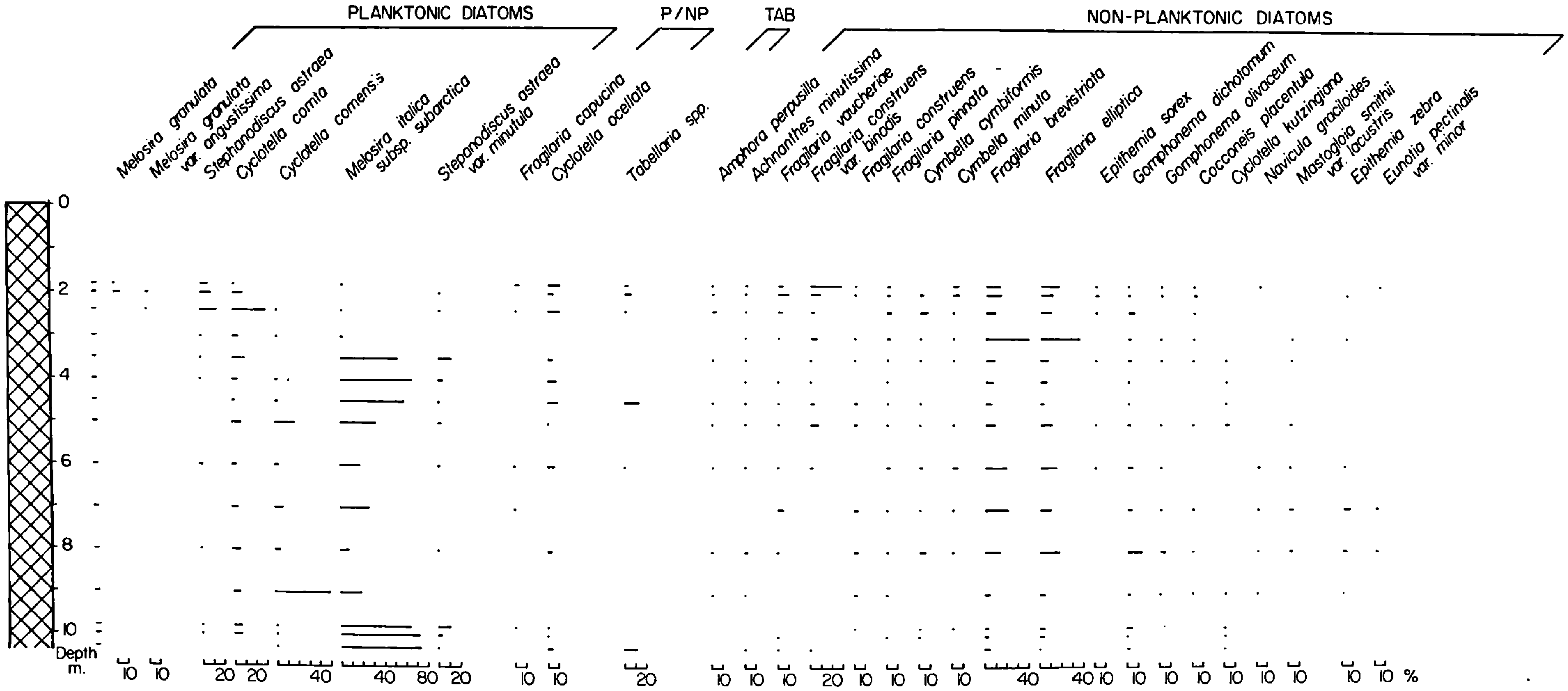
ROSTHERNE MERE, core 3, diatom diagram, planktonic diatoms and *Tabellaria spp.* (TAB.) as a percentage of diatom sum vs. depth in metres.

Fig. 36



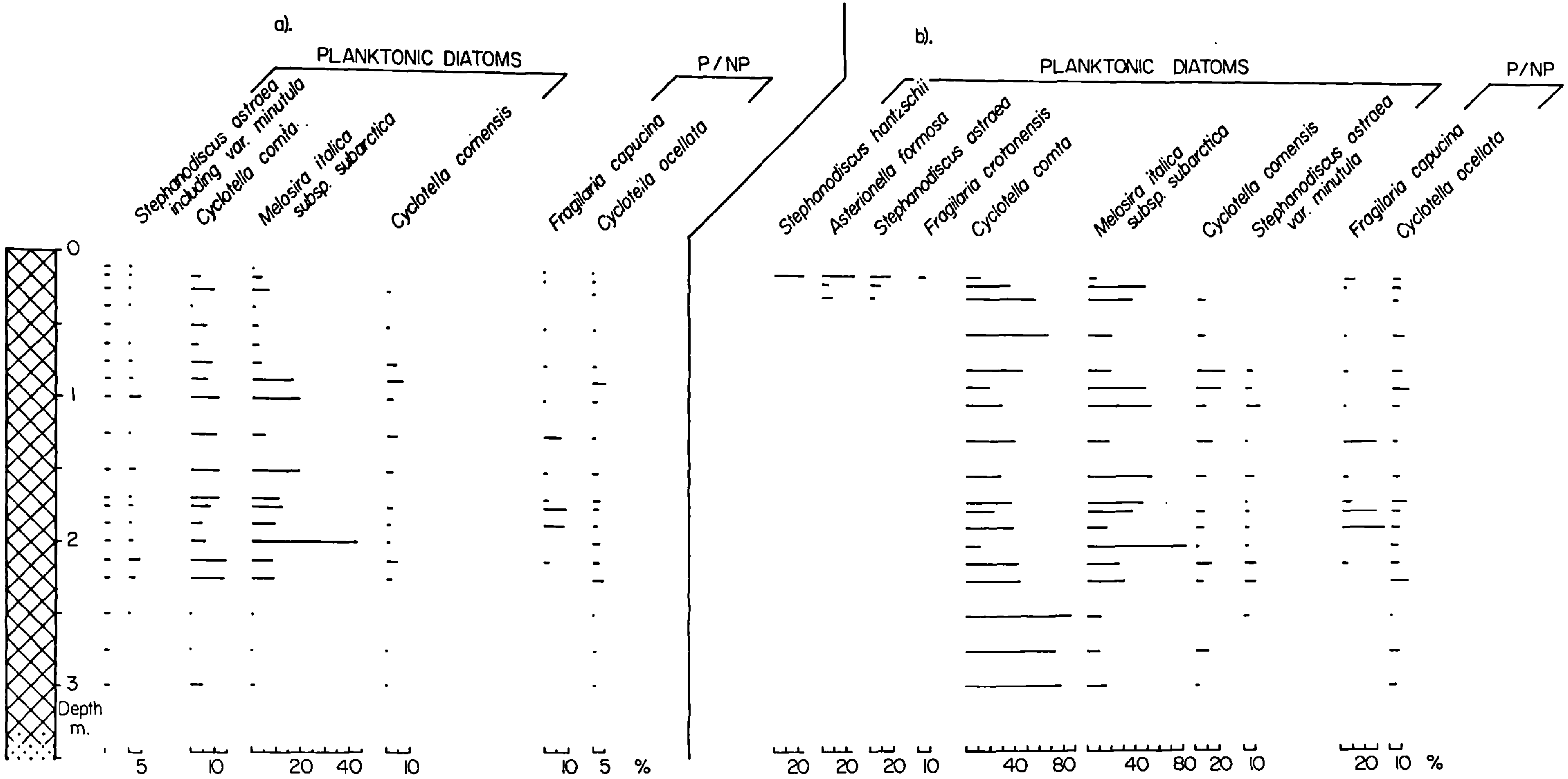
ROSTHERNE MERE, core 3, diatom diagram, occasionally planktonic (P/NP) and non-planktonic diatoms as a percentage of diatom sum vs. depth in metres

Fig. 37



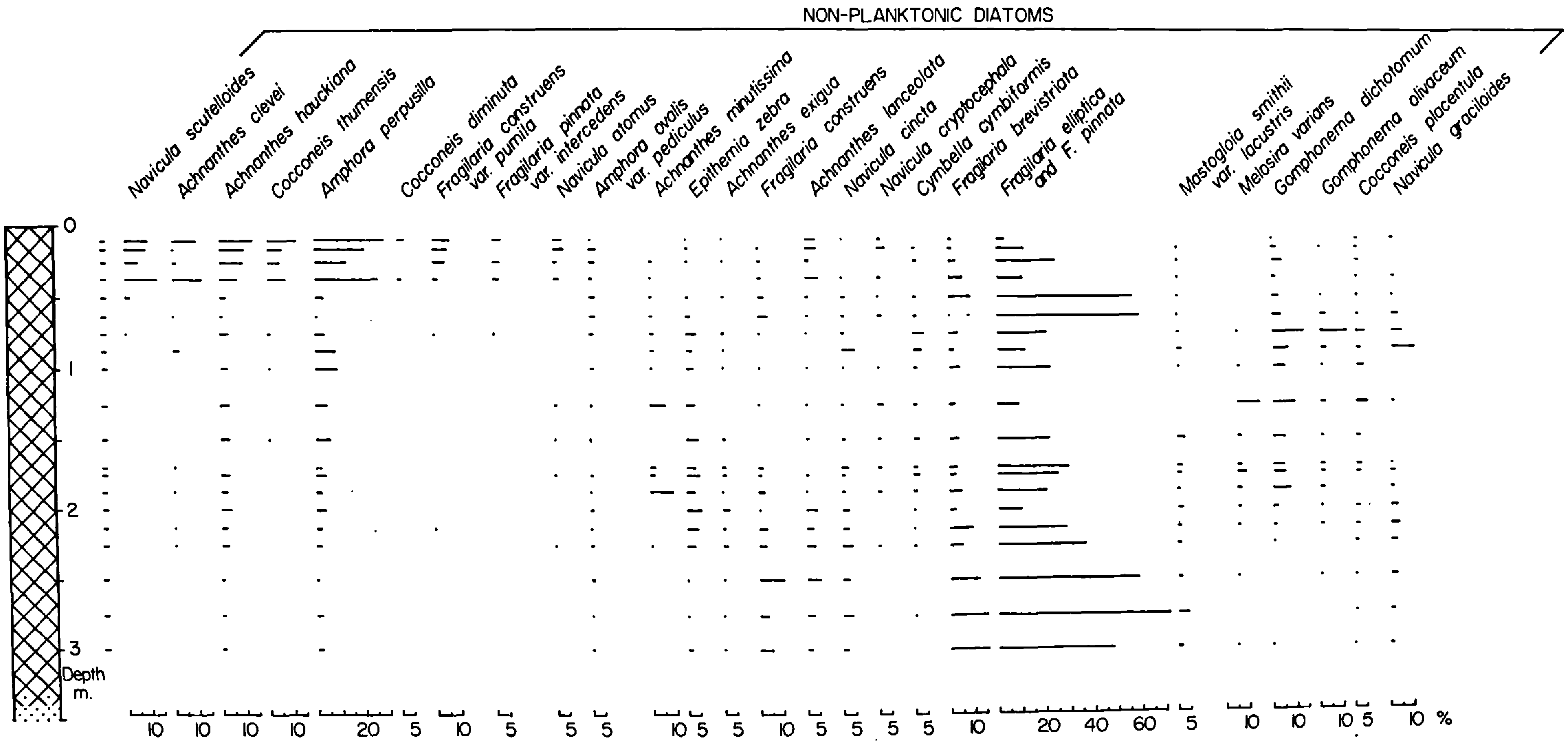
ROSTHERNE MERE, core 10·5, diatom diagram showing diatoms as a percentage of diatom sum vs. depth in metres.

Fig. 38



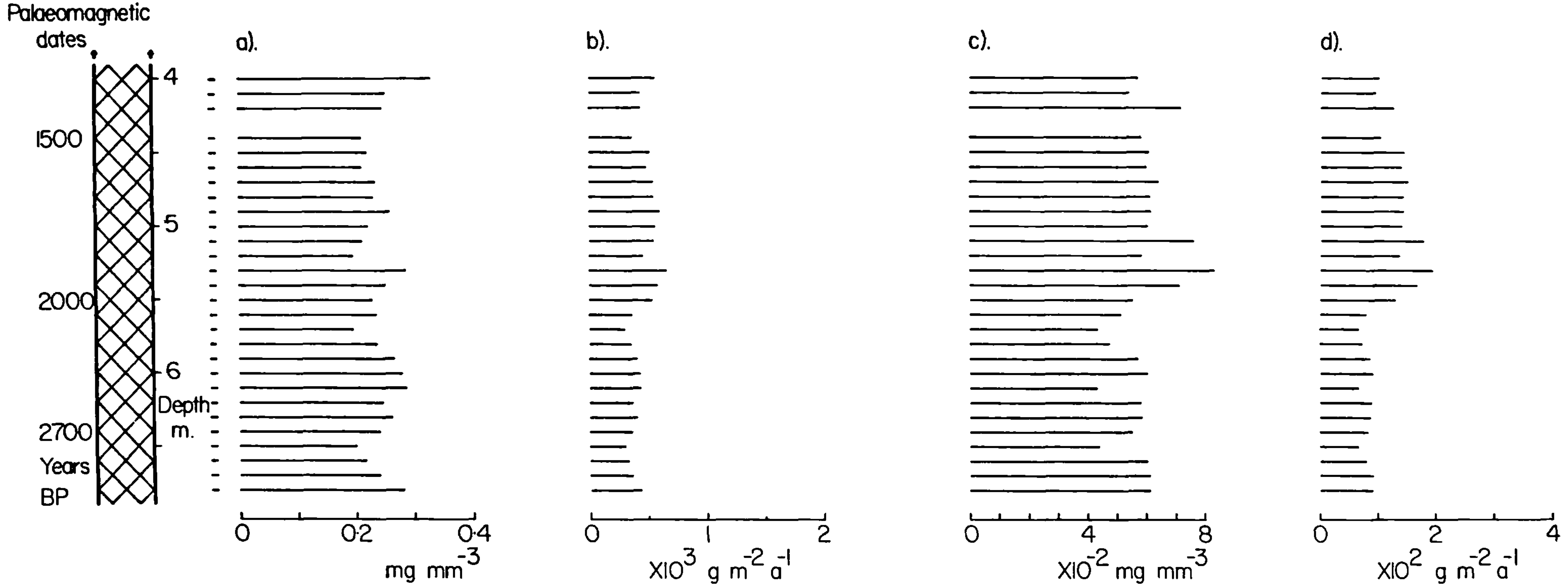
ROSTHERNE MERE, Russian core G, diatom diagram, planktonic and occasionally planktonic (P/NP) diatoms a), as percentage of diatom sum vs. depth in metres.
b), as percentage of planktonic and occasionally planktonic diatom sum vs. depth in metres.

Fig. 39



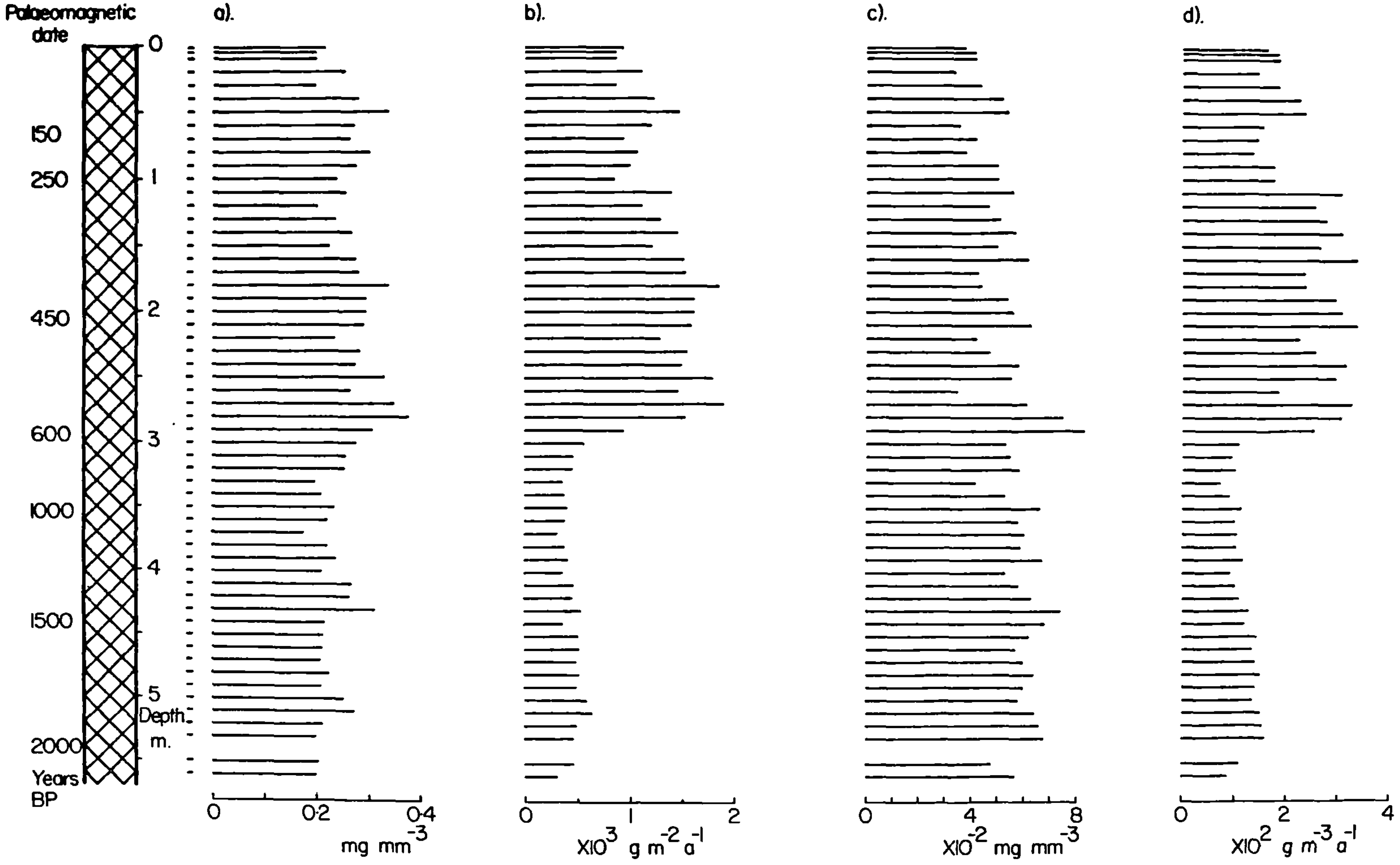
ROSTHERNE MERE, Russian core G, diatom diagram showing non-planktonic diatoms as a percentage of diatom sum vs. depth in metres

Fig. 40



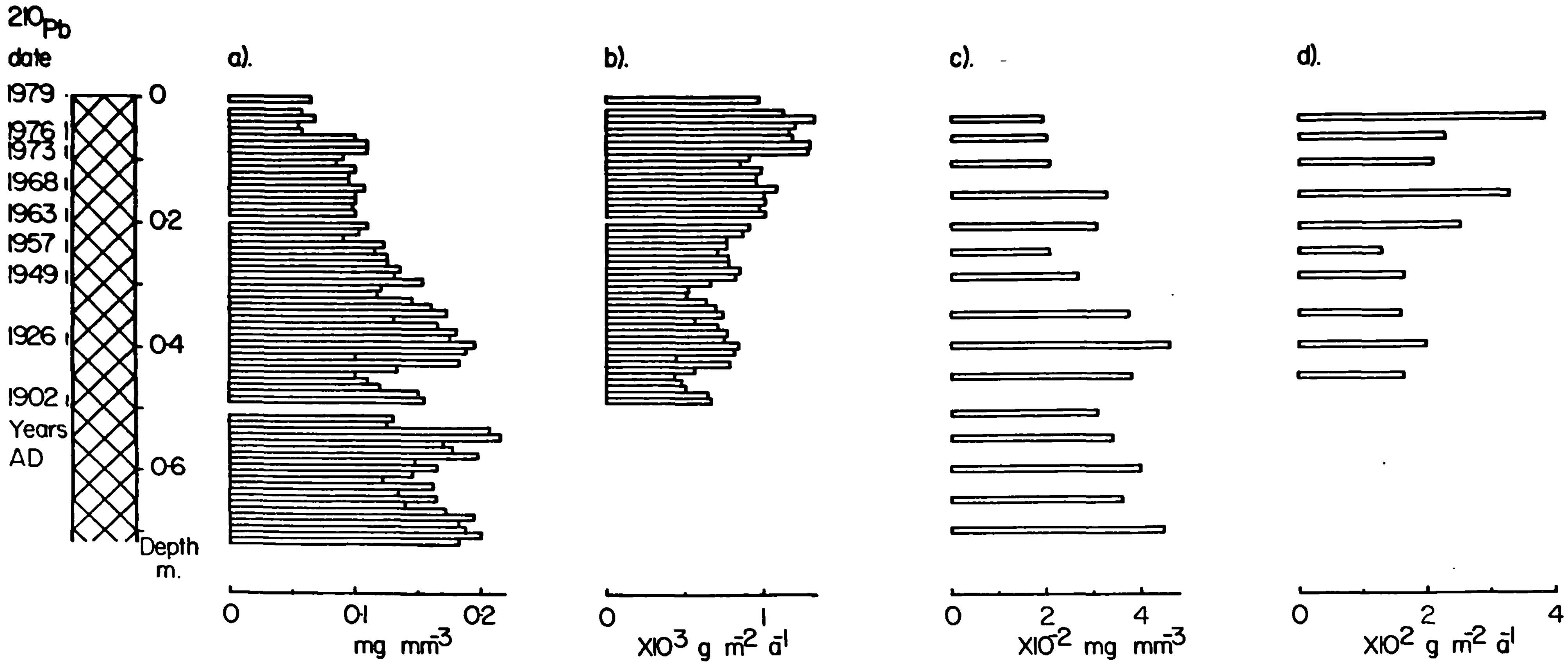
ROSTHERNE MERE, Extension core, a), dry mass in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), dry mass in grams accumulating per square metre per annum vs. depth in metres.
c), mass lost on ignition at 450 °C in milligrams per cubic millimetre of wet sediment vs. depth in metres.
d), mass lost on ignition at 450 °C in grams accumulating per square metre per annum vs. depth in metres.

Fig. 41



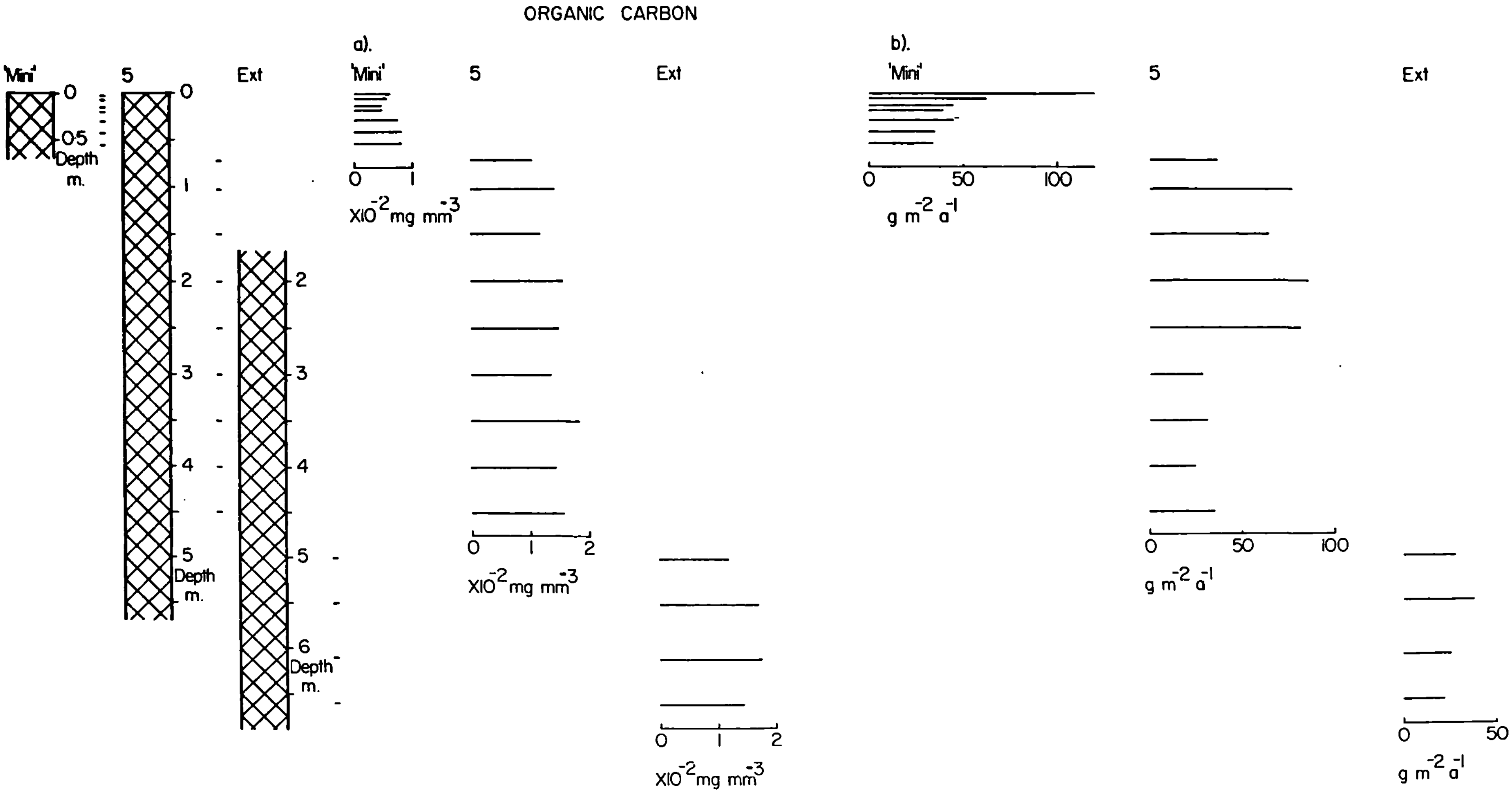
ROSTHERNE MERE, core 5, a), dry mass in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), dry mass in grams accumulating per square metre per annum vs. depth in metres.
c), mass lost on ignition at 450 °C in milligrams per cubic millimetre of wet sediment vs. depth in metres
d), mass lost on ignition at 450 °C in grams accumulating per square metre per annum vs. depth in metres.

Fig. 42



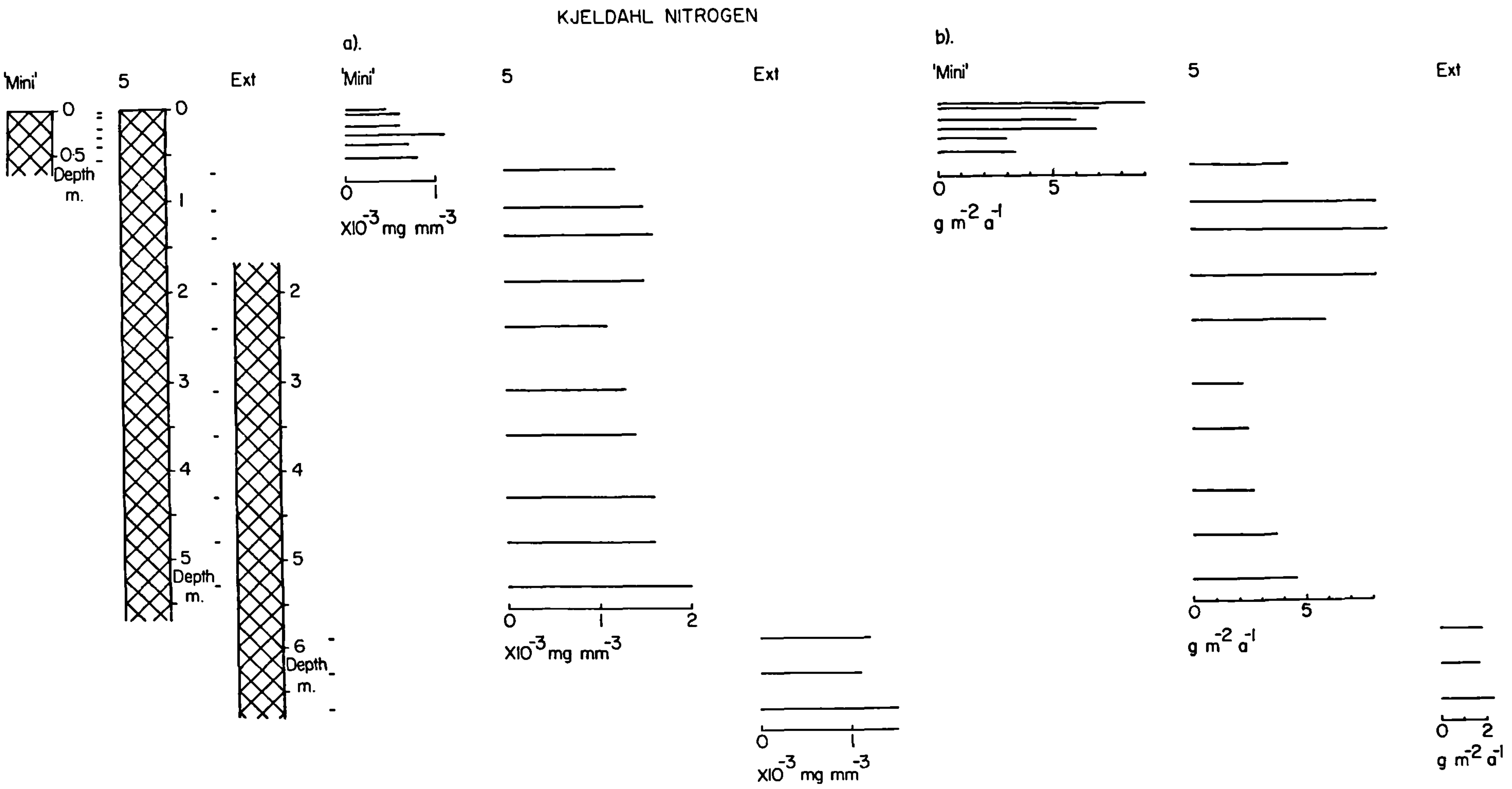
ROSTHERNE MERE, 'Mini'core, a), dry mass in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), dry mass in grams accumulating per square metre per annum vs. depth in metres.
c), mass lost on ignition at 450°C in milligrams per cubic millimetre of wet sediment vs. depth in metres.
d), mass lost on ignition at 450°C in grams accumulating per square metre per annum vs. depth in metres.

Fig. 43



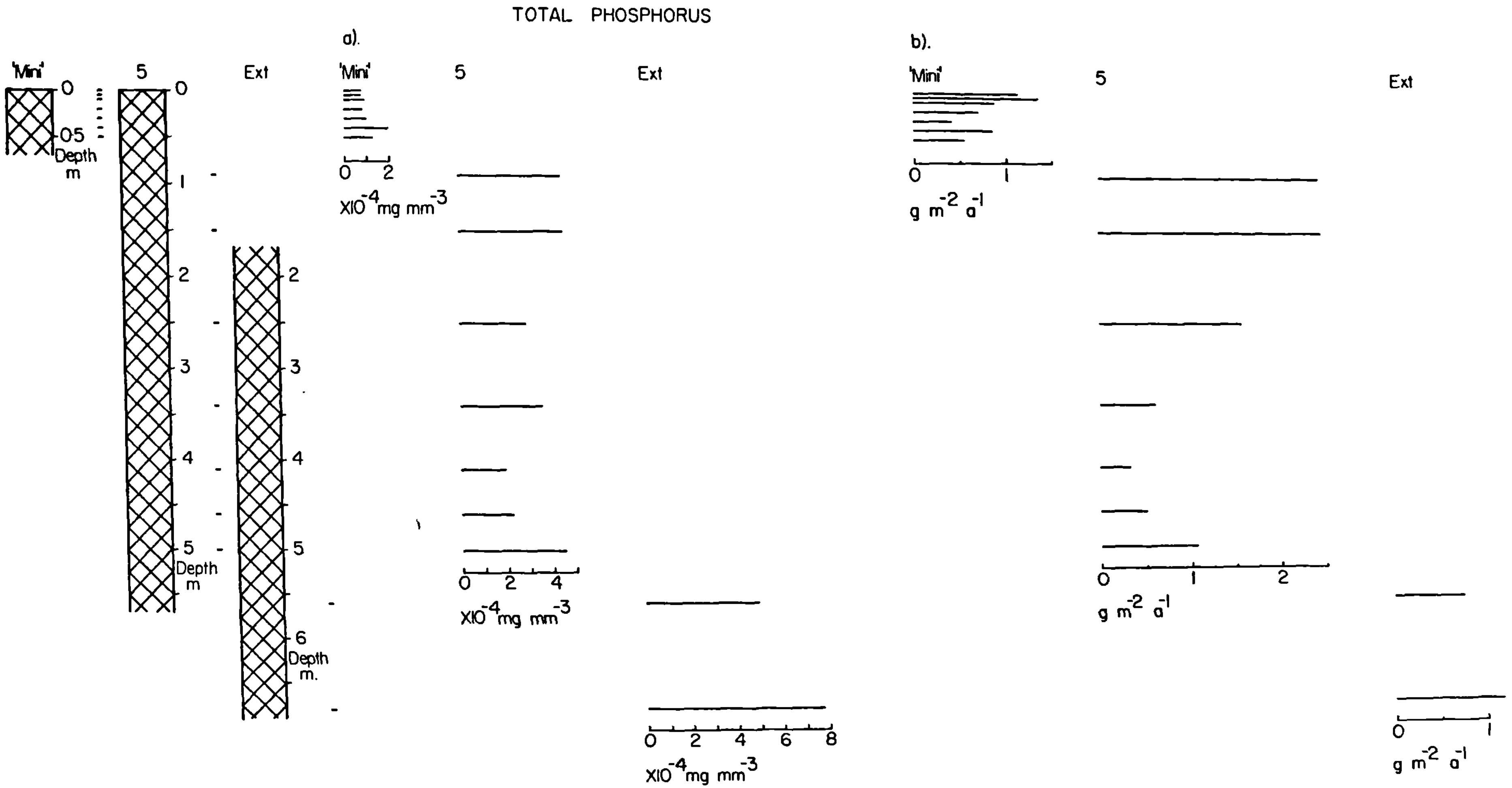
ROSTHERNE MERE, 'Mini', 5 and Extension cores, a), CARBON in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), CARBON in grams accumulating per square metre per annum vs. depth in metres

Fig. 44



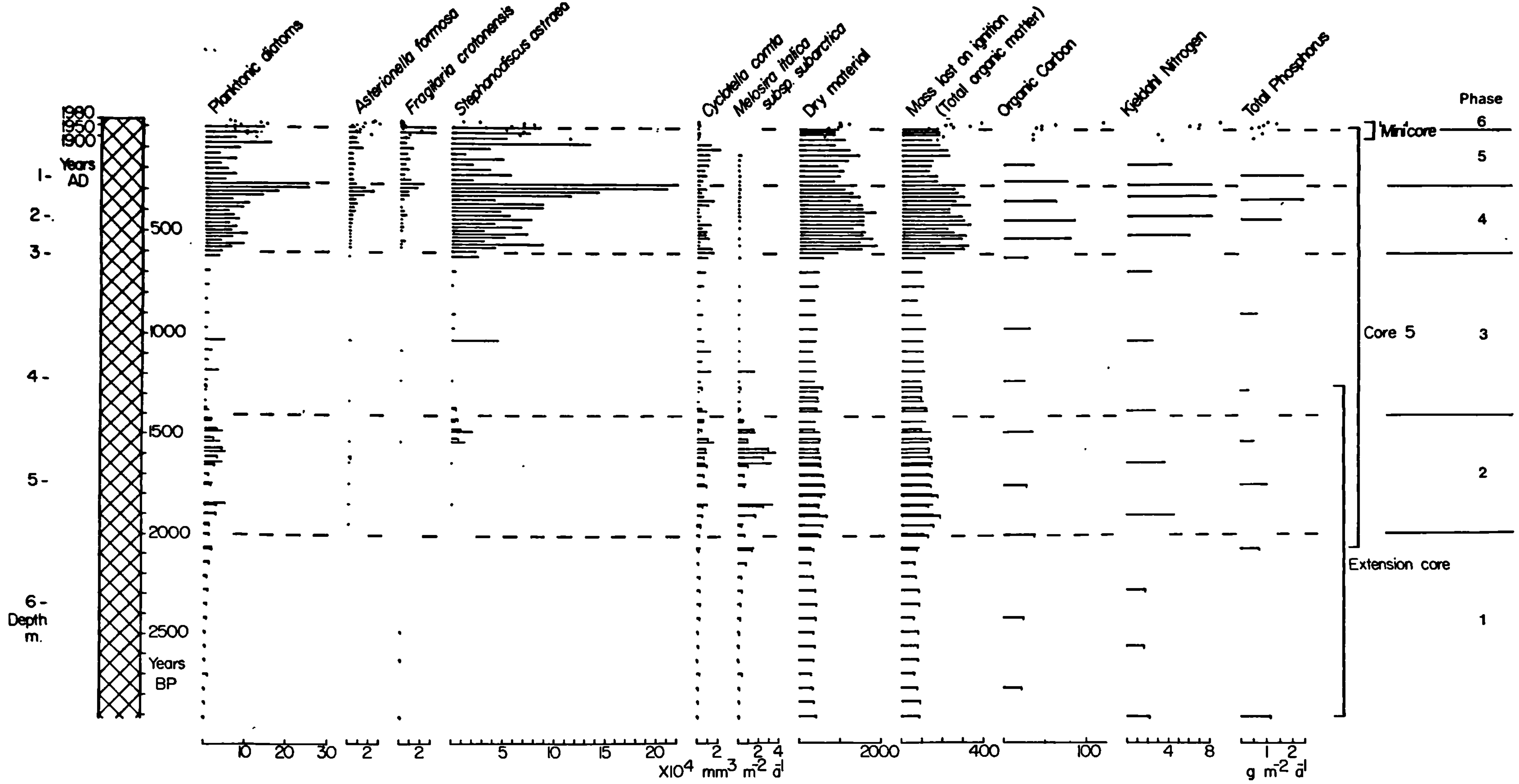
ROSTHERNE MERE, 'Mini', 5 and Extension cores a), NITROGEN in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), NITROGEN in grams accumulating per square metre per annum vs. depth in metres.

Fig. 45



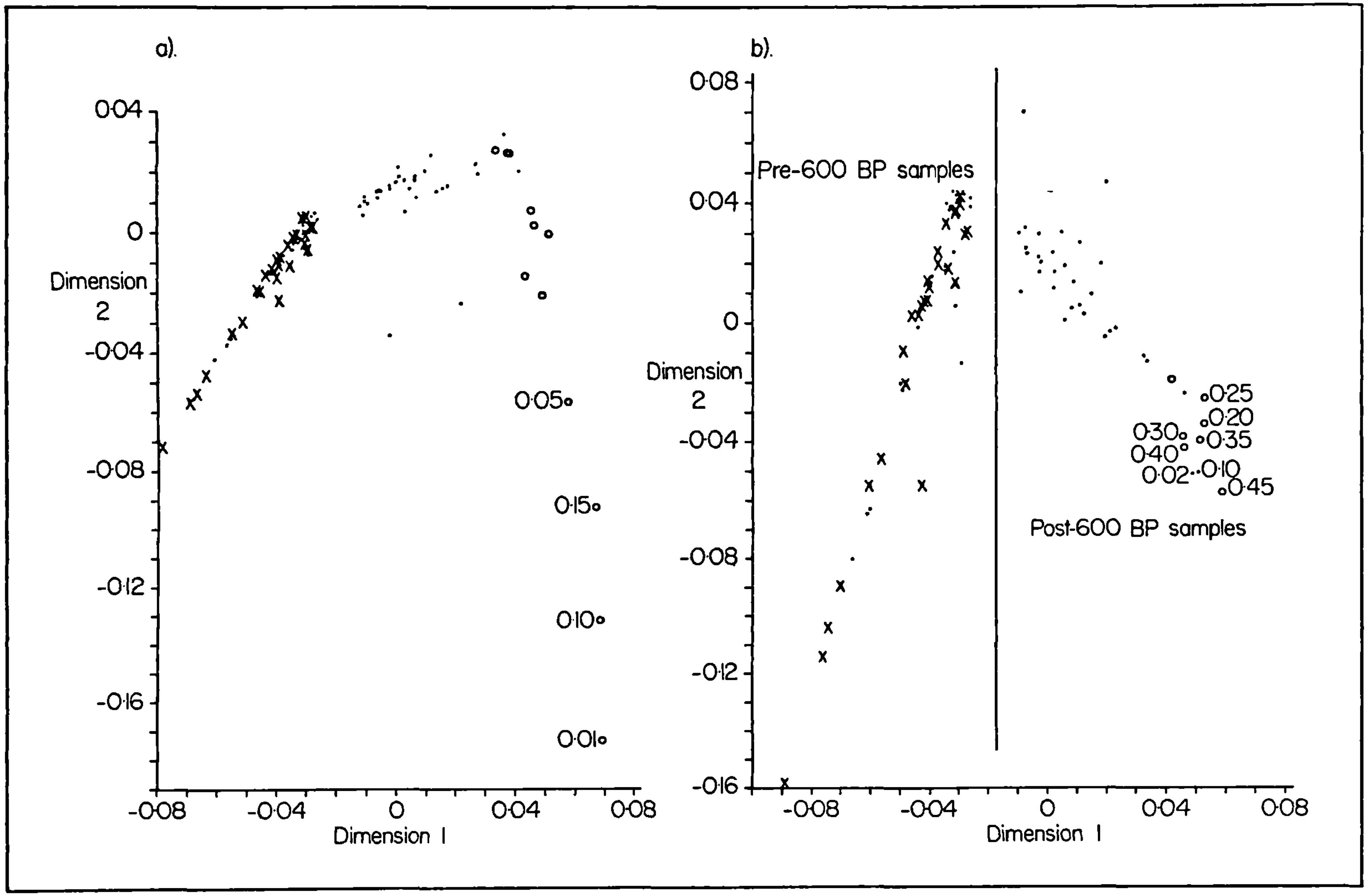
ROSTHERNE MERE, 'Mini', 5 and Extension cores, a), PHOSPHORUS in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), PHOSPHORUS in grams accumulating per square metre per annum vs. depth in metres.

Fig. 46



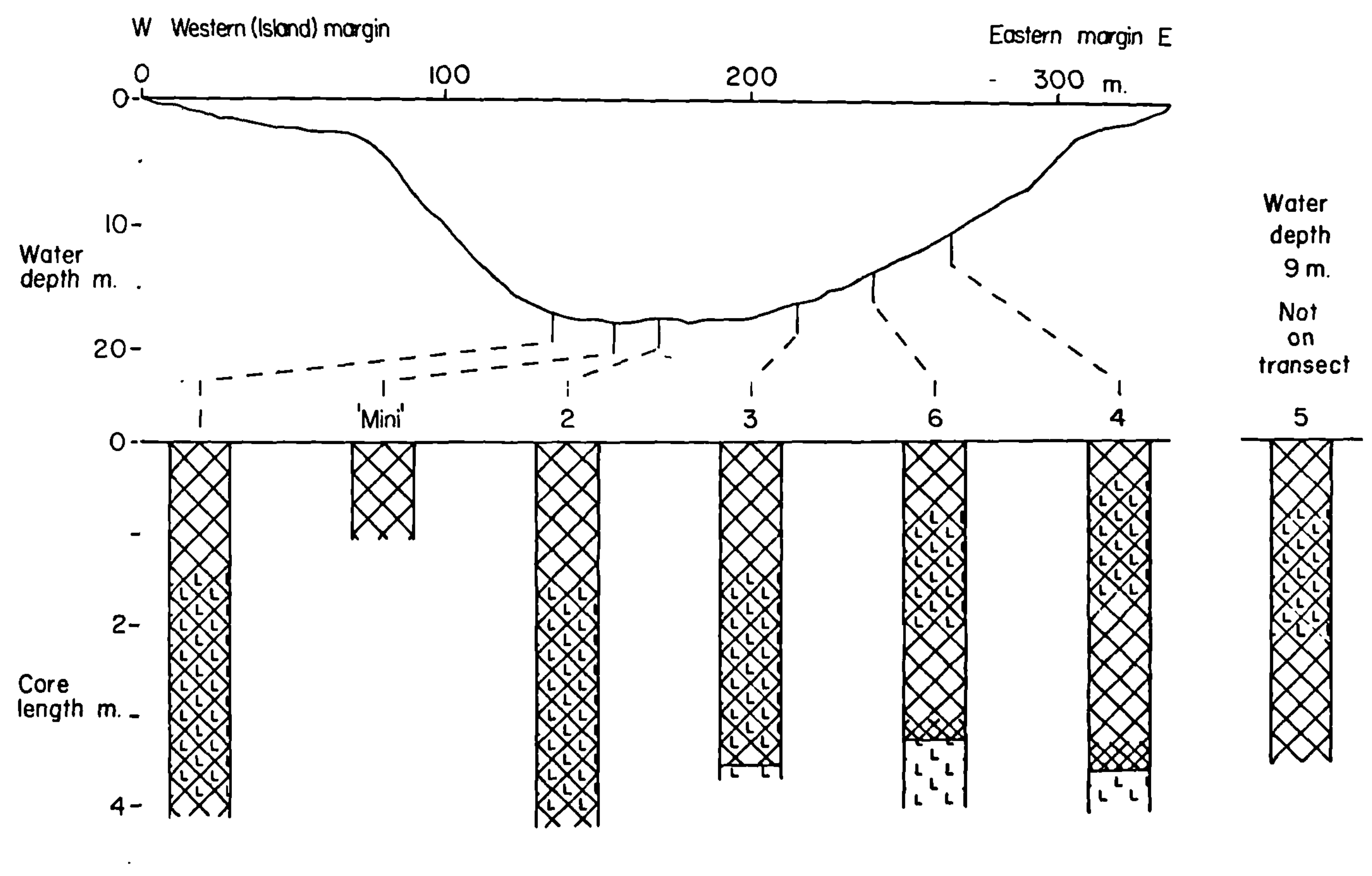
ROSTHERNE MERE, 'Mini'core (·), core 5 (–) and Extension core (⌐), selected diatom and other accumulation rates vs. time.

Fig. 47



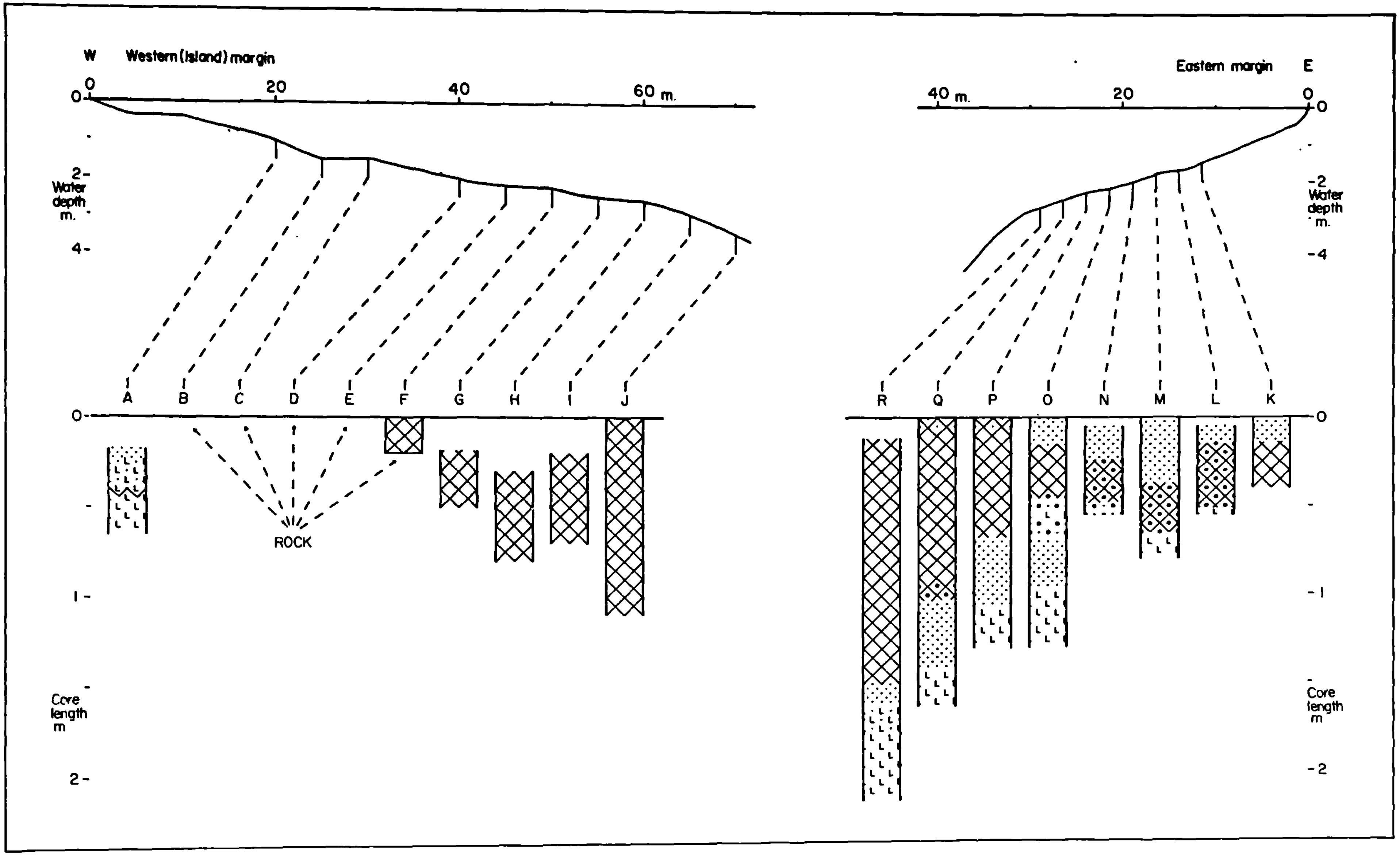
ROSTHERNE MERE, Correspondence analysis of diatom accumulation rate data for 'Mini'core (∘), core 5 (·) and Extension core (x), sample depths in metres.
a), all samples, showing unusual character of 'Mini'core samples 0·01-0·15.
b), all samples except 'Mini'core 0·01-0·15, showing resemblance of core 5 samples 0·02 and 0·10 to 'Mini'core samples 0·35-0·45, and distinct division, along Dimension I, between samples younger than, and older than 600 years BP.

Fig. 48



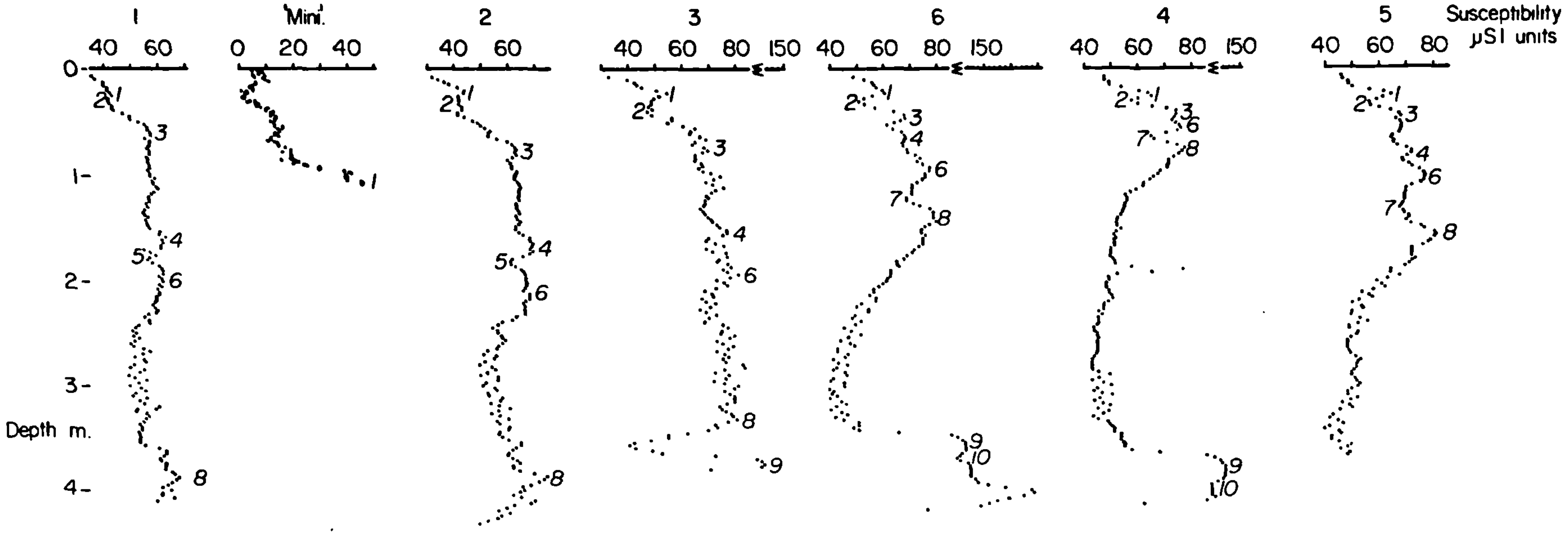
ELLESMERE, water depth, stratigraphy and position of Mackereth cores along transect W-E, and from core site 5.

Fig. 49



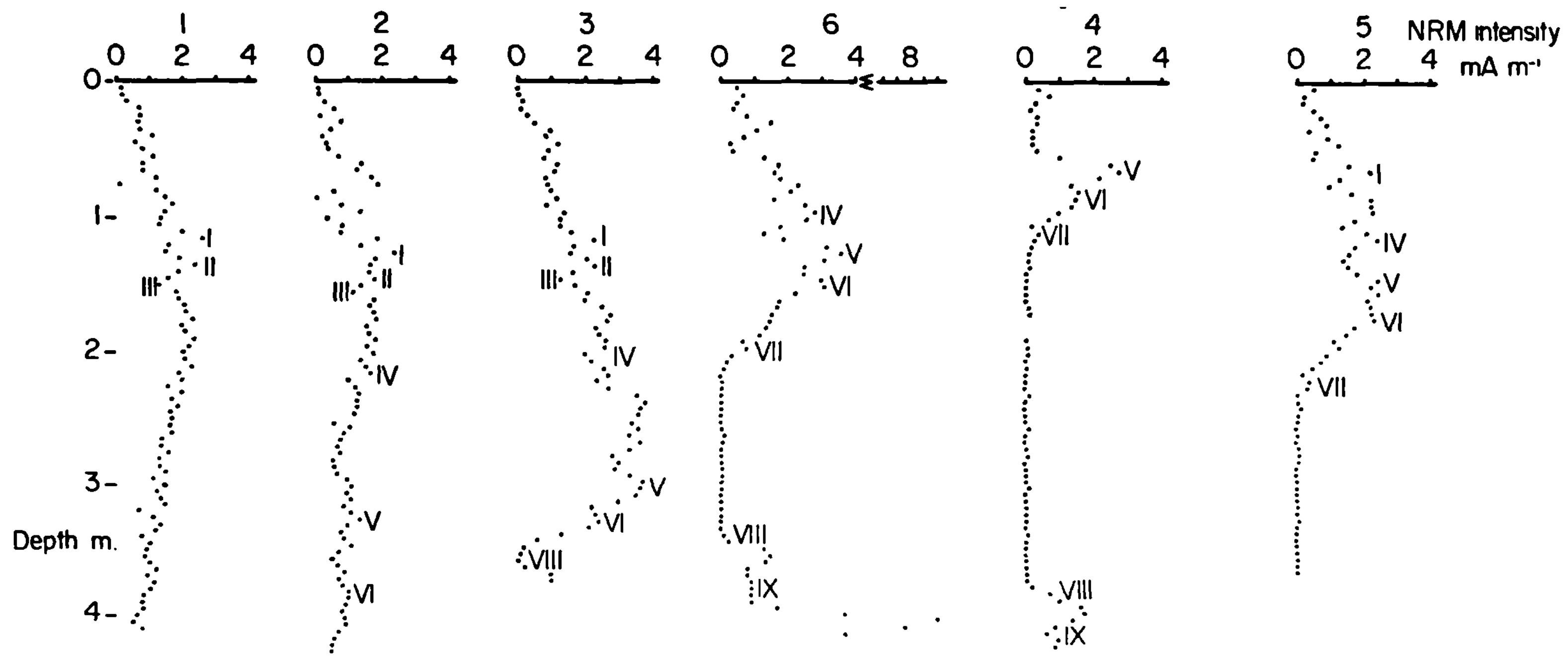
ELLESMERE, water depth, stratigraphy and position of Russian cores taken near to the ends of transect W-E.

Fig. 50



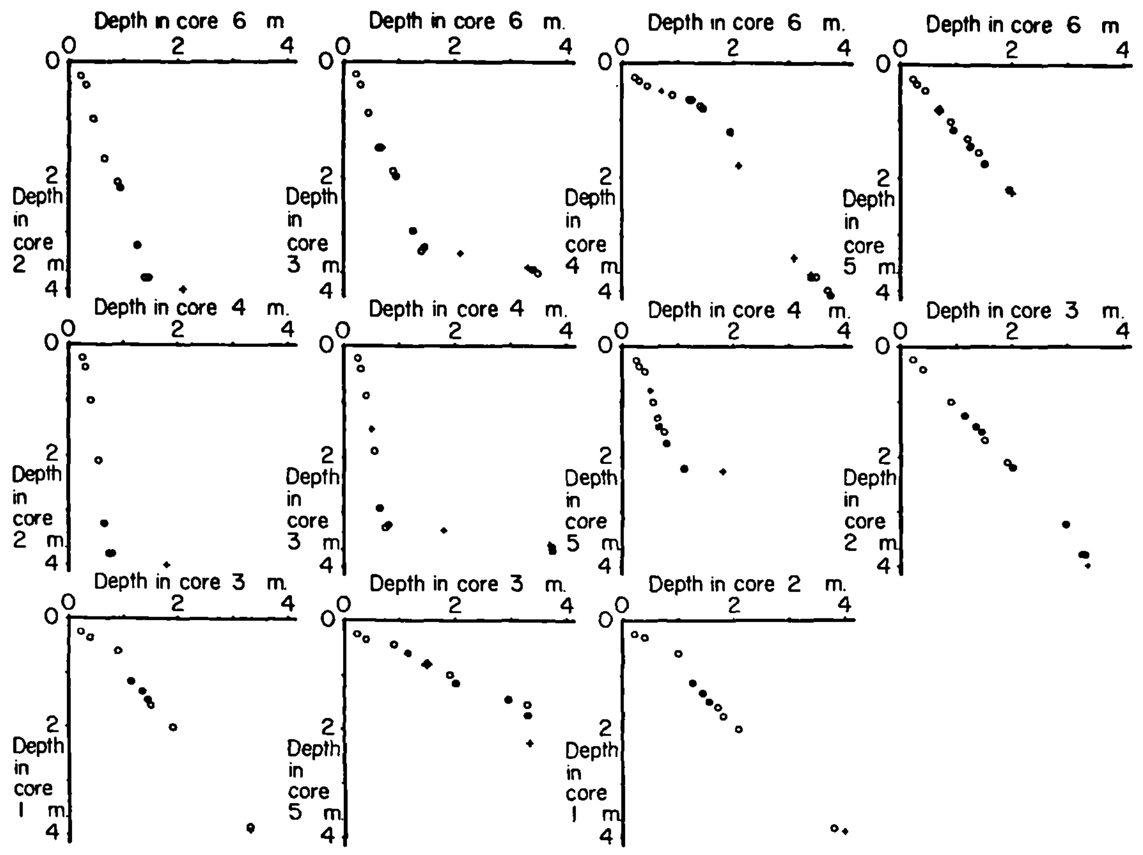
ELLESMERE, whole core (cores 1 - 6) and single sample ('Mini') susceptibility in μSI units vs. depth in metres in Mackereth cores, numerals *1* to *10* denote possible correlations

Fig. 51



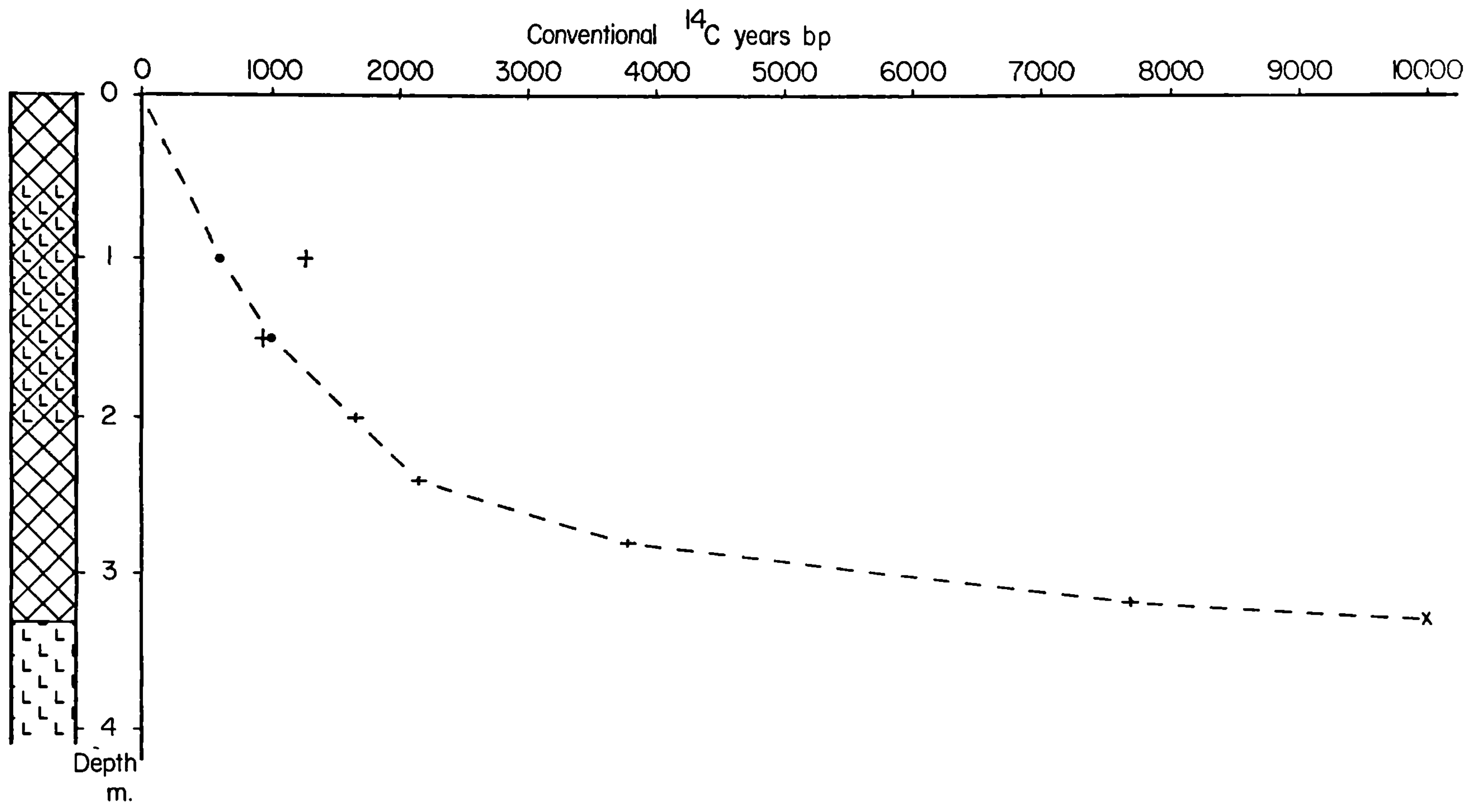
ELLESMERE, whole core intensity of natural remanent magnetization (NRM intensity) in mA m^{-1} vs. depth in metres in Mackereth cores 1 to 6, Roman numerals I to IX denote possible correlations.

Fig. 52



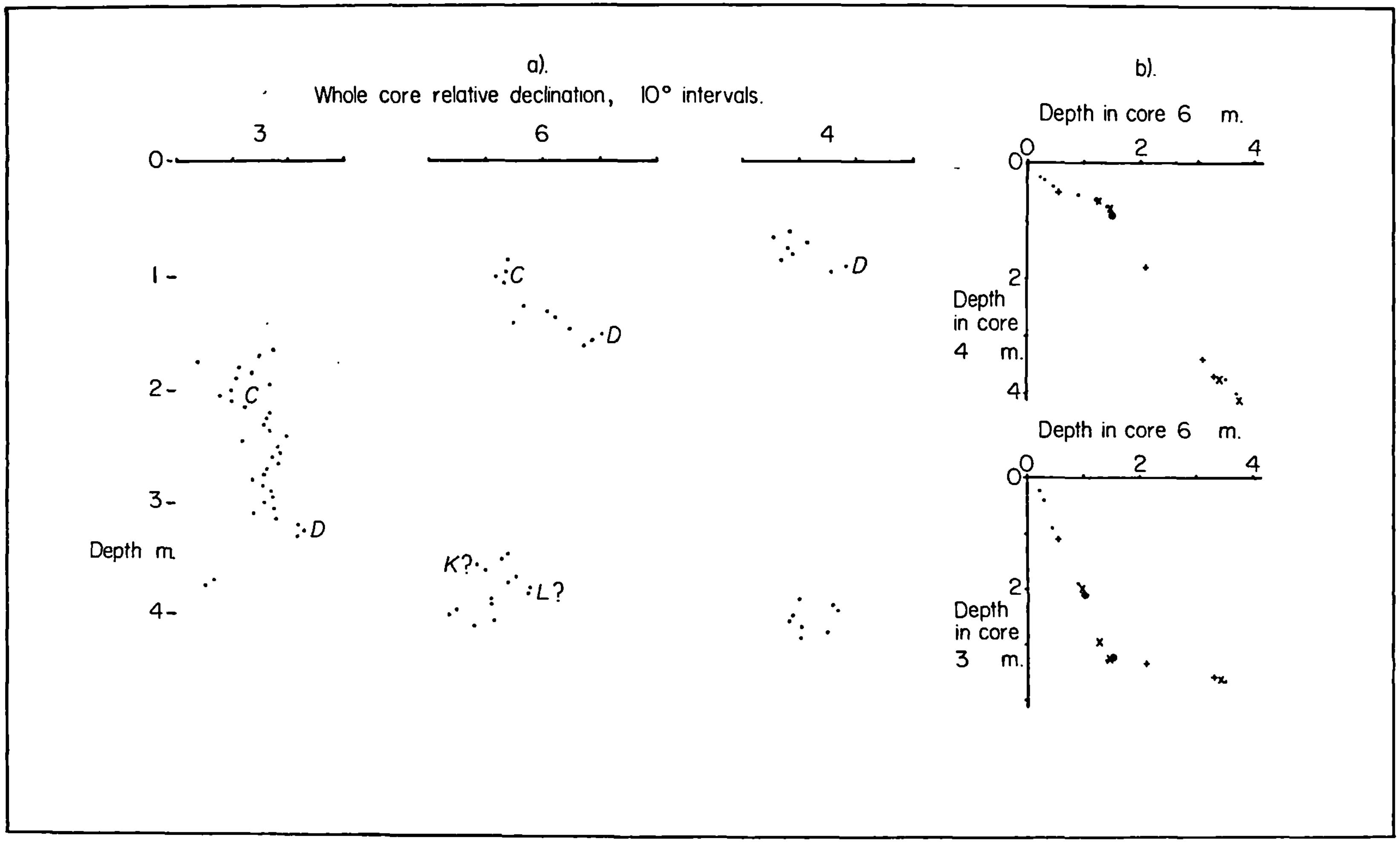
ELLESMERE, comparison of depth in metres of independant correlations derived from susceptibility (○), NRM intensity (●) and stratigraphy (+) in cores 6 vs. 2, 6 vs. 3, 6 vs. 4, 6 vs. 5, 4 vs. 2, 4 vs. 3, 4 vs. 5, 3 vs. 2, 3 vs. 1, 3 vs. 5 and 2 vs. 1.

Fig. 53



ELLESMERE, ^{14}C age in years bp vs. depth in metres in core 6, the ^{14}C (+), palaeomagnetic (•) and stratigraphic/palynological/palaeomagnetic (x) dates have been used to construct an age vs. depth curve (- -)

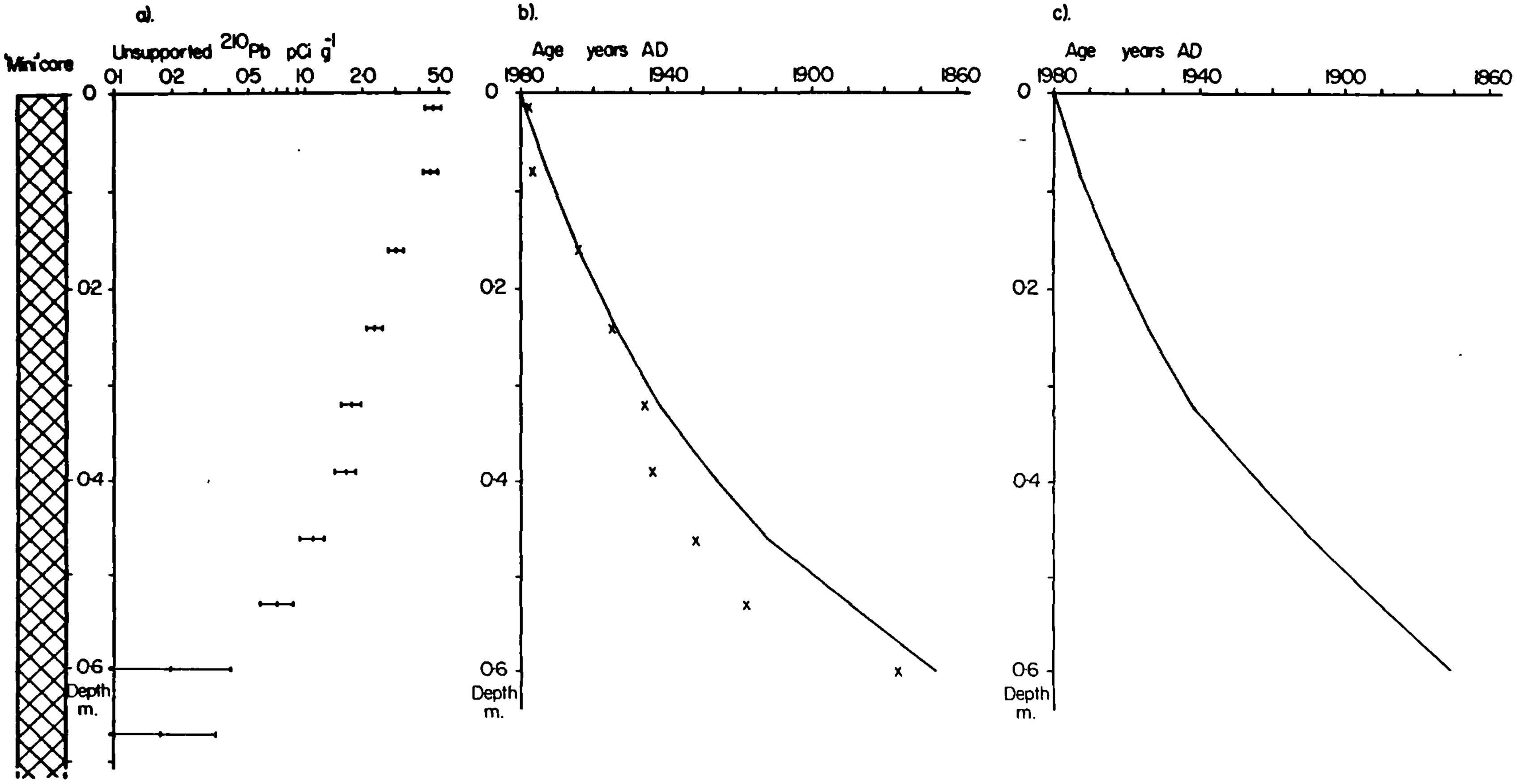
Fig. 54



a). ELLESMERE, whole core relative declination, 10° intervals vs. depth in metres in cores 3, 6 and 4, letters *C,D,K?* and *L?* denote possible palaeomagnetic declination features.

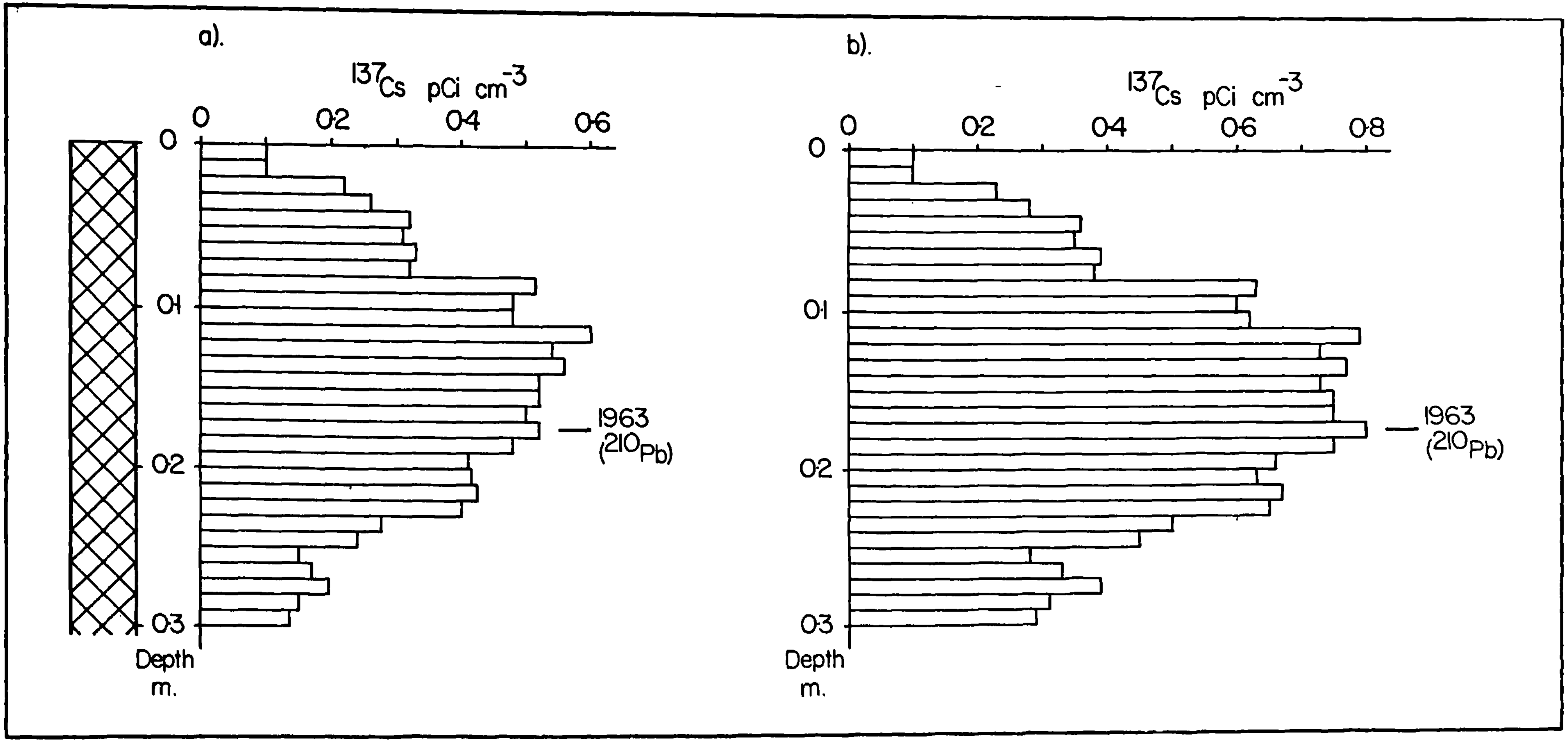
b). ELLESMERE, comparison of depth in metres of independant correlations derived from susceptibility (·), NRM intensity (x) and stratigraphy (+) with depth in metres of declination features (•) .in cores 6 vs. 4 and 6 vs. 3.

Fig. 55



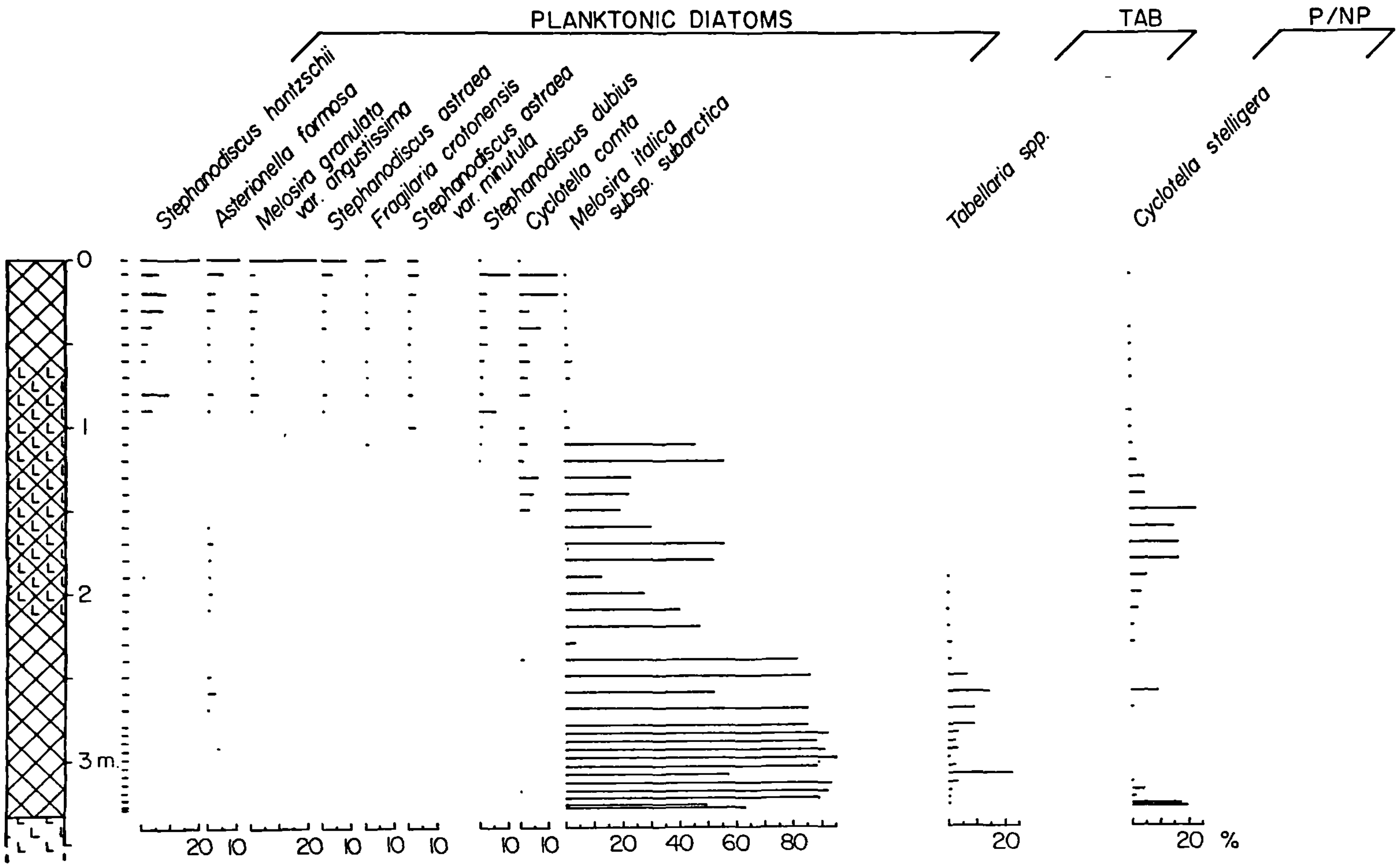
ELLESMERE, a), unsupported ^{210}Pb, showing 95 % counting error limits, in picoCuries per gram of dry sediment, vs. depth in metres.
b), age in years AD, calculated using the 'constant initial concentration' method (x), and 'constant rate of supply' method (~), vs. depth in metres.
c), age in years AD, using 'constant rate of supply' method where models are in agreement, and interpolation where agreement is weaker, vs. depth in metres

Fig. 56



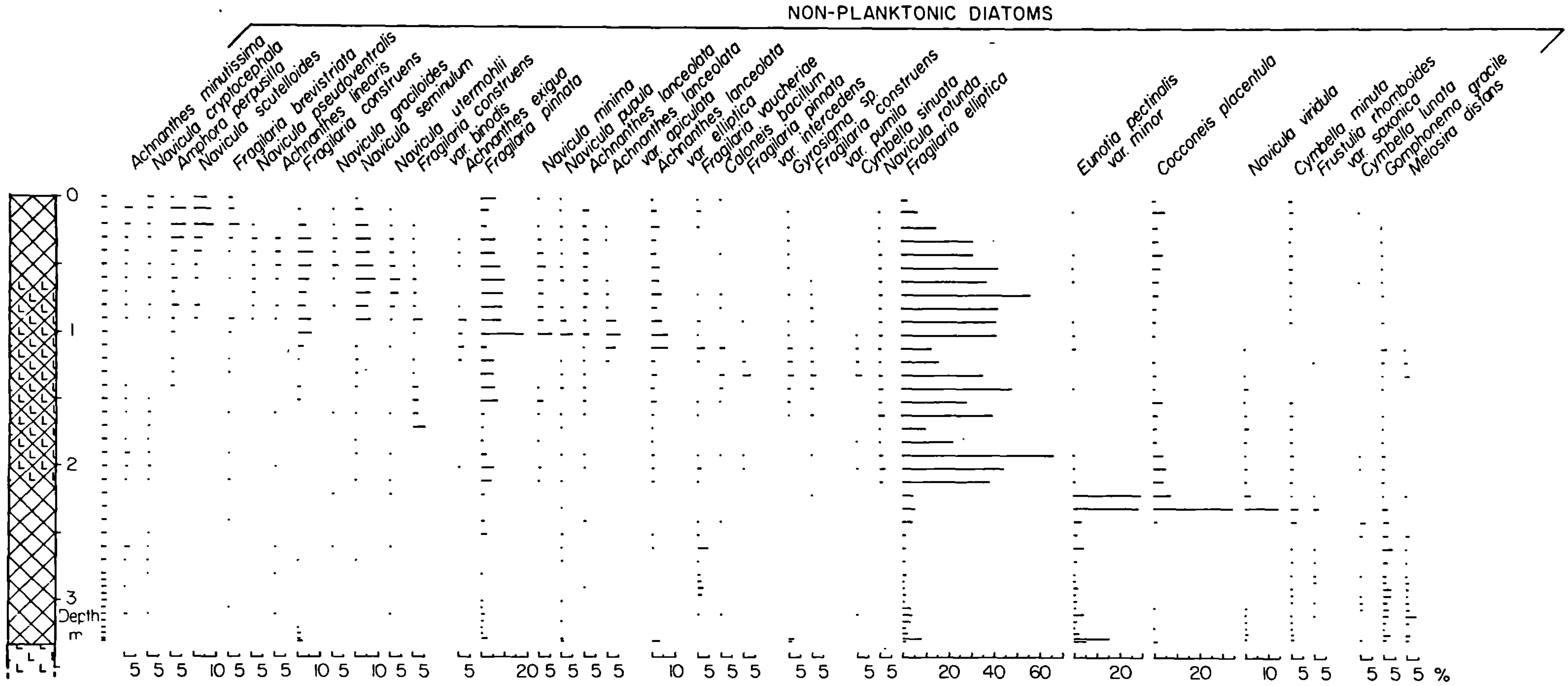
ELLESMERE, a), ^{137}Cs in picoCuries per cubic centimetre vs. depth in metres.
b), ^{137}Cs, corrected for radioactive decay (30 year half-life) using ^{210}Pb chronology, in pCi cm^{-3} vs. depth in metres.

Fig. 57



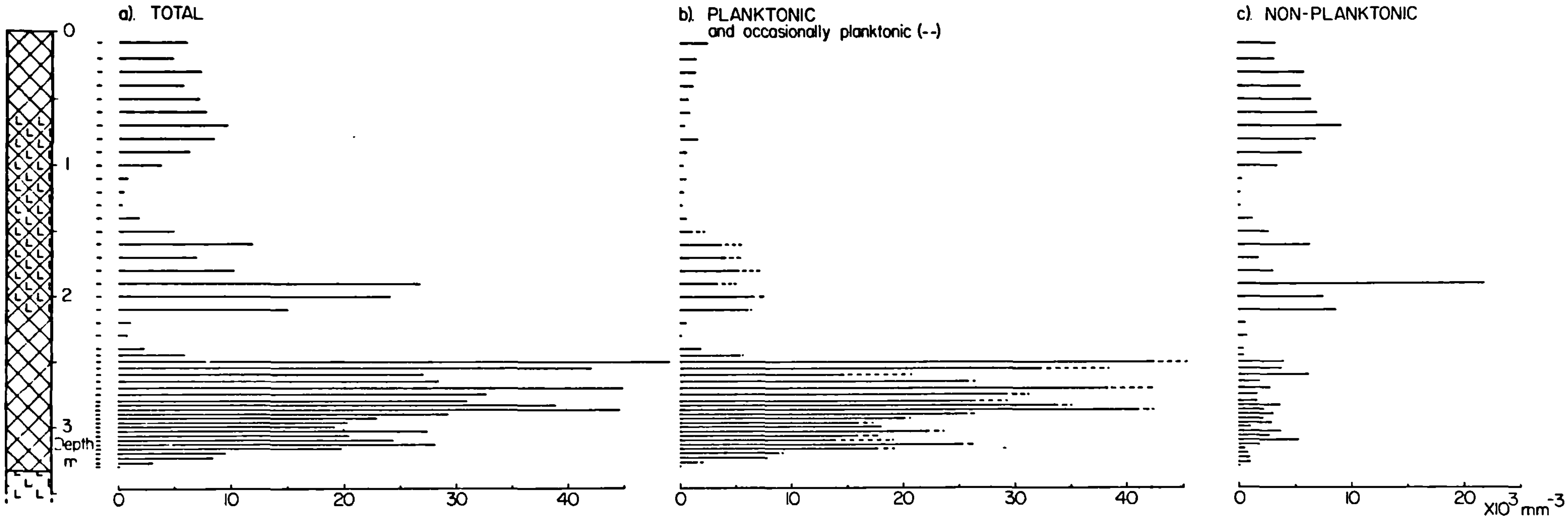
ELLESMERE, core 6, diatom diagram, planktonic and occasionally planktonic (P/NP) diatoms and *Tabellaria spp.*(TAB) as a percentage of diatom sum vs. depth in metres.

Fig. 58



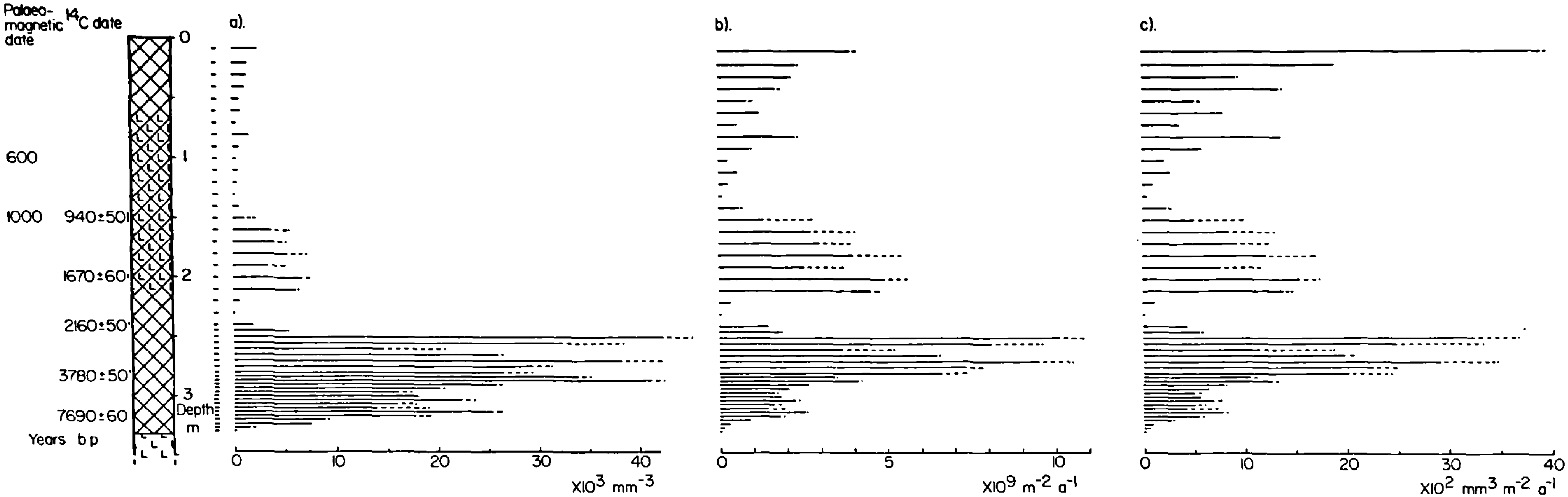
ELLESMERE, core 6, diatom diagram showing non-planktonic diatoms as a percentage of diatom sum, vs. depth in metres.

Fig. 59



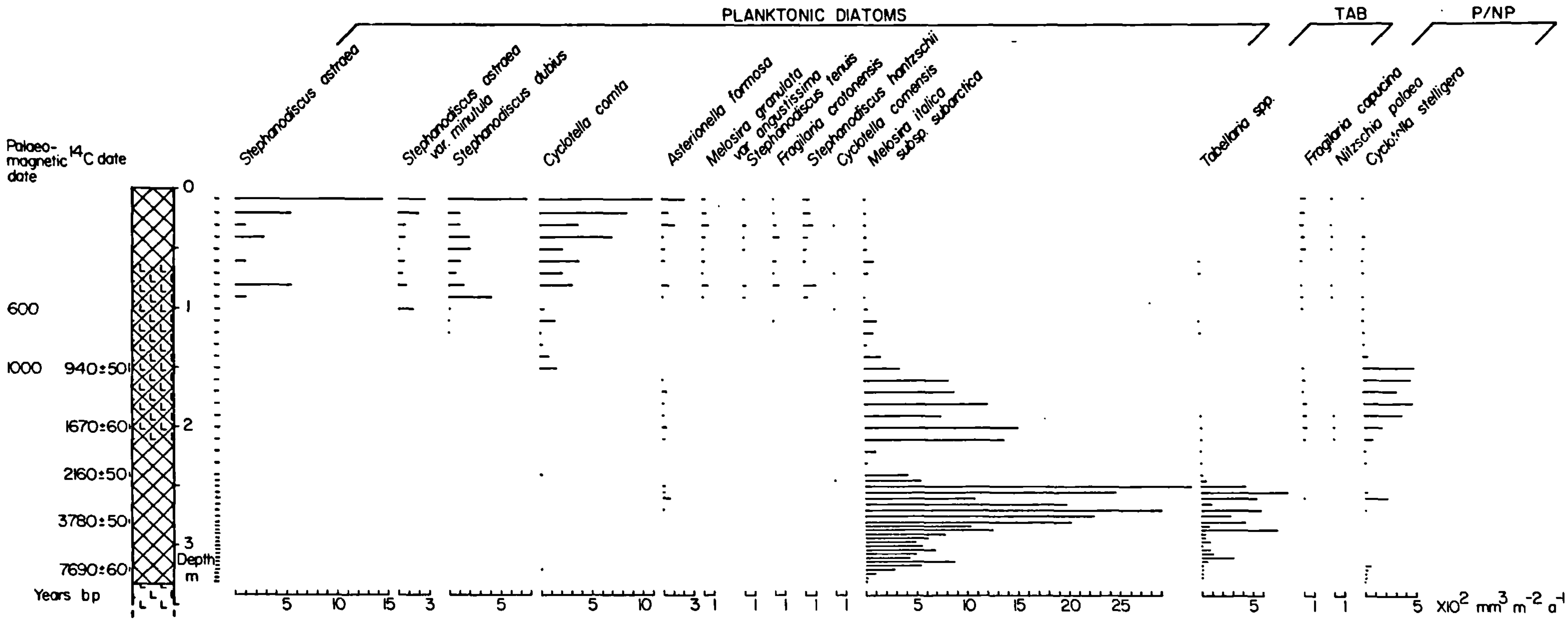
ELLESMERE, core 6, numbers of diatom cells per cubic millimetre of wet sediment vs depth in metres

Fig. 60



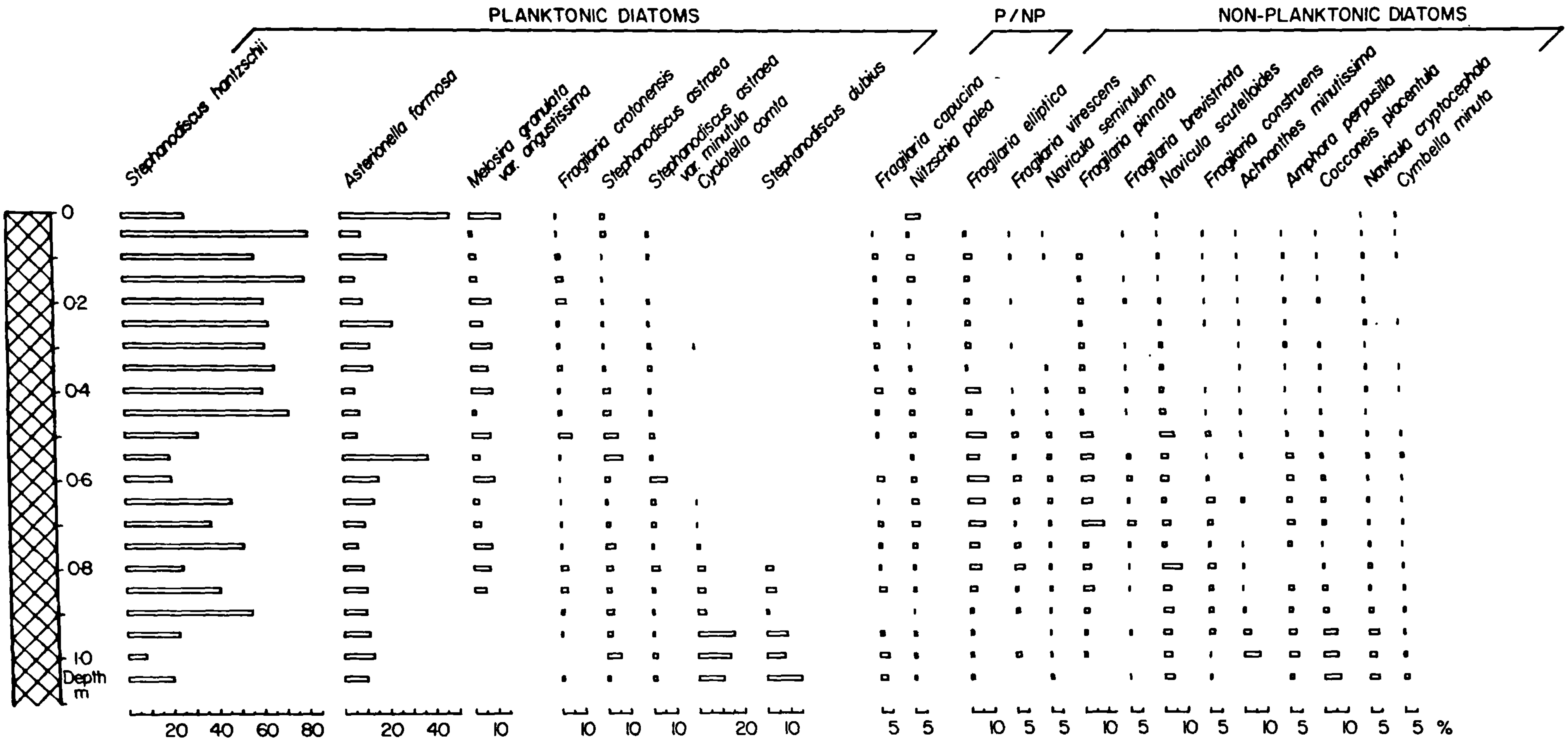
ELLESMERE, core 6, planktonic diatoms (—) with *Tabellaria spp.* and other occasionally planktonic diatoms (--), a), numbers per cubic millimetre of wet sediment vs. depth in metres.
b), numbers accumulating per square metre per annum vs depth in metres.
c), volume in cubic millimetres accumulating per square metre per annum vs depth

Fig. 61



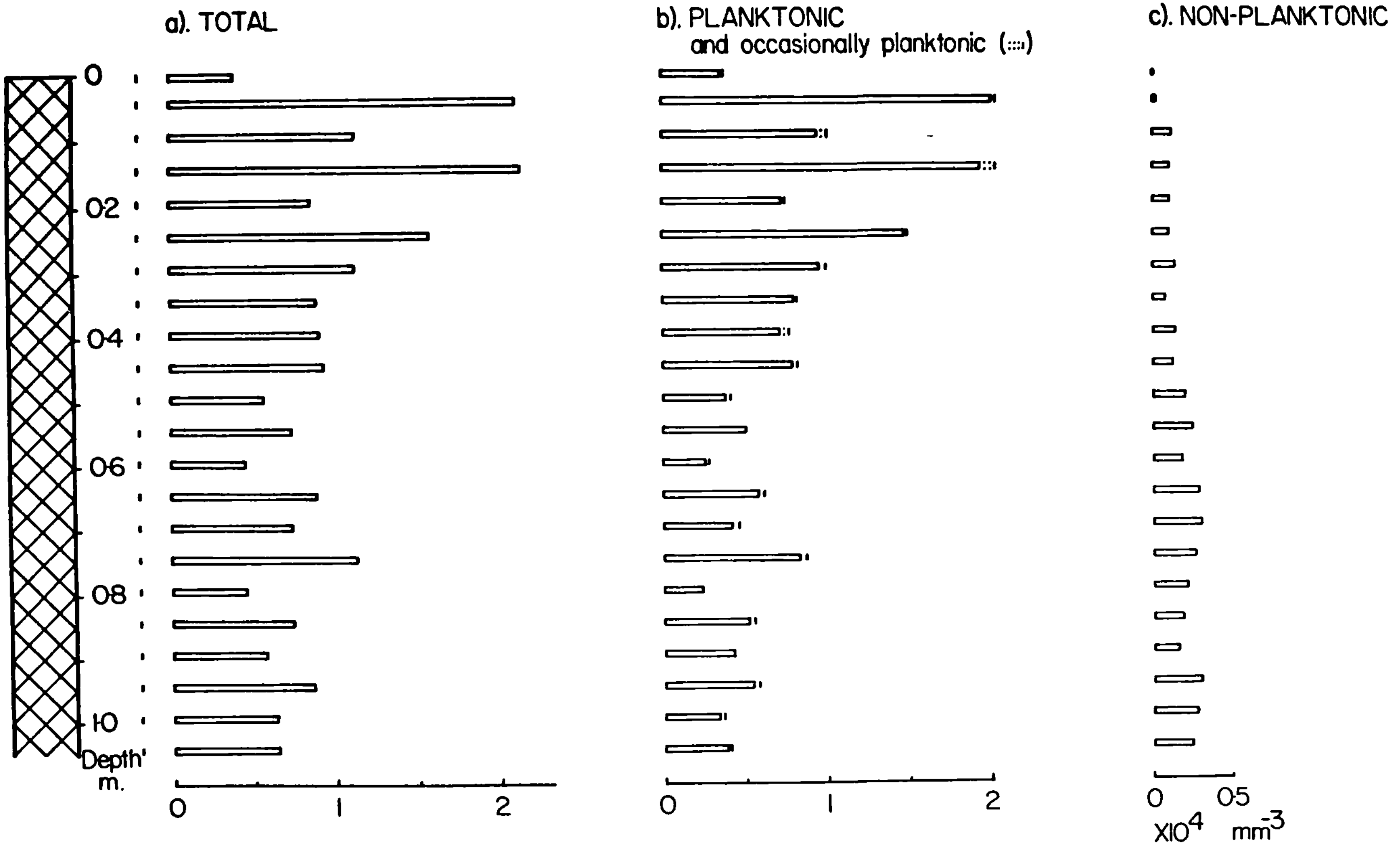
ELLESMERE, core 6, diatom diagram showing planktonic and occasionally planktonic (P/NP) diatoms and *Tabellaria spp.* (TAB) as volume accumulating per square metre per annum vs. depth in metres

Fig. 62



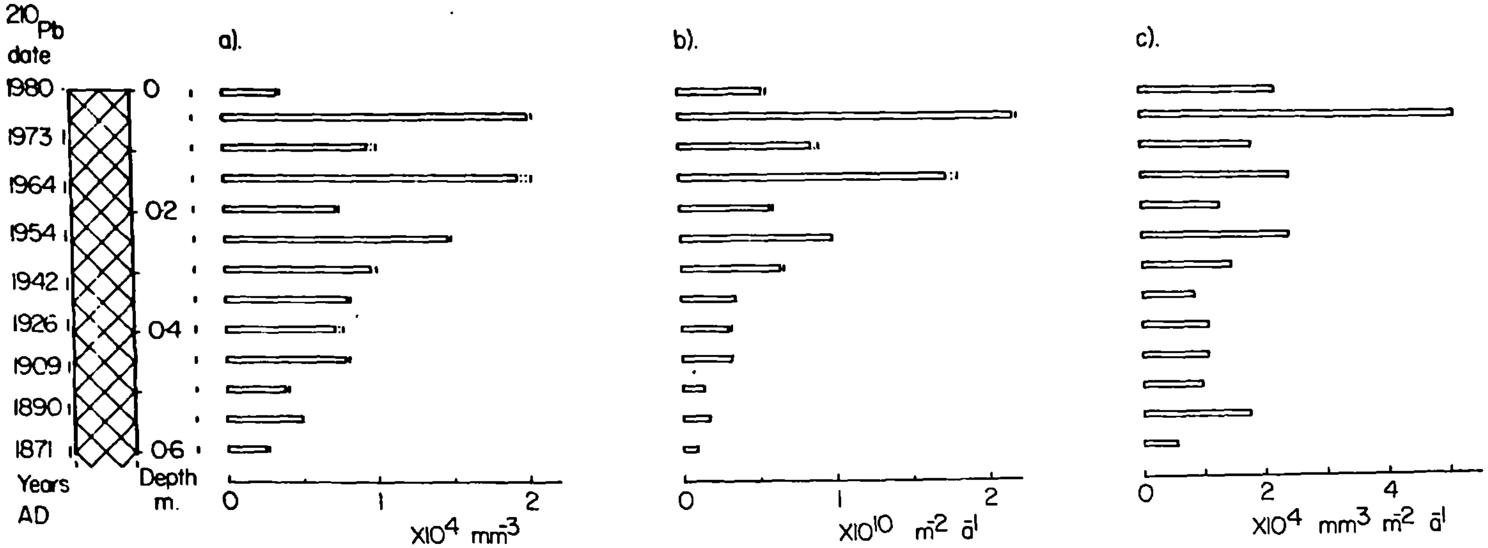
ELLESMERE, 'Mini'core, diatom diagram showing planktonic, occasionally planktonic (P/NP) and non-planktonic diatoms as a percentage of diatom total vs. depth in metres.

Fig. 63



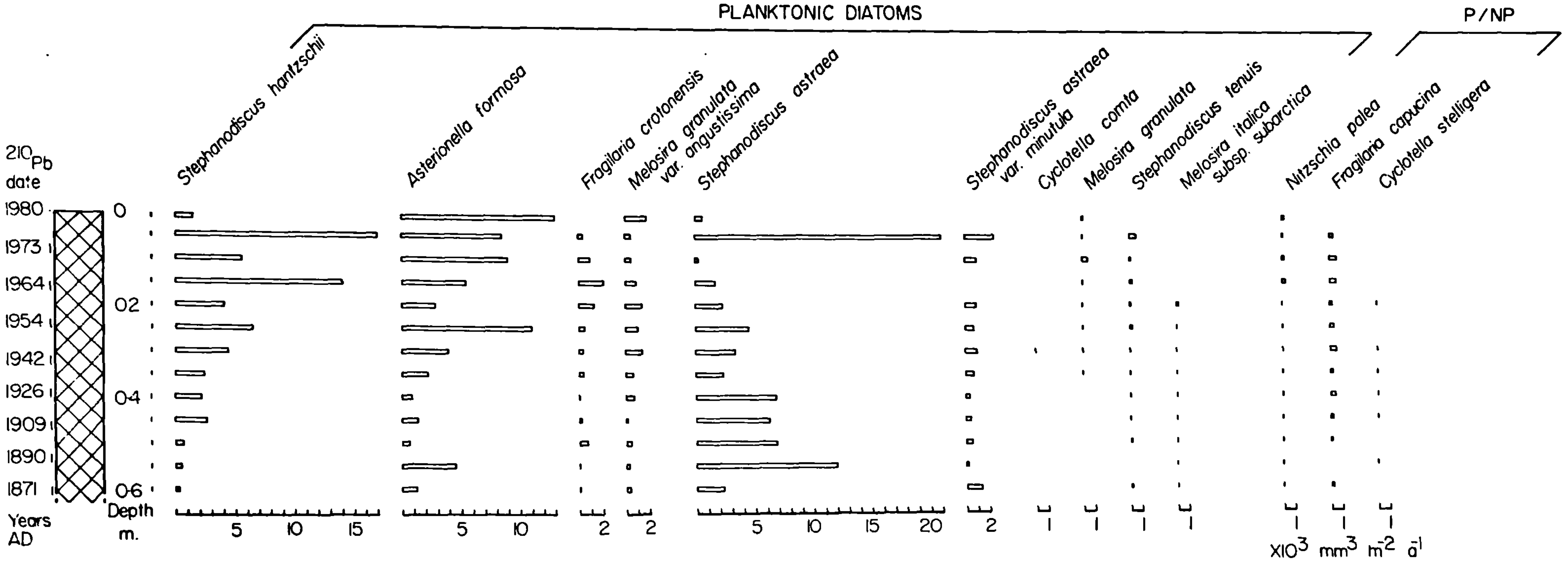
ELLESMERE, 'Mini'core, numbers of diatoms per cubic millimetre of wet sediment vs. depth in metres.

Fig. 64



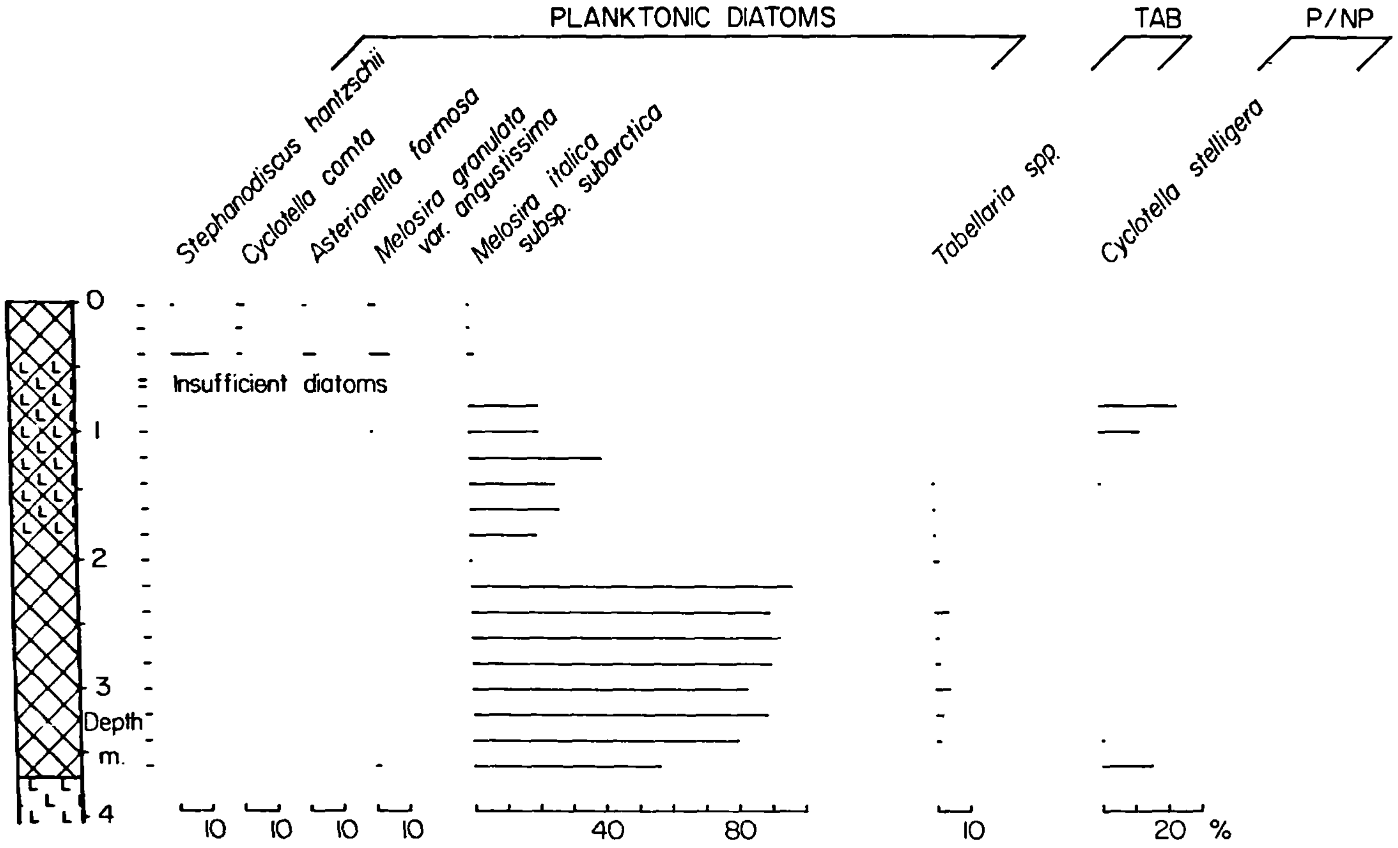
ELLESMERE, 'Mini'core, planktonic (=) with *Tabellaria spp.* and other occasionally planktonic (·) diatoms a), numbers per cubic millimetre of wet sediment vs. depth in metres.
b), numbers accumulating per square metre per annum vs. depth in metres.
c), volume in cubic millimetres accumulating per square metre per annum.

Fig. 65



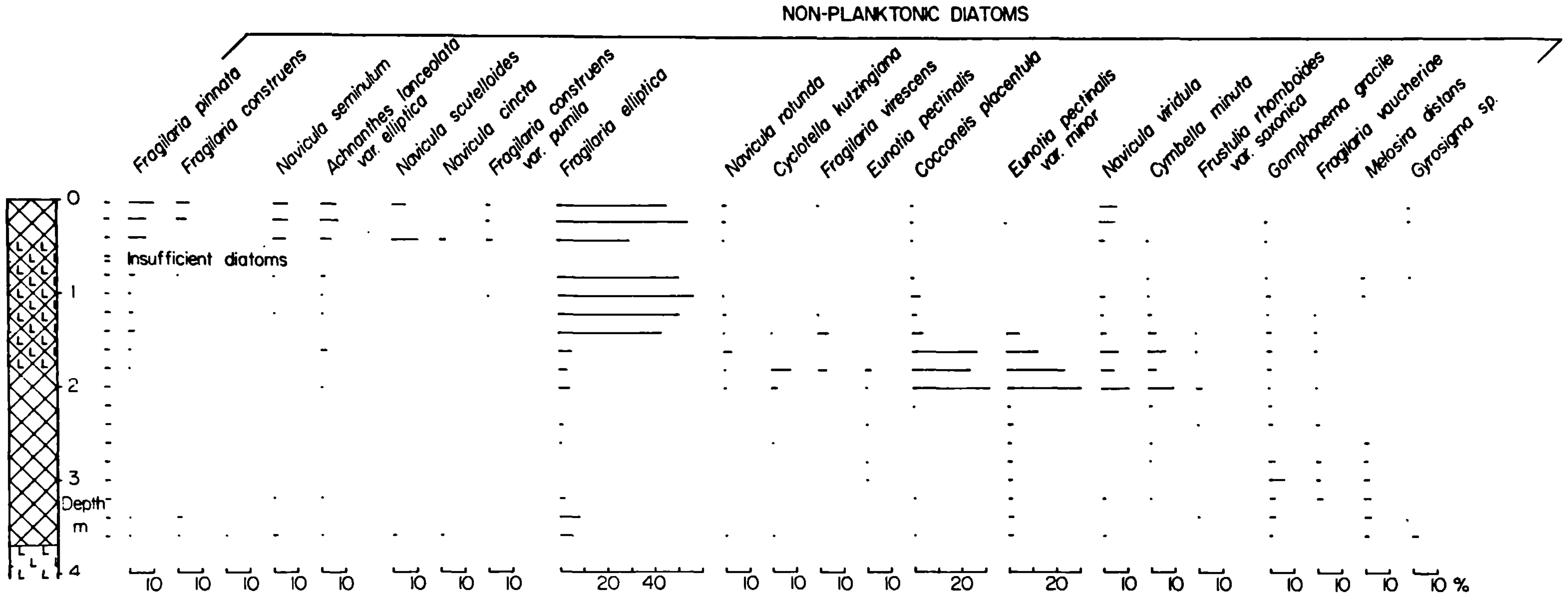
ELLESMERE, 'Mini'core, diatom diagram showing planktonic and occasionally planktonic (P/NP) diatoms as volume in cubic millimetres accumulating per square metre per annum vs. depth in metres.

Fig. 66



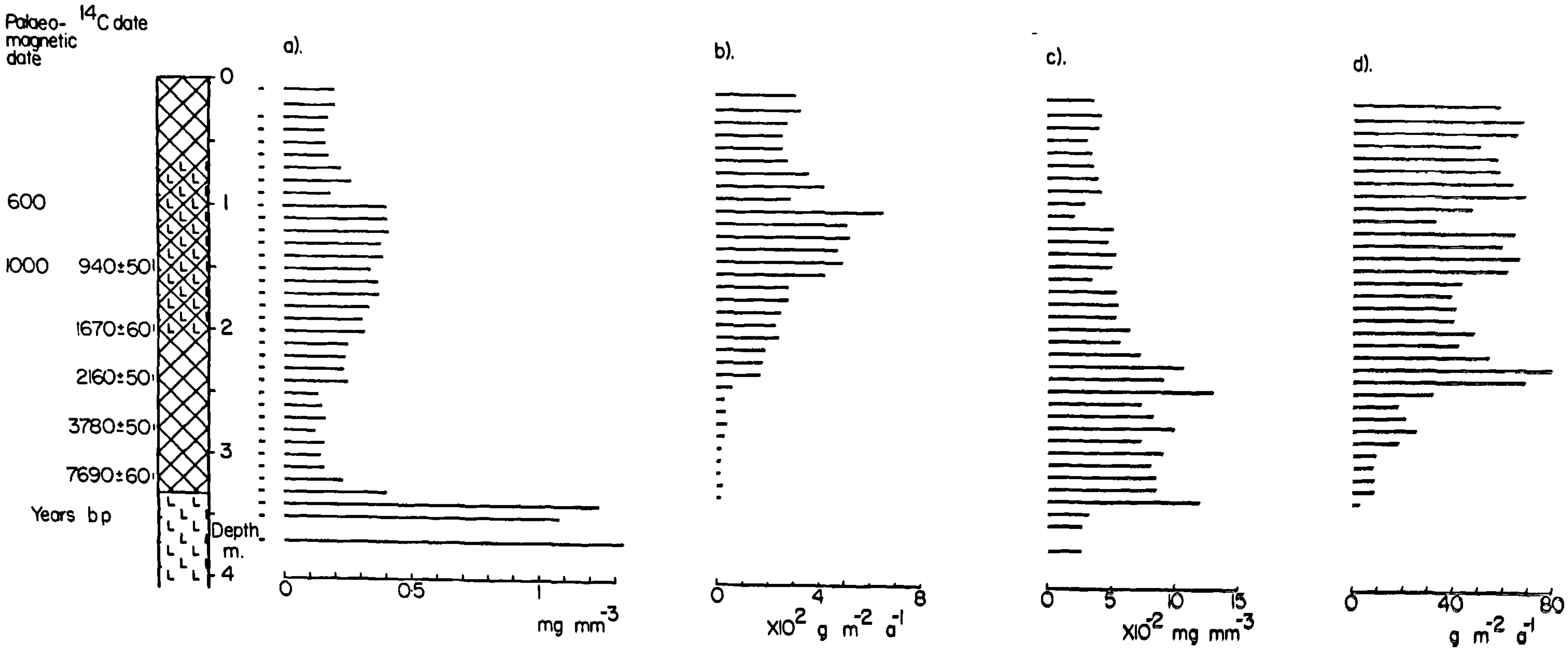
ELLESMERE, core 4, diatom diagram, planktonic and occasionally planktonic (P/NP) diatoms and *Tabellaria spp.* (TAB), as a percentage of diatom sum vs. depth in metres.

Fig. 67



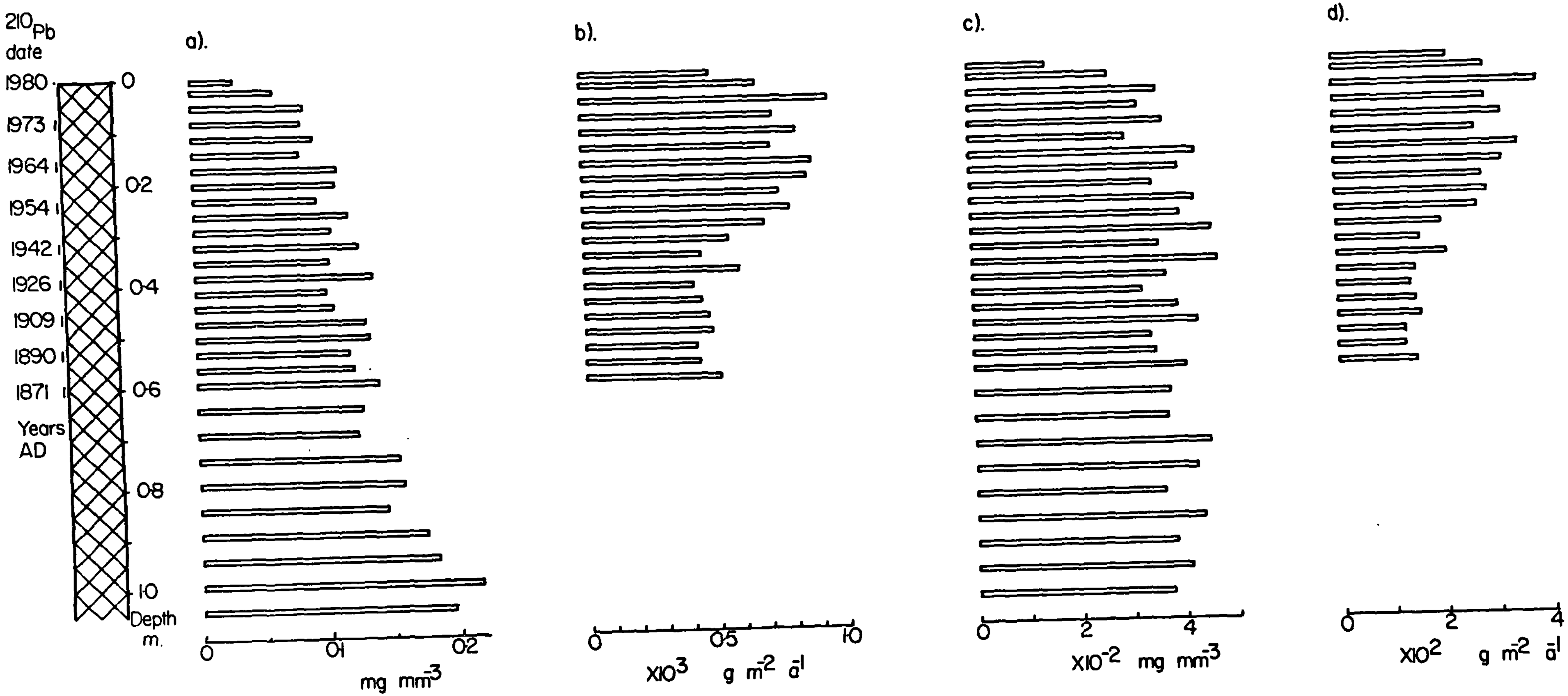
ELLESMERE, core 4, diatom diagram showing non-planktonic diatoms as a percentage of diatom sum vs. depth in metres.

Fig. 68



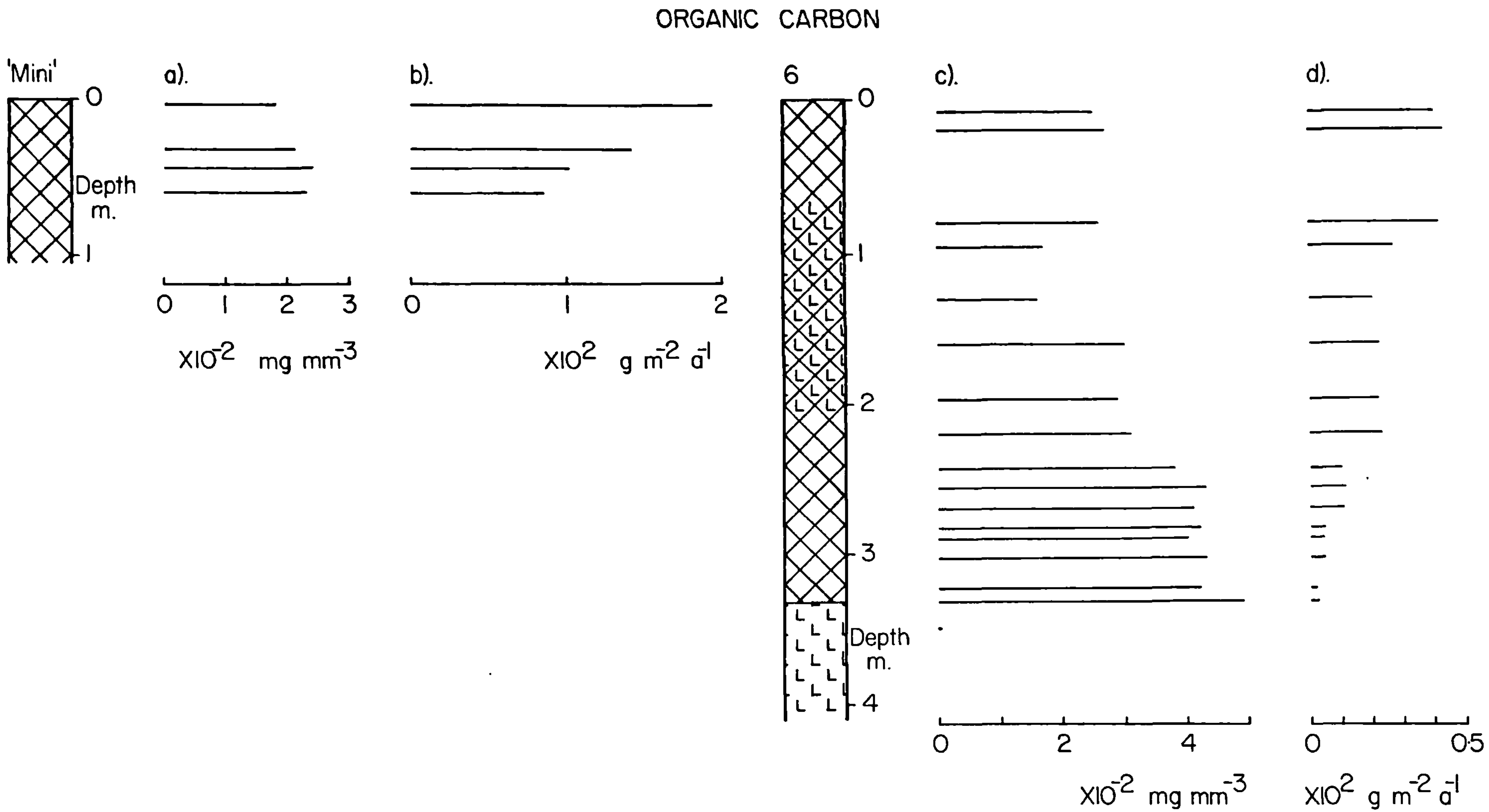
ELLESMERE, core 6, a), dry mass in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), dry mass in grams accumulating per square metre per annum vs. depth in metres.
c), mass lost on ignition at 450 °C in milligrams per cubic millimetre of wet sediment vs. depth in metres.
d), mass lost on ignition at 450 °C in grams accumulating per square metre per annum vs. depth in metres.

Fig. 69



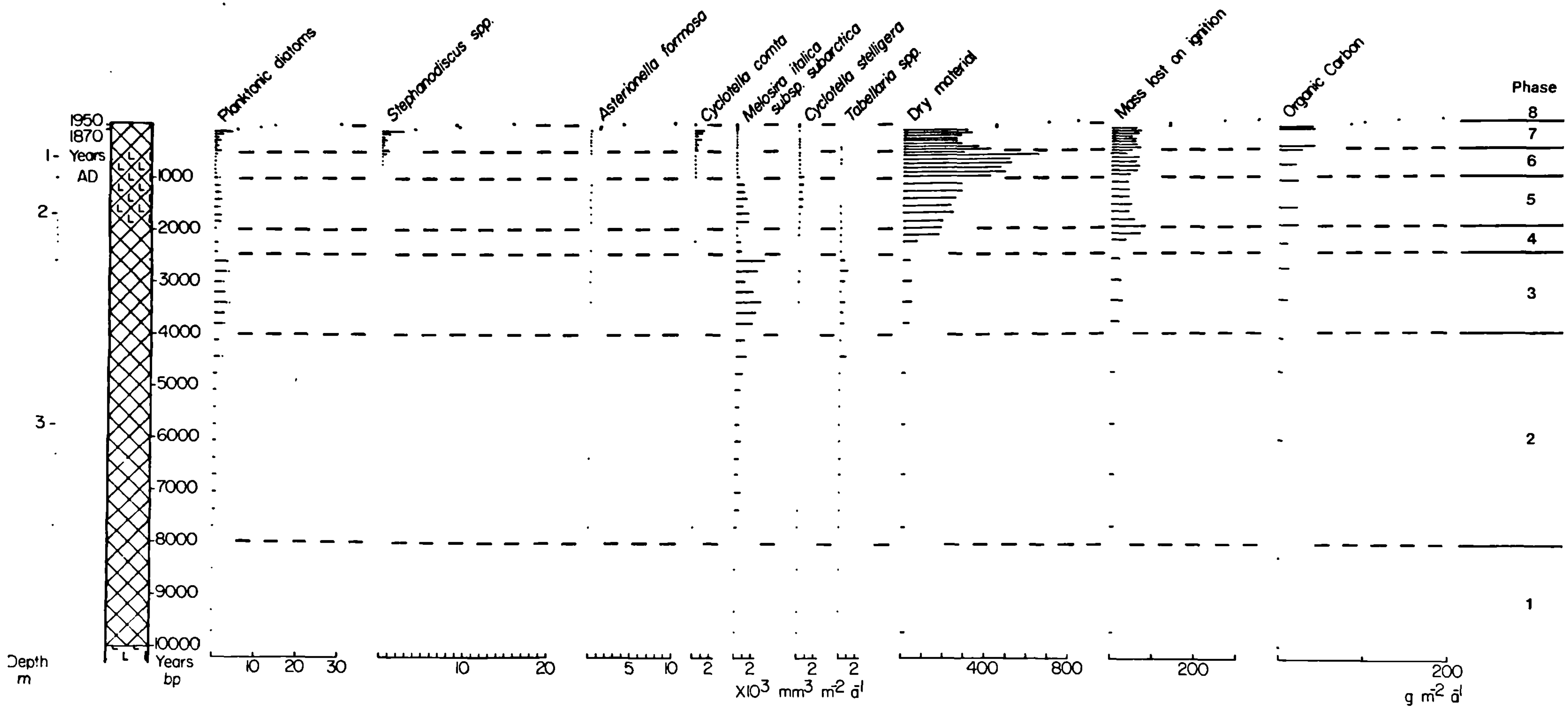
ELLESMERE, 'Mini' core, a), dry mass in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), dry mass in grams accumulating per square metre per annum vs. depth in metres.
c), mass lost on ignition at 450 °C in milligrams per cubic millimetre of wet sediment vs. depth in metres.
d), mass lost on ignition at 450 °C in grams accumulating per square metre per annum vs. depth in metres.

Fig. 70



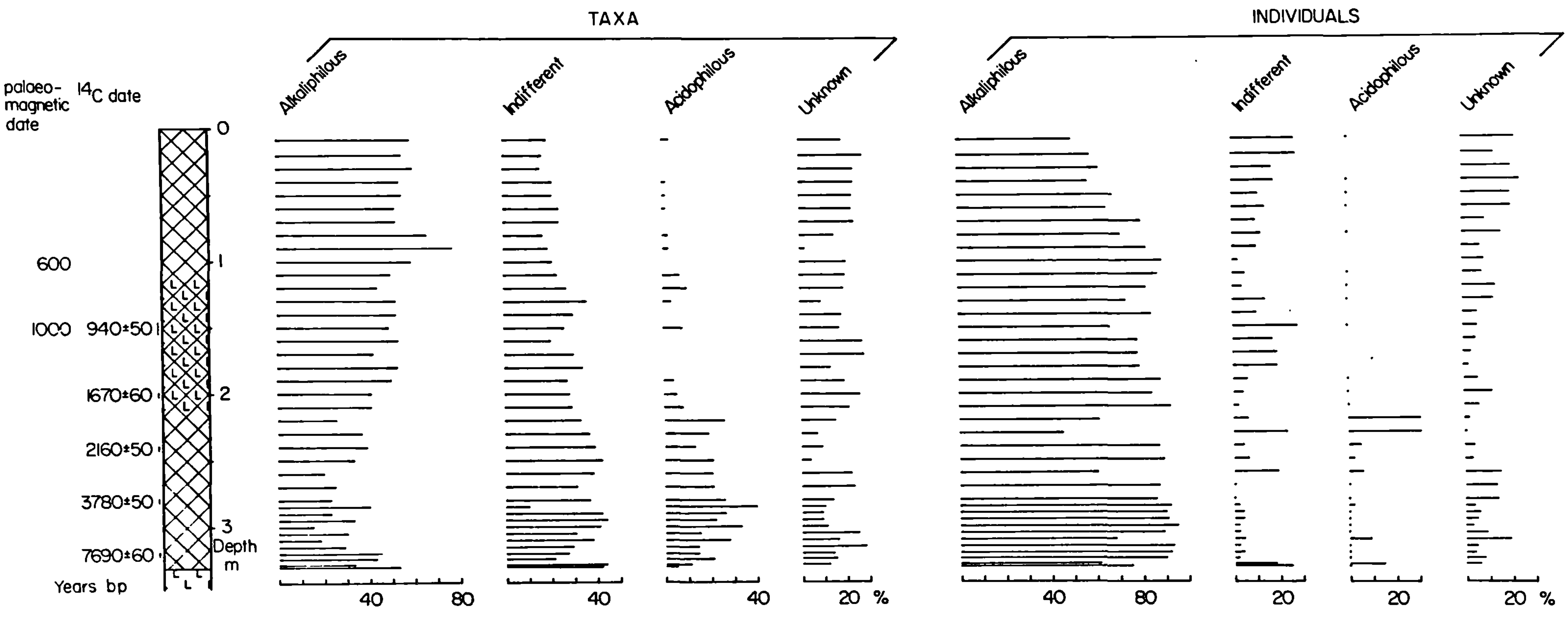
ELLESMERE, 'Mini'core and core 6 , a), and c), CARBON in milligrams per cubic millimetre of wet sediment vs. depth in metres.
b), and d), CARBON in grams accumulating per square metre per annum vs. depth in metres.

Fig. 71



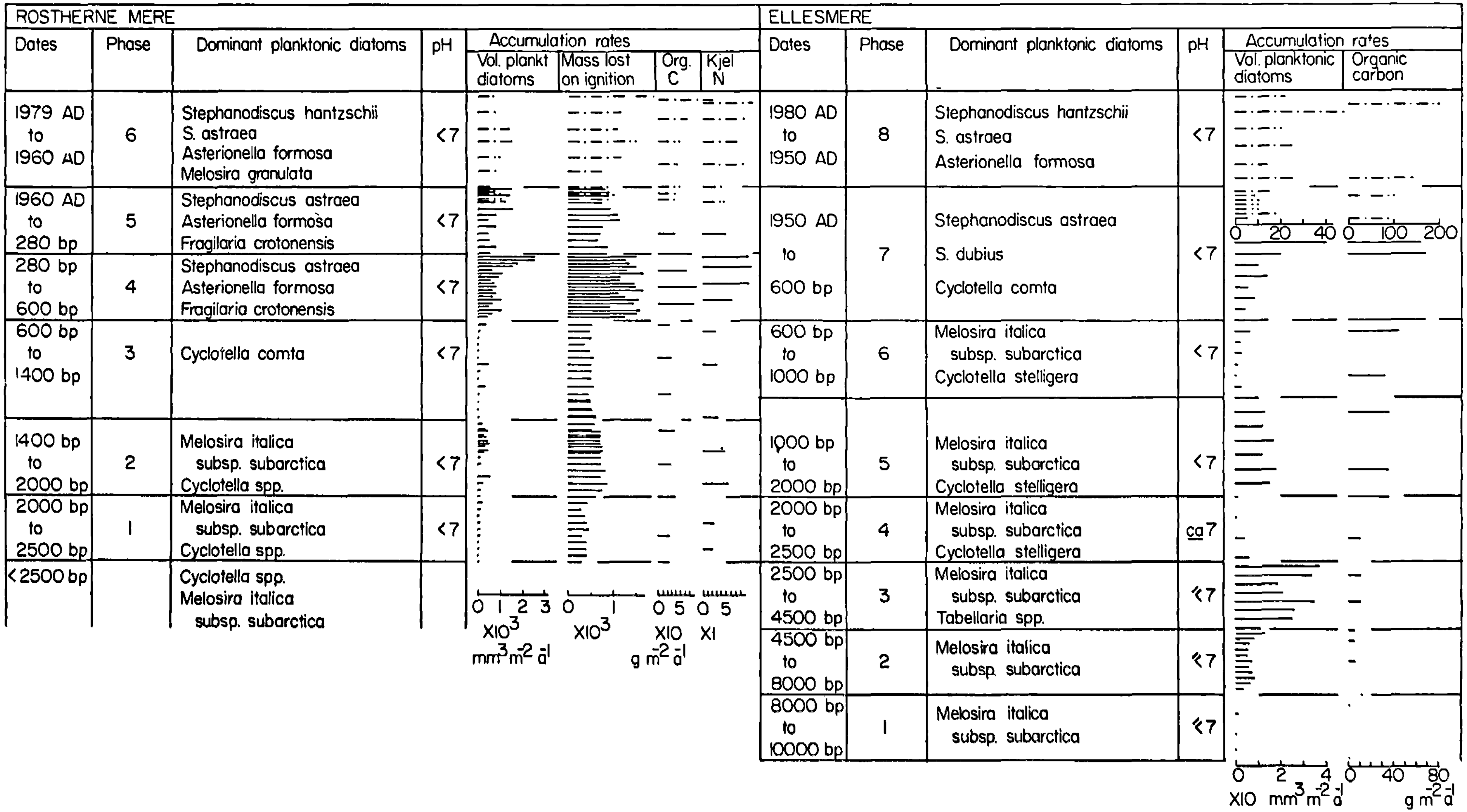
ELLESMERE, 'Mini'core (·) and core 6 (–), selected diatom and other accumulation rates vs time.

Fig. 72



ELLESMERE, core 6, diatom pH spectrum, for taxa as percentage of total number of taxa, and for individuals as percentage of diatom sum, vs. depth in metres.

Fig. 73



ROSTHERNE MERE

Dates	Phase	Dominant planktonic diatoms	pH
1979 AD to 1960 AD	6	Stephanodiscus hantzschii S. astraea Asterionella formosa Melosira granulata	<7
1960 AD to 280 bp	5	Stephanodiscus astraea Asterionella formosa Fragilaria crotonensis	<7
280 bp to 600 bp	4	Stephanodiscus astraea Asterionella formosa Fragilaria crotonensis	<7
600 bp to 1400 bp	3	Cyclotella comta	<7
1400 bp to 2000 bp	2	Melosira italica subsp. subarctica Cyclotella spp.	<7
2000 bp to 2500 bp	1	Melosira italica subsp. subarctica Cyclotella spp.	<7
<2500 bp		Cyclotella spp. Melosira italica subsp. subarctica	

ELLESMERE

Dates	Phase	Dominant planktonic diatoms	pH
1980 AD to 1950 AD	8	Stephanodiscus hantzschii S. astraea Asterionella formosa	<7
1950 AD to 600 bp	7	Stephanodiscus astraea S. dubius Cyclotella comta	<7
600 bp to 1000 bp	6	Melosira italica subsp. subarctica Cyclotella stelligera	<7
1000 bp to 2000 bp	5	Melosira italica subsp. subarctica Cyclotella stelligera	<7
2000 bp to 2500 bp	4	Melosira italica subsp. subarctica Cyclotella stelligera	ca 7
2500 bp to 4500 bp	3	Melosira italica subsp. subarctica Tabellaria spp.	≤7
4500 bp to 8000 bp	2	Melosira italica subsp. subarctica	≤7
8000 bp to 10000 bp	1	Melosira italica subsp. subarctica	≤7

Comparison of age, in ^{210}Pb years AD and uncalibrated ^{14}C years bp, of phases in Rostherne Mere and Ellesmere, showing dominant planktonic diatoms, pH, and accumulation rates for volume of planktonic diatoms and some organic chemicals.('Mini'core accumulation rates (–·–·) and long core accumulation rates (——) are shown).

Fig. 74