Geological Survey of Finland

Bulletin 352

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Geologian tutkimuskeskus
Espoo 1991

Geological Survey of Finland, Bulletin 352

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TUULIKKI GRÖNLUND

with 10 figures in the text and 2 plates and 2 appendices

GEOLOGIAN TUTKIMUSKESKUS
ESPOO 1991

Vammala 1991, Vammalan Kirjapaino Oy

Grönlund, Tuulikki 1991. New cores from Eemian interglacial deposits in Ostrobothnia, Finland. *Geological Survey of Finland, Bulletin 352,* 23 pages, 10 figures, 2 plates and 2 appendices.

Till-covered sediments containing marine diatoms have been found at Norinkylä (Teuva) and Ukonkangas (Kärsämäki) in Ostrobothnia, western Finland. The different types of diatom stratigraphy at these sites are described, and the sites are correlated with the Eemian interglacial stage.

At Norinkylä, Eemian marine deposits are underlain by freshwater deposits whose diatom flora contains the same taxa as the Holocene Ancylus Lake. The deposits of the Eemian Baltic Sea proper at Ukonkangas and Norinkylä have a rich marine diatom flora with the same taxa as encountered earlier in Eemian deposits in Ostrobothnia.

The phases of the Eemian Baltic Sea are discussed.

Key words: stratigraphy, diatoms, interglacial environment, marine environment, freshwater environment, sediments, Eemian, Baltic Sea, Ostrobothnia, Finland.

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ISBN 951-690-417-3
ISSN 0367-522-X

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INTRODUCTION

In recent years, sediments containing diatoms have been found underlying glacial till at several sites, particularly in Ostrobothnia, western Finland. Many of these sediments can be interpreted as having deposited in the Baltic Sea basin during the last, i.e., the Eemian, interglacial stage.

Fig. 1. A) A map showing the main localities of Eemian marine diatom bearing sediments in Fennoscandia and the north-western Soviet Union and the sites mentioned in the text. B) A location map of Fennoscandia, the north-western Soviet Union and the Baltic Sea. Ostrobothnia is indicated by shading.

The correlation is based on lithostratigraphy and pollen stratigraphy. The main Eemian marine sites in Finland studied by means of diatoms are Evijärvi (Eriksson *et al.* 1980), Ollala (Haapavesi) (Forsström *et al.* 1987, 1988 and Grönlund 1988) and Viitala (Peräseinäjoki) (Nenonen *et al.* in press). The location of the sites is shown in Figure 1. The Eemian Baltic Sea diatom flora of Suur-Prangli, nowadays Prangli (see Liivrand in press), an island off the coast of northern Estonia, has also been presented, first by Cheremisinova (1961) and later by Liivrand (1984, 1987, in press) on the basis of the diatom studies of Cheremisinova (Fig. 1). Eemian marine deposits and diatoms are also found redeposited or mixed with freshwater diatom flora in several places in Finland, Sweden and Soviet Karelia (e.g. Halden 1915, Brander 1937 a, b, 1943, Tynni 1971, Miller & Persson 1973, Niemelä & Tynni 1979, Grönlund *et al.* 1985, Påsse *et al.* 1988, García Ambrosiani 1990).

New coring was undertaken at Norinkylä (Teuva), the site already studied by Niemelä and Tynni (1979) and Donner (1988). Samples were also taken from a silt deposit underlying till at Ukonkangas (Kärsämäki) and Haapalankangas (Jurva) (Fig. 1). The diatom stratigraphy of these sites is presented in order to provide new information about the Eemian Baltic Sea, its northern and northeastern parts in particular.

SAMPLING AND METHODS

At Norinkylä the samples were taken using a percussion drill with a flow-through bit sampler. At Ukonkangas and Haapalankangas they were taken by spade from an exposed section.

The samples were first bleached with diluted H_2O_2 for 24 h at 50°C, and then subjected to repeated suspensions and decantations. The mounting medium was Hyrax Liquid with a refractive index of 1.65. Whenever possible, at least 500 diatom valves were identified from each sample depth.

The diatoms were classified according to salinity preference as polyhalobous (salinity in the habitat 35—17 parts per mille), mesohalobous including meso- and pleioeyryhaline polyhalobous (salinity in the habitat 35—3 parts per mille) and oligohalobous, which are freshwater species. The classification is that of Simonsen (1962) as applied to Finnish conditions by Tynni (Niemelä & Tynni 1979).

THE NORINKYLÄ SITE AT TEUVA

The Norinkylä site lies in the municipality of Teuva (62°35′45′′N and 22°01′07′′E) (Fig. 1). The sequence occurs in a narrow till-covered esker trending north to south, and bounded on its western side by Rahkaneva mire.

The Norinkylä site was first studied by Niemelä and Tynni (1979). The section they studied was on the western slope of the esker, with its crest at 112 m above sea level. When Donner (1988) later studied the same site, the crest was at 110 m above sea level because a 2—3 m thick till bed had been removed from the surface. A disturbed clay layer, about 12 cm thick, was included in the section studied by Niemelä and Tynni (1979). This clay contained a marine diatom flora with species commonly found in marine Eemian deposits. According to Niemelä and Tynni, the clay had deposited close to the shore during the Eemian marine stage. This marine Eemian clay was not encountered in the section studied

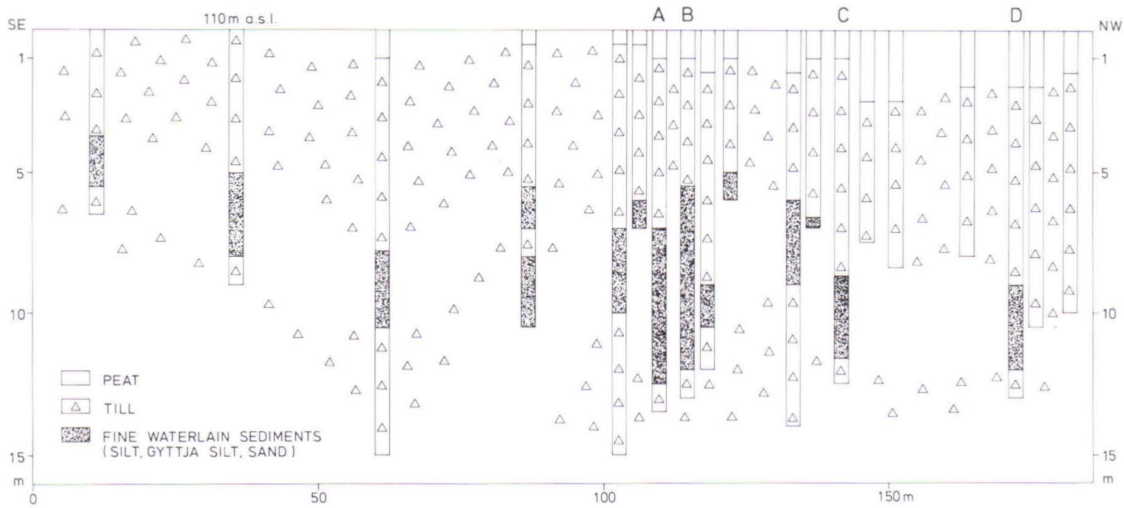

Fig. 2. Cores from the Norinkylä (Teuva) site. Cores A, B, C and D were studied.

by Donner (1988). Besides the clay layer, there was a lens of gyttja (organic mud) with marine diatoms in its upper part, although the rest of the gyttja was regarded as a freshwater deposit. This gyttja had later been mixed with probably reworked sediments containing Eemian diatoms (Niemelä & Tynni 1979).

New samples for diatom analysis were collected from the Rahkaneva mire in 1987 and 1989. The sample site lies northwest of the section studied by Niemelä and Tynni (1979) and Donner (1988), in the direction from which the glacier approached. Eighteen attempts to drill good cores through very hard till deposits with big boulders (cf. Fig. 2) produced only four satisfactory cores (A—D). Their distances from the section studied by Niemelä and Tynni and Donner were as follows: core A 120 m, core B 130 m, core C 140 m and core D 175 m (Fig. 2). Rahkaneva mire is at 110 m a.s.l. The thickness of the peat layer overlying the till deposits is 0—3 m at the sites of the cores studied.

Core A

The core, almost 4 m long, consists of organic silt covered by till. The silt is underlain by about 30 cm of clay, the lower part of which is mixed with the till deposit (Fig. 3 and Appendices 1—2). The uppermost part of the silt layer was probably cut away when the overlying till deposited or then it was missed in sampling.

The succession of the diatom taxa is given in Appendix 1 (polyhalobous and mesohalobous species) and Appendix 2 (freshwater species). The diatoms, classified according to their salinity and temperature demands (cold or warm water conditions) mainly after Hustedt (1930), Cleve-Euler (1940), Miller (1964) and Guillard and Kilham (1977), are presented in Figure 3. Environmental changes shown by diatom stratigraphy are also shown. The lowermost sample of the core, from a depth of 12.75 m, contains a small number of diatoms (Fig. 3). The main species are the mesohalobous *Grammatophora oceanica* Grunow and *Hyalodiscus scoticus* (Kützing) Grunow, both earlier interpreted as typical of the Eemian Baltic Sea. *Aulacoseira lirata* (Ehrenberg) Ross (*Aulacoseira = Melosira,* see Simonsen 1979 and e.g. Hartley 1986), which is a freshwater species, is also common. Otherwise the clay layer in the bottom of the core contains diatoms characteristic of freshwater conditions, with *Aulacoseira lirata, A. islandica* (O. Müller) Simonsen and *A.*

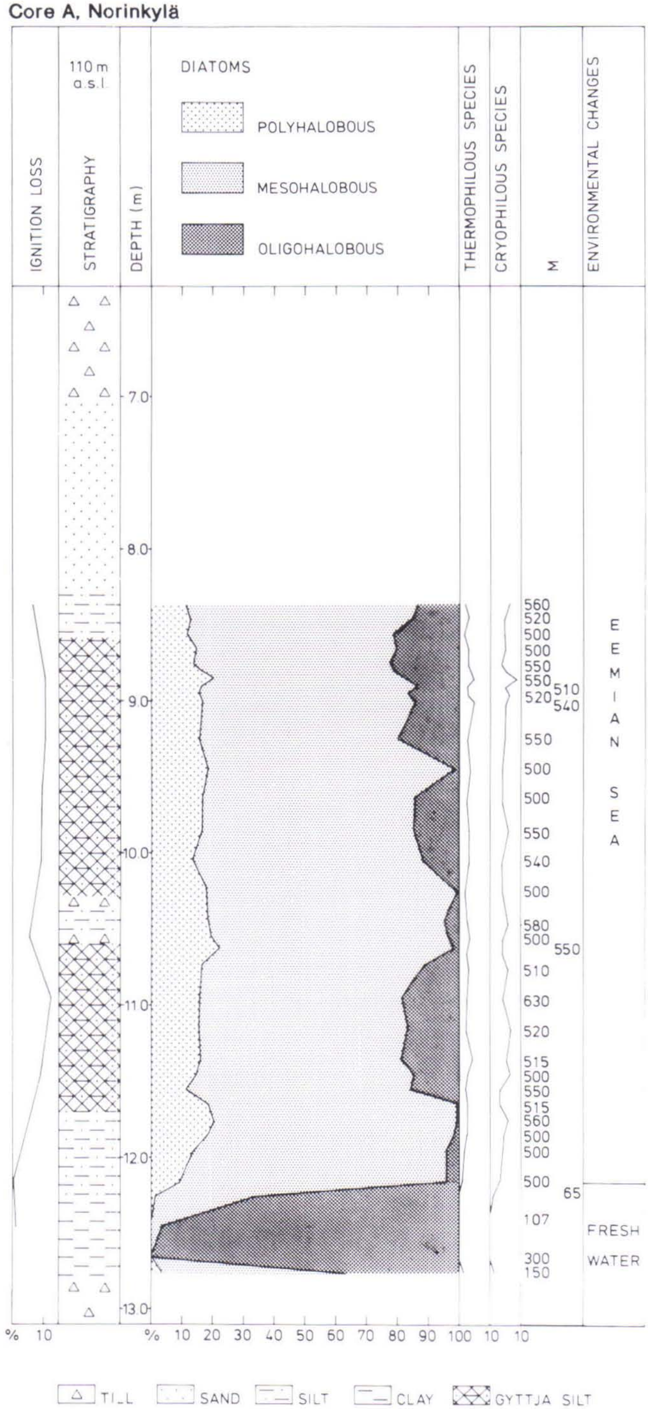

Fig. 3. Diatom groups by salinity, temperature demand (thermophilous and cryophilous species) and changes in sedimentary environment (lake/sea) according to the diatom spectra in core A, Norinkylä.

islandica subsp. *helvetica* (O. Müller) Simonsen (often as resting spores), *A. italica* (Ehrenberg) Simonsen, *Cyclotella kützingiana* Thwaites and species of the genus *Pinnularia* dominating.

At a depth of 12.15 m the diatom flora changes, and *Aulacoseira* species are almost totally lacking from the rest of the core. The diatom flora in the sediments above a depth of 12.15 m is rich and very homogeneous. The dominant mesohalobous species account for about 60—80 %, polyhalobous species for about 20 % and freshwater species for 1—23 % (Fig. 3).

The mesohalobous species *Grammatophora oceanica, G. oceanica* var. *macilenta* (W. Smith) Grunow, *Hyalodiscus scoticus, Rhabdonema arcuatum* (Lyngbye) Kützing and *Melosira sulcata* (Ehrenberg) Kützing dominate, as they do at the sites studied by Niemelä and Tynni (1979), and at Evijärvi, Ollala and Viitala.

Other species typical of the diatom flora of the Eemian Baltic Sea include *Actinocyclus kützingii* (A. Schmidt) Simonsen, *Actinoptychus senarius* Ehrenberg, *Auliscus sculptus* (W. Smith) Ralfs, *Campylodiscus fastuosus* Ehrenberg, *Dimeregramma (Dimerogramma) minor* (Gregory) Ralfs, *Navicula abrupta* (Gregory), Grunow, *N. lyroides* Hendey, *Stephanopyxis turris* (Greville) Ralfs, *Thalassionema nitzschiodes* Grunow, *Thalassiosira eccentrica* (Ehrenberg) Cleve and *T. gravida* Cleve, all of which are polyhalobous. *Podosira hormoides* (Montagne) Kützing and *P. montagnei* Kützing, which were not found at Evijärvi, Ollala or Viitala, are quite common in this core. *P. montagnei* favours waters of lowered salinity, too, and is common in the Baltic Sea and on all North Sea coasts (Hustedt 1930, Hendey 1964), but no observations have been reported from the Finnish coast (Mölder & Tynni 1967). The species is also common on all European coasts, as is *P. hormoides* (Hustedt 1930). Several *P. montagnei* specimens have been found in the silt layers of Hietakangas and Rova, in the clay of Norinkylä esker (Niemelä & Tynni 1989) and in deposits at Rouhiala (Brander 1937a) and Mga (Brander 1937a, b).

The most characteristic mesohalobous species are *Actinocyclus octonarius* Ehrenberg (syn. *A. ehrenbergii* Ralfs), *Cocconeis peltoides* Hustedt, *C. scutellum* Ehrenberg, *Navicula digitoradiata* (Gregory) A. Schmidt, *N. peregrina* (Ehrenberg) Kützing, *Nitzschia sigma* (Kützing) W. Smith, *Pleurosigma angulatum* (Quekett) W. Smith, *Rhopalodia gibberula* (Ehrenberg) O. Müller and *Synedra tabulata* (Agardh) Kützing.

Many *Diploneis* species, e.g. *D. mediterranea* (Grunow) Cleve, *D. notabilis* (Greville) Cleve, *D. papula* (A. Schmidt) Cleve, *D. subcincta* (A. Schmidt) Cleve, *D. suborbicularis* (Gregory) Cleve and *D. vacillans* (A. Schmidt) Cleve, which were also encountered in the Eemian sediments at Evijärvi and Ollala, are common. *Diploneis chersonensis* (Grunow) Cleve and *D. crabro* Ehrenberg, which favour high salinity, were also found in this core. Many of the above *Diploneis* species indicate warm water conditions and thus lend support to the concept of an oceanic connection in the west (cf. Zans 1936, Niemelä & Tynni 1979). As well as the thermophilous species, some cold or Arctic water species such as *Campylodiscus angularis* Gregory, *Grammatophora arcuata* Ehrenberg, *Navicula glacialis* (Cleve) Grunow, *Rhizosolenia hebetata* for. *hiemalis* Gran and *Trachyneis aspera* (Ehrenberg) Cleve imply access to the White Sea (cf. Niemelä & Tynni 1979, Grönlund 1988). According to Cleve-Euler (1940), *Pinnularia cruciformis* (Donkin) Cleve and *P. trevelyana* (Donkin) Rabenhorst also thrive in cold water. The frequency of the diatoms indicating warm or cold water is similar throughout the core (cf. Fig. 3).

The lagoonal species *Amphora robusta* Gregory, *Campylodiscus clypeus* Ehrenberg and *Nitzschia scalaris* (Ehrenberg) W. Smith were encountered throughout the profile, although in lower abundances.

Some silicoflagellates, which are marine plankton algae, have also been encountered. In the Rouhiala clay in the Karelian Isthmus (Brander 1937a) and in the Eemian deposits studied earlier in Ostrobothnia (e.g. Niemelä & Tynni 1979, Eriksson *et al.* 1980, Grönlund 1988) they are quite common. *Distephanus speculum* (Ehrenberg) Haeckel, commonly believed to be a cold-water form, was most common in this core, and was found throughout its whole length in clusters of 1—8 specimens in almost every sample studied. Although rare, *Distephanus speculum* var. *septenarius* (Ehrenberg) Joergensen was also found. *Dictyocha fibula* Ehrenberg, which is believed to favour warm water, was noted but it is not so common as *D. speculum* (1—3 specimens in some samples). The ratios of the silicoflagellates *Dictyocha* to *Distephanus* have been used to determine cold and warm periods in the recent geological record. Schrader and Richert (1974) report that the percentage of *Distephanus* increases exponentially as the surface sea temperature falls from 16.5°C to 8°C, whilst the percentage of *Dictyocha* increases within the range 19.5°C—25°C. Niemelä and Tynni (1979) discuss and present *Dictyocha/Distephanus* ratios which are used to determine the palaeotemperatures of oceanic waters (cf. Gibbard *et al.* 1989). The abundance of silicoflagellates in core A is so low that there is no reason to apply the ratio here. According to Round (1981), *Distephanus* has a higher dissolution rate than *Dictyocha* and therefore the fossil assemblages do not necessarily give an accurate picture of the palaeoenvironment. Furthermore, Sancetta (1990) has recently shown that forms of silicoflagellates do not have a simple and consistent relationship to the temperature of the overlying water column.

Ebria tripartita (Schumann) Lemmermann, which belongs to the order Ebriales, was also found, although rarely. In contrast, occurrences of the dinoflagellate species *Actiniscus pentasterias* Ehrenberg are common.

Above a depth of 12.15 m, freshwater species of interest in the core are *Cymbella cuspidata* Kützing, *C. turgida* Gregory, *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg, *S. javanica* (Grunow) Cleve and genera of *Eunotia* and *Pinnularia*. The aerophilic species found in modern terrestrial habitats, e.g. *Hantzschia amphioxys* (Ehrenberg) Grunow, *Pinnularia borealis* (Ehrenberg) and *Aulacoseira epidendron* (Ehrenberg) Crawford, are also fairly common. These freshwater diatoms are very different from those found in the clay layer underlain by silt.

As shown by the diatoms, the clay in the lower part of the core was deposited in freshwater. The lowermost sample (at a depth of 12.75 m) was probably contaminated in the course of sampling, and the Eemian species derive from the overlying deposits. The bulk of the core deposited in the littoral part of the Eemian Baltic Sea, which is characterized by the rich diatom flora interpreted as typical of it.

Core B

Owing to the difficulty of sampling, core B is discontinuous (Fig. 4). It is composed of silt and gyttja silt. The diatom flora in the basal part (at a depth of 9—10 m) is similar to that in the silt of core A. *Grammatophora oceanica, G. oceanica* var. *macilenta, Hyalodiscus scoticus, Melosira sulcata and Rhabdonema arcuatum* are the dominant species, although other diatoms characteristic of the Eemian Baltic Sea also occur. The silicoflagellates *Distephanus speculum* and *Dictyocha fibula* and also *Actiniscus pentasterias* are all present.

The species change at a depth of 8 m, and the lagoonal species *Campylodiscus clypeus* and *Nitzschia scalaris* predominate (Fig. 4). These species are classified among the *Clypeus* flora, which were typical of the Holocene Litorina Sea of the Baltic Sea, indicating the lagoonal phase slightly before the basin was isolated from the sea (in detail cf. Grönlund in press).

A corresponding *Clypeus* flora was earlier encountered in an Eemian deposit at the Evijärvi site in a silt layer interpreted as having accumulated in a shallow bay of the Eemian Baltic Sea (Eriksson *et al.* 1980). At Evijärvi, the *Clypeus* flora accounts for less than 5 % of the species

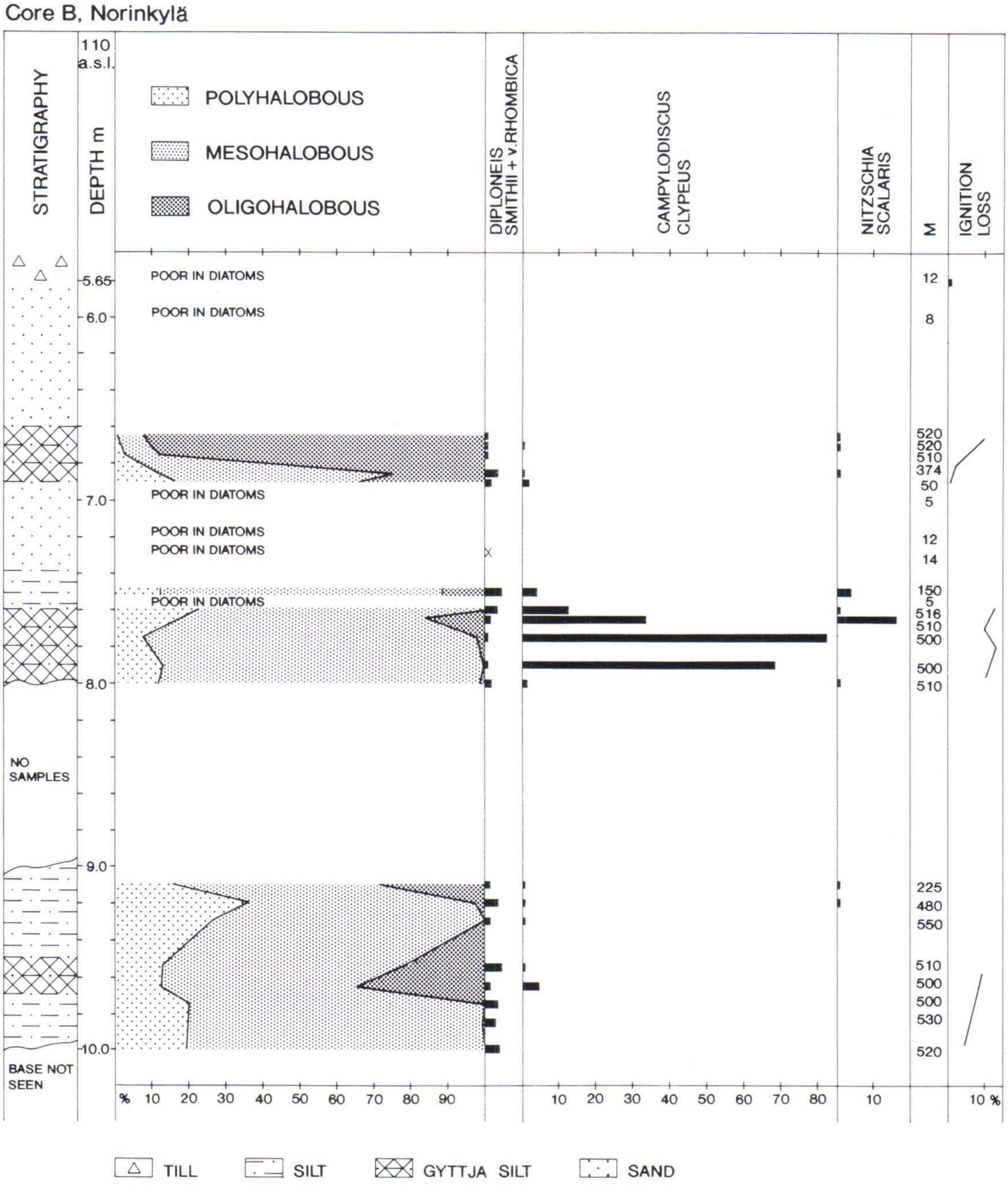

Fig. 4. The diatom groups by salinity and lagoonal species in core B, Norinkylä.

and is thus not as abundant as in core B at Norinkylä.

According to the pollen composition, the deposit containing the *Clypeus* flora at Norinkylä is distinctly interglacial: *Corylus* pollen account for about 20 % of total arboreal pollen (Brita

Core C, Norinkylä

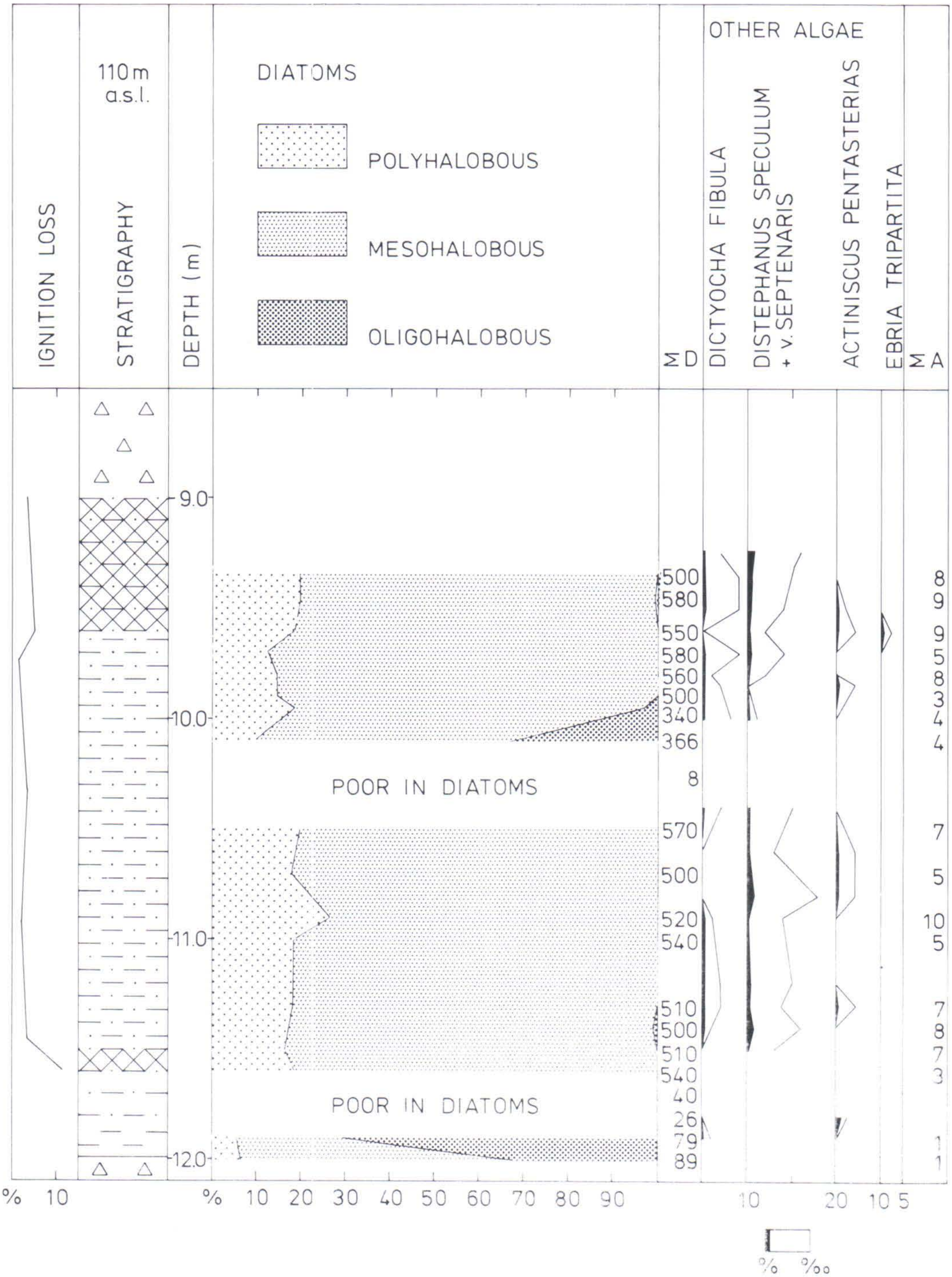

Fig. 5. The diatom groups by salinity and investigated silicoflagellates and other algae (calculated from total diatoms) in core C, Norinkylä. Sediment symbols as in Figure 3.

Eriksson, oral communication). Moreover, at 110 m a.s.l., the Norinkylä site is above the highest local Holocene Litorina Sea shore at about 90 m a.s.l. (Hyyppä 1966, Eronen 1974). Therefore, the *Clypeus* flora cannot be attributed to contamination of the sample.

Freshwater diatoms increase markedly in the upper part of the core, accounting for over 90 % of the species. *Cymbella aspera* (Ehrenberg) Peragallo, *C. cistula* (Ehrenberg) Kirchner, *C. cuspidata, C. tumida* (Brébisson) Grunow and *C. turgida* as well as the genera *Eunotia* and *Pinnularia* predominate.

The upper part of core B deposited in shallow lagoonal water of the Eemian Baltic Sea. Eventually the basin was already isolated from the marine water body.

Core C

Lowermost in the profile is a 15 cm thick layer of clay overlain by silt with organic matter (Fig. 5). Only one sample of the clay deposit was analysed for diatoms (at a depth of 11.90 m). Freshwater diatoms predominate in the sample, with *Aulacoseira islandica* and its resting spores, *A. lirata* and *A. italica* var. *valida* (Grunow) Simonsen as the main species. *Cyclotella kützingiana* and *Melosira arenaria* Moore are also fairly abundant.

The lower part of the silt deposits and the sample at a depth of 10.30 m are poor in diatoms, but otherwise the silt deposit contains the same rich Eemian Baltic Sea diatom flora as the previous profiles. *Distephanus speculum, Dictyocha fibula* and *Actiniscus pentasterias* are also fairly abundant. The diatoms, classified according to their salinity demand are presented in Figure 5. The diagram also shows the silicoflagellates, and *Ebria tripartita* and *Actiniscus pentasterias* encountered. The abundances of the latter are given as pro mil curves calculated from the total diatom abundance (Fig. 5).

The diatom flora is composed almost exclusively of polyhalobous and mesohalobous taxa. Surprisingly enough, at a depth of 10.10 m, the sample contains 32 % freshwater species but the number of species is very low. *Pinnularia lata* (Brébisson) W. Smith predominates (24 %), the others being *Melosira arenaria, Eunotia praerupta* Ehrenberg, *Tetracyclus lacustris* var. *capita* Hustedt, *Aulacoseira islandica* and fragments of *Pinnularia* species. Most of these are oligotrophic lake species and probably derive from the upper horizons as a result of contamination in the course of sampling.

Core D

The profile is composed of silt and gyttja silt (Fig. 6). In its diatom assemblage the lower part of the profile resembles that of profile C. In the lowermost samples (at a depth of 11.85—11.90 m), which are silt, not clay as in profile C, *Aulacoseira* species predominate. Here, too, *A. islandica* and its resting spores and *A. lirata* are clearly dominant. *Diploneis domblittensis* (Grunow) Cleve, *Cymbella sinuata* Gregory, *Stephanodiscus astraea s.l.* (Ehrenberg) Grunow and *A. islandica* are all considered to be great-lake species. This flora is typical of the Holocene Ancylus Lake stage of the Baltic Sea and similar habitats.

From a depth of 11.75 m upwards the taxa are composed almost exclusively of diatom flora typical of the Eemian Baltic Sea, and the species are the same as those in the previous cores.

Five samples were studied from the till overlying the silt at a depth of 8—9 m (Fig. 6). Their loss-on-ignition is fairly high, 4—7 %, indicating a high content of reworked older organic material. The samples are moderately rich in diatoms. Three of the samples are composed almost exclusively of freshwater diatoms. The flora is typical of oligotrophic lakes, with abundant species of the genera *Pinnularia* and *Eunotia*. Diatoms of the genera *Navicula, Neidium* and *Cymbella* are also present. The diatom flora

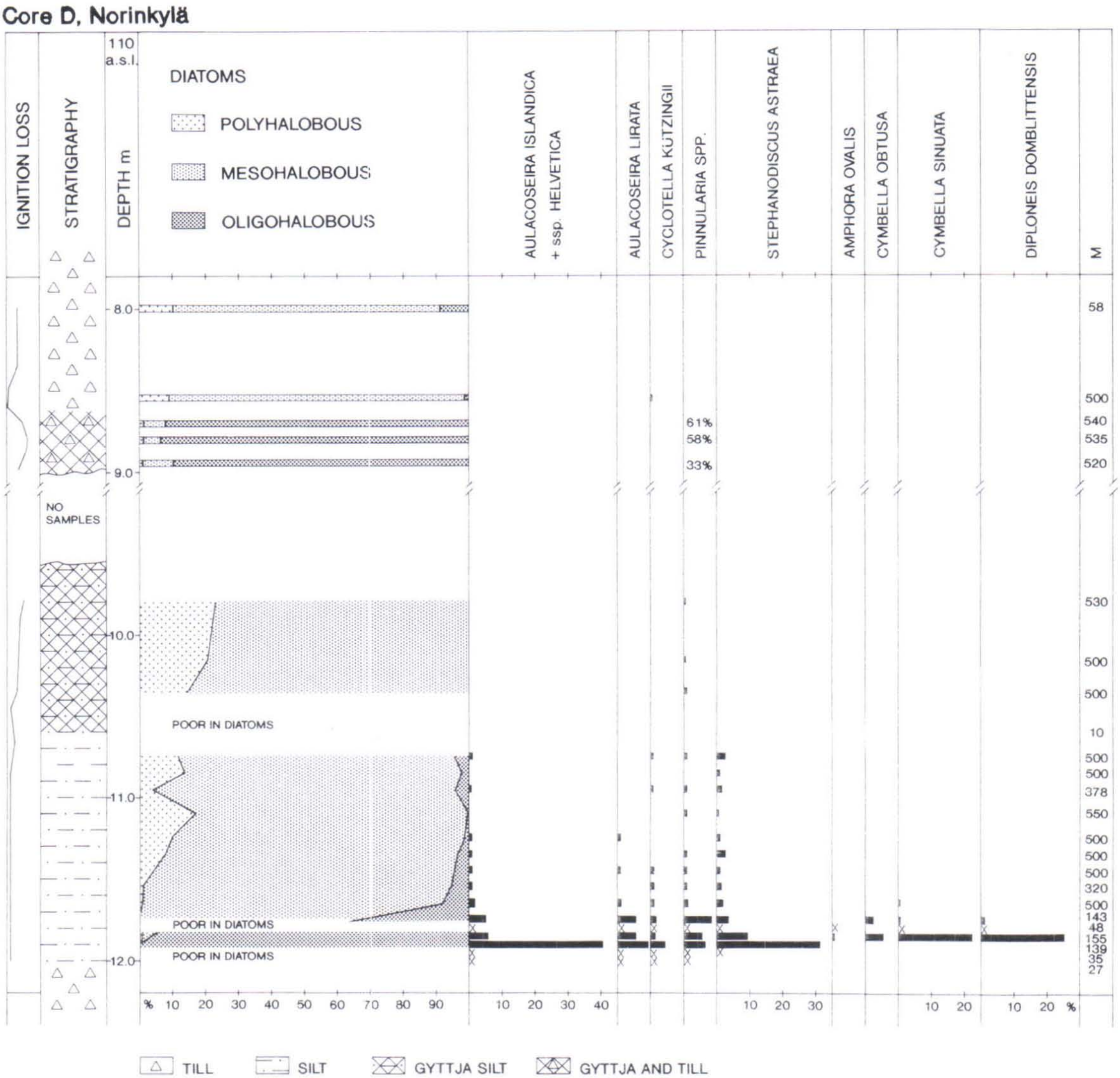

Fig. 6. The diatom groups by salinity and some selected freshwater species in core D, Norinkylä.

is comparable to that in core B at a depth of 6.65—6.85 m. One of the samples contains only diatoms typical of the Eemian Baltic Sea, with *Grammatophora oceanica* and *Hyalodiscus scoticus* as the dominant species. In the last subsample, mesohalobous diatoms are in the majority (81 %), with lagoonal phase *Campylodiscus clypeus* (67 %) as the dominant species. Material from the underlying Eemian deposits has obviously become intermixed with the till.

The lower part of profile D deposited in a freshwater basin of the Holocene Ancylus Lake type, which was soon inundated by the Eemian Baltic Sea. The topmost part of the Eemian deposit, which contains materials from sea, lagoonal, isolation and lacustrine phases, was later pushed into the till layer covering it.

OPEN SECTION OF THE HAAPALANKANGAS ESKER AT JURVA

A silt deposit from a section in Haapalankangas (Jurva) (62° 40′ N, 21°55′E), which is part of an adjoining till-covered esker chain, was also studied. This esker chain trends in the same direction as that studied by Niemelä and Tynni (1979) and Donner (1988) but lies about 12 km further north. The elevation of the section is 95 m a.s.l. The silt studied is in the same stratigraphic position as the silt in the core profiles and in the section investigated by Niemelä and Tynni (1979) and Donner (1988).

A silt layer encountered in the Haapalankangas section is about 1 m thick. The diatoms in the layer were studied from a sample taken at a depth of 3 m. The stratigraphy of the section is as follows: lowermost is gravel overlain by about one metre of till, followed by a silt layer and 2 m of gravel, and uppermost is about 80 cm of till. Diatoms are moderately abundant, although the number of species is low. *Aulacoseira islandica* is overwhelmingly predominant, accounting for 78 % of the taxa. Other freshwater diatoms are *Amphora ovalis* Kützing, *Cyclotella kützingiana, Cymatopleura elliptica* (Brébisson) W. Smith, *Diploneis domblittensis* (Grunow) Cleve and *Stephanodiscus astraea s.l.*, all of which are found in Ancylus Lake sediments. The taxa also include some diatoms indicating saline water such as *Grammatophora oceanica, Actinocyclus kützingii, Chaetoceros mitra* (Bailey) Cleve and *Nitzschia punctata* (W. Smith) Grunow.

THE UKONKANGAS SITE AT KÄRSÄMÄKI

The Ukonkangas site at Kärsämäki is a gravel pit in a till covered esker (63°55′05′′N, 25°51′40′′E) (Fig. 7). Its elevation is the same as that of Norinkylä, i.e. 110 m a.s.l. The site, which is the easternmost of the Eemian sites encountered in Ostrobothnia thus far, was found by Hannu Peltoniemi in 1988 in the course of a gravel resource inventory undertaken by the Ministry of Roads and Waterways in Finland. The samples were taken by Matti Saarnisto in 1989. The stratigraphy of the pit is as follows: lowermost is gravel followed by blue silt obviously *in situ* overlain by laminated sand and gravel, and uppermost is about 2 m of compact till. Silt occurs in the exposed section over a distance of about 15 m. The samples for diatom analysis were taken from the silt layer at a spot where the layer was about 0.5 m thick.

The silt contained diatoms in moderate abundance, but none were found in the thin sand layer cutting the silt layer. The diatom flora is presented in Figure 8, where it is divided into polyhalobous, mesohalobous and oligohalobous species. Some selected diatom species are also shown.

The taxa in the silt below the sand layer are the same as those interpreted as typical of the Eemian Baltic Sea, e.g. the species encountered at Norinkylä and earlier in Ostrobothnia (Niemelä & Tynni 1979, Eriksson *et al.* 1980, Forsström *et al.* 1987, 1988, Grönlund 1988, Nenonen *et al.* in press), the Karelian Isthmus (Brander 1937a and b, 1941, 1943) and Prangli island (Cheremisinova 1961, Liivrand 1984, 1987). Mesohalobous diatoms predominate, with polyhalobous species accounting for slightly over 20 % and oligohalobous species for 5.4 % at the most. *Grammatophora oceanica, Hyalodiscus scoticus, Melosira sulcata* and *Rhabdonema arcuatum* are the dominant species. The polyhalobous *Podosira montagnei* is also fairly common. Of the other polyhalobous species, mention should be made of *Actinocyclus kützingii, Chaetoceros mitra, C. subsecundus* (Grunow) Hustedt,

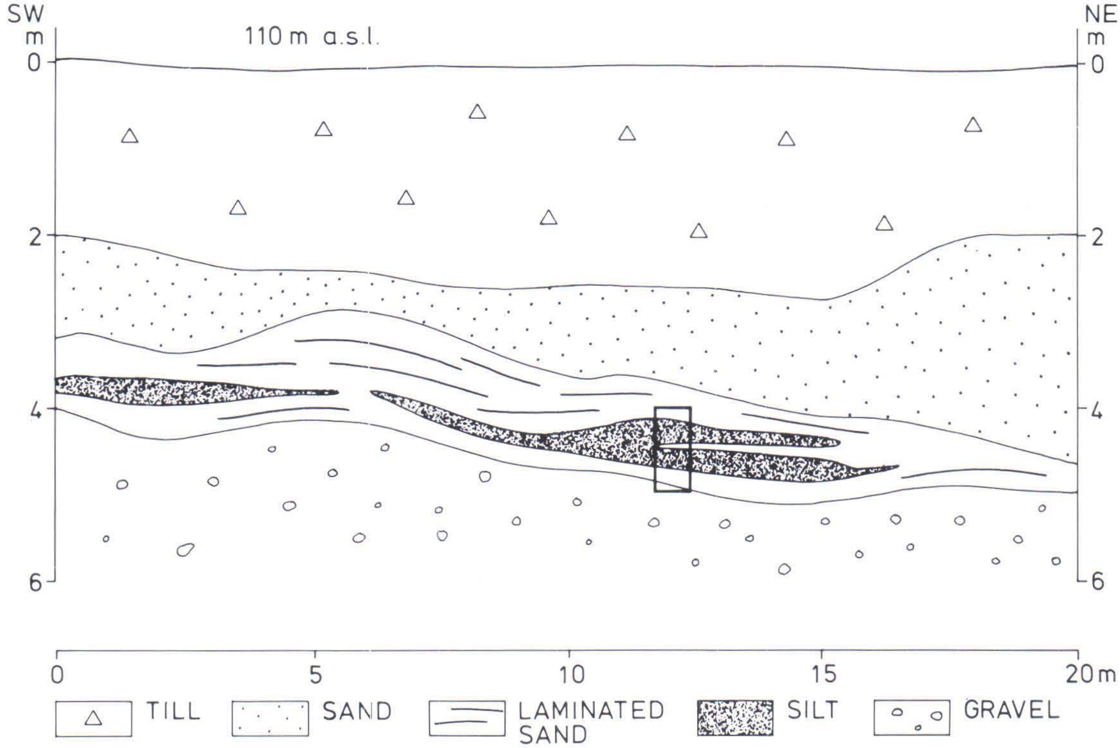

Fig. 7. Section of the gravel pit in the Ukonkangas (Kärsämäki) site.

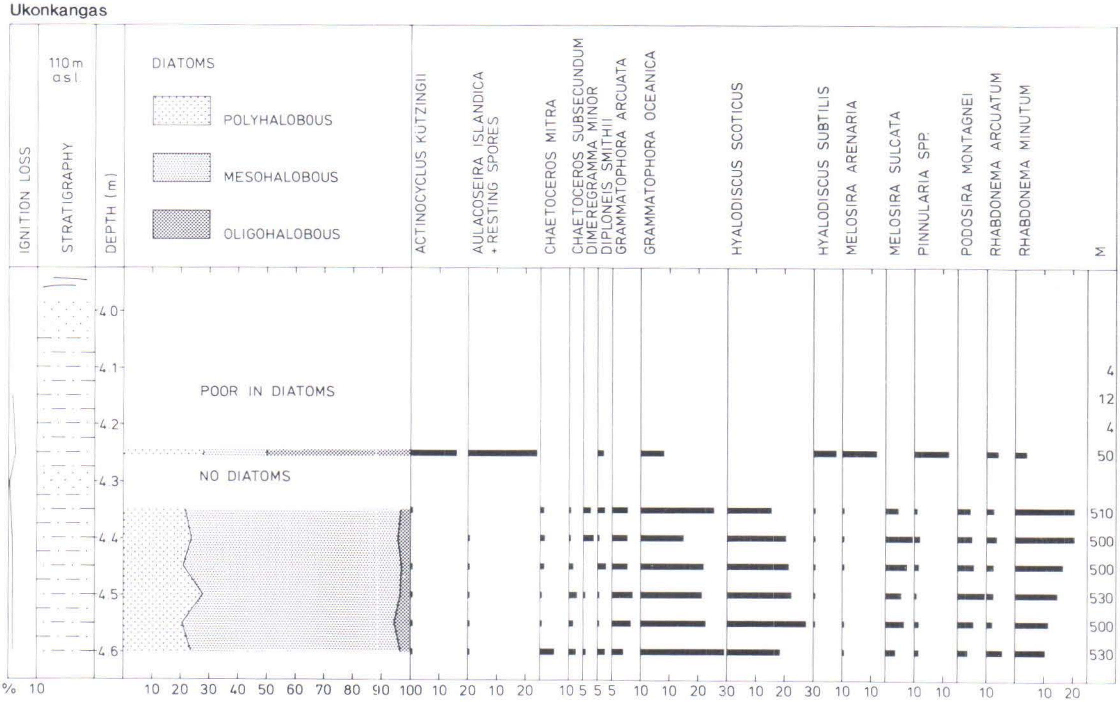

Fig. 8. The diatom groups by salinity and some selected diatom species in the Ukonkangas site. Sediment symbols as in Figure 7.

Dimeregramma minor, Navicula glacialis and *Thalassiosira eccentrica*. *Campylodiscus clypeus*, which is one of the lagoonal species, is encountered in all samples, but *Amphora robusta* and *Nitzschia scalaris* of the same group occur only in some.

The silicoflagellates *Distephanus speculum, D. speculum* var. *pentagonus* Lemmerman, *D. speculum* var. *septenarius* and *Dictyocha fibula* were encountered, as were *Ebria tripartita* and *Actiniscus pentasterias*.

The silt above the sand layer was markedly poorer in diatoms than was the underlying silt. The number of species was also low, about half of them being freshwater diatoms. *Aulacoseira islandica* and its resting spores, *Melosira arenaria, Stephanodiscus astraea s.l.* and some species of the genus *Pinnularia* are included in the diatom flora. The species indicating saline water are the same as those in the silt below the sand layer.

The till-covered silt at Ukonkangas deposited in the littoral phase of the Eemian Baltic Sea, where the diatom flora is similar to that encountered in the corresponding sediments in Ostrobothnia. As the flora includes diatoms indicating a shallow lagoonal phase, the basin was probably growing shallower and its water less saline.

Preliminary pollen analyses conducted at Ukonkangas show the presence of *Betula, Alnus* and *Pinus* pollen with some low values of *Picea* in the pollen stratigraphy of the silt layer. Also present are pollen of *Corylus,* typical of the Eemian. This pollen assemblage refers to a very constant vegetation, probably of the late temperate Eemian stage (B. Eriksson, oral communication). Temporally, the silt at Ukonkangas obviously represents a rather short period in the history of the Eemian Baltic Sea.

DISCUSSION

Several sediment cores representing the Eemian interglacial are described above from Norinkylä and sections from Ukonkangas and Haapalankangas. As the cores were discontinuous it is not possible to give a complete stratigraphic column. The discontinuity of the sample sets is partly due to the difficulty of sampling, although it is feasible that the till-covered sedimentary deposits were initially incomplete, having been eroded and displaced by the overriding continental ice sheet.

At the Norinkylä site the peat deposit is underlain by the till that covers the eskers in the surroundings including the esker studied by Niemelä and Tynni (1979) and Donner (1988), and Haapalankangas (Jurva). Drilling (Fig. 2) revealed a layer of fine-grained sediment containing material of the Eemian Baltic Sea below this till. In holes drilled closer to the esker the fine-grained sedimentary deposits also contain sand from the esker fringes. Successful drill holes intersected the older till below the sedimentary deposit, showing that the Eemian sediments are sandwiched between two till layers differing in age.

Three of the Norinkylä cores (A, C and D) have sediments with freshwater diatoms as the lowermost unit. Two of these (A and C) are clay, and one (D) is silt. At Haapalankangas, there is also one separate silt sample from a till-covered esker containing mainly freshwater diatoms. A feature shared by all the diatom assemblages is the abundance of great-lake species, *Amphora ovalis, Aulacoseira islandica, A. islandica* subsp. *helvetica, Cymbella aspera, C. sinuata, Diploneis domblittensis, Melosira arenaria* and *Stephanodiscus astraea s.l.* In addition to them, core A contains abundant *Aulacoseira lirata*, common in smaller lakes, and some species of the genus *Pinnularia*. The diatom flora encountered correlates with that in the clay below the Eemian Baltic Sea deposit at Viitala about 60 km to the northeast of Norinkylä (cf. Nenonen *et al.* in press).

According to available data, the sediment of the lake preceding the Eemian Baltic Sea is directly overlain by a deposit of that sea only at Norinkylä and Viitala in southern Ostrobothnia. In the course of till studies in Ostrobothnia till-covered sediments containing freshwater diatoms have been found, at some sites e.g. the Vesiperä site (Nenonen *et al.* in press). These diatoms often represent great-lake diatoms (Ancylus Lake) in which *Aulacoseira islandica* and *A. islandica* subsp. *helvetica* and their resting spores predominate. As these deposits are isolated, and diatoms have not been encountered either above or below them, it is not possible to place them in the diatom stratigraphy.

Freshwater diatoms have also been found intermixed with Eemian Sea flora (cf. Niemelä & Tynni 1979). These deposits either refer to littoral areas of the Eemian Baltic Sea or then their diatom flora includes redeposited species. Freshwater diatoms, which are often encountered redeposited in till, may derive from interglacial or interstadial freshwater deposits.

According to Cheremisinova (1961) (see also Liivrand 1987, in press), the diatom flora indicating cool fresh water, and intermixed with the Eemian Baltic Sea diatom flora of encountered in the Prangli deposit below the sediments of the Eemian Baltic Sea, derive from a glacial lake invaded by the Eemian Baltic Sea. The glacial lake was comprised the basin of the Gulf of Finland and the lakes Ladoga and Onega. Its diatom flora contained cold freshwater relict species, such as the *Cocconeis disculus* (Schumann) Cleve, *Diploneis domblittensis* and *D. domblittensis* var. *subconstricta* A. Cleve mentioned by Cheremisinova. The flora also includes *Stephanodiscus astraea, Navicula tuscula Ehrenberg, Melosira arenaria* and species of the genera *Pinnularia, Epithemia* and *Neidium.* The cold water relicts mentioned by Cheremisinova are also encountered in Holocene Ancylus Lake deposits (Clever-Euler 1953). Among the flora described by Cheremisinova are the same species as those in the freshwater deposits underlying the Eemian deposits in Ostrobothnia. The greatest difference is that *Aulacoseira islandica,* which is common in Ostrobothnia, is absent from the Prangli deposit. In Ostrobothnia, particularly in the lowermost samples, the *Aulacoseira* species often occur as resting spores, suggesting adverse, probably cold, conditions.

The history of the Baltic Sea since the latest glaciation (Late Weichselian) includes the Baltic Ice Lake, which covered the area that emerged from the ice sheet as far as the Salpausselkä marginal formations during Late Weichselian time, that is, before 10 000 B.P., and the Yoldia phase, which started when the Baltic Ice Lake drained to ocean level. The Yoldia Sea preceded the Ancylus Lake, which is usually marked by a rise in the number of diatoms. Information about the diatoms of the two first mentioned stages (the Baltic Ice Lake and the Yoldia Sea) is meagre; indeed these stages are marked by a scarcity of diatoms (cf. also Brunnberg & Miller 1990). It is possible that muddy water from the thawing ice was a limiting factor on the growth of diatoms. *Aulacoseira islandica* subsp. *helvetica* is the most common diatom in the Baltic Ice Lake. The Yoldia phase is characterized by a mixture of brackish water, great freshwater lake and small-lake diatoms. *Aulacoseira islandica* subsp. *helvetica* is a common species in the Yoldia flora, too. Assuming that post-glacial development in the basin of the Eemian Baltic Sea was similar to that during the Holocene, it may well be that the Eemian freshwater diatom flora encountered in Ostrobothnia also contains older diatoms, perhaps species similar to those of a glacial lake, e.g. *Aulacoseira islandica* and *A. islandica* subsp. *helvetica.* The same may hold for the »cold water relict species» found on Prangli island. From the above it follows that the freshwater sediments predating the Eemian marine sediments encountered in Ostrobothnia and on Prangli island mainly deposited in the same basin, which resembled the Holocene Ancylus lake rather than a glacial lake. This freshwater basin may contain redeposited cold water species.

In the Norinkylä deposit, the freshwater deposit is overlain by silt that clearly deposited in the Eemian Baltic Sea. The silt layer varies in thickness, being thickest in core A. This variation may partly be due to the sampling, but it may also reflect primary depositional conditions. The diatom flora in the silt is of a type that flourishes in fairly saline water. The same diatom flora is also encountered in the silt at Ukonkangas. A total of 152 taxa of diatom species indicating saline water were named from the Norinkylä cores, 89 of them polyhalobous and 63 mesohalobous (including meso- and pleioeyryhaline polyhalobous). Littoral diatoms predominate and pure plankton diatoms are scarce. The mesohalobous *Grammatophora oceanica, G. oceanica* var. *macilenta, Hyalodiscus scoticus, Rhabdonema arcuatum* and *Melosira sulcata* are clearly dominant. In addition to them, the flora includes several species foreign to or very rare in the Holocene diatom flora of the Baltic Sea. These include *Amphora acuta, Diploneis chersonensis, D. crabro, D. mediterranea* and *D. schmidti,* demonstrating that the water was more saline than in the Holocene Litorina stage. The salinity of the water is also indicated by silicoflagellates, *Ebria tripartita* and *Actiniscus pentasterias.* Many of the species favour warm water habitats, although there are some that thrive in cold water. The presence of these species confirms that the Eemian Baltic Sea was connected with the Atlantic Ocean in the west and the White Sea in the east. In terms of diatom flora, the situation was similar to that prevailing in the present Gulf of Bothnia in relation to the Baltic Sea proper.

Besides saline species, the silts at Norinkylä contain up to 20 % fresh water diatoms. At Ukonkangas, freshwater diatoms account for a mere 2—3 %, excluding the uppermost sample, which contains abundant diatoms, 50 % of them freshwater species. The sample probably refers to a sea bay turning progressively less saline before being isolated as a freshwater basin due to isostatic land uplift. The freshwater diatom flora in the till overlying the silt in core D at Norinkylä may also represent a post-isolation interglacial freshwater basin. In other respects, the occurrence of freshwater diatoms in the silt deposits is probably due to the proximity of the shore.

The upper part of the silt deposit in core B at Norinkylä contains diatom flora indicative of a lagoonal phase preceding the isolation of the basin from the sea. The beginning of the isolation is recorded in the same profile at about a metre above the lagoonal sediments. In profile D the sediments of the lagoonal phase and isolation were obviously mixed with the overlying till. The Ukonkangas site shows the earlier part of a lagoonal phase.

CONCLUSION

Figures 9 and 10 summarize the stages of the Eemian Baltic Sea based on data from deposits in Ostrobothnia. Figure 9 presents four new cores from Norinkylä, and the cores from Viitala (110 m a.s.l.) (Nenonen *et al.* in press), Evijärvi (67 m a.s.l.) (Eriksson *et al.* 1980), Ukonkangas (110 m a.s.l.) and Ollala (125 m a.s.l.) (Forsström *et al.* 1987) plotted in a south-north direction according to their elevation and location. Figure 10 shows the same sites projected in accordance with the stages of the Eemian Baltic Sea.

It seems highly probable that, in the present basin of the Baltic Sea, the Eemian Baltic Sea was preceded by a lake stage with diatom flora similar to that of the Holocene Ancylus Lake. The Ancylus Lake was considerably larger than the present Baltic Sea, partly because of the pronounced glacio-isostatic depression of the crust

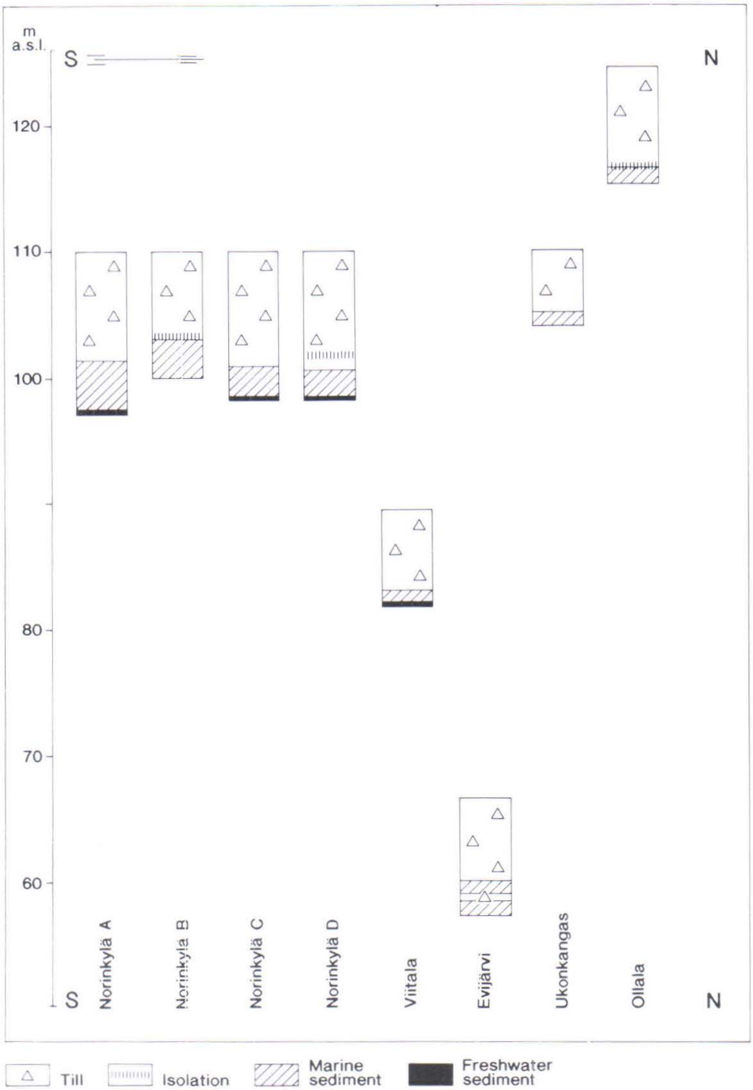

Fig. 9. The cores studied plotted with their elevations above the present sea level from south to north.

within the Baltic basin. Sufficient data are not available for us to establish either the size or the northern extent of the lake preceding the Eemian Baltic Sea.

All the above sites contain deposits of the Eemian Baltic Sea proper. Their diatom floras are rich in species and very similar to each other, representing littoral areas of the sea. Several species are alien to later stages of the Baltic Sea. Many of the diatoms indicate highly saline and warm water conditions.

Diatoms indicating a lagoonal phase, the species being the same as in the *Clypeus* flora encountered in the Holocene Litorina Sea, are best represented in profile B at Norinkylä and, intermixed with the overlying till, in profile D. The lagoonal phase is also recorded at the Evijärvi site (Eriksson *et al.* 1980).

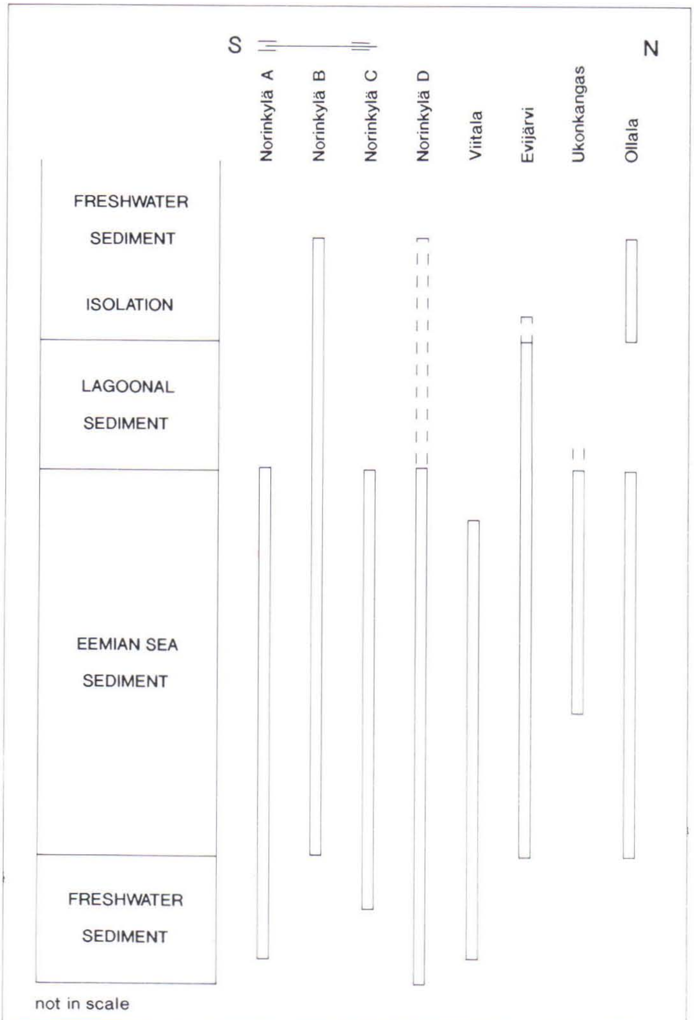

Fig. 10. Schematic stratigraphic sequences according to environmental changes in the Eemian Baltic Sea based on sediment cores from the sites studied.

The basin became progressively less saline until it was finally isolated from the sea as an independent freshwater basin in the same way as later basins were isolated from the Holocene Litorina Sea and the present Baltic Sea. The isolation event is most clearly recorded at the Ollala and Norinkylä sites, although Evijärvi, too, shows indications of incipient isolation.

On the basis of a tentative pollen stratigraphy from the Norinkylä site (cores B and D) the sediments of the lake preceding the Eemian Baltic Sea probably deposited during the pre-temperate substage characterized by birch and pine. The deposits of the Eemian Baltic Sea proper accumulated during the temperate substage characterized by birch, alder, oak and hazel, and the isolation from the sea at the end of it (B. Eriksson, oral communication). The core studied by Niemelä and Tynni (1979) also referred to the temperate substage. According to the schematic interglacial pollen diagram of Donner (1988, p. 26, Fig. 12), the sediments from Norinkylä studied by Niemelä and Tynni (1979) predate those from the Evijärvi site, which can also be considered to represent a temperate stage. The Evijärvi site is situated at a lower elevation and thus emerged from the sea later. The pollen dating is in accordance with the emergence history of the area.

According to Eriksson (oral communication), it is likely that the sediments from the Ukonkangas site also deposited at the end of the temperate substage.

ACKNOWLEDGEMENTS

I wish to thank Professors Urve Miller and Matti Saarnisto for critically reading the manuscript and making valuable comments.

I am also grateful to Brita Eriksson for our many useful discussions, especially about pollen analysis, and Hannu Peltoniemi for providing the material from Ukonkangas. My warmest thanks are due to Heikki Hirvas and Keijo Nenonen for useful discussions about till stratigraphy of Ostrobothnia and for providing the material from Norinkylä.

Pertti Hakala and Eila Paavilainen helped in the field and in the laboratory, Satu Moberg did the drawings and Gillian Häkli translated the manuscript; to all of them I express my cordial thanks.

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Plate I

Fig. 1. *Amphora crassa* Gregory
2. *Amphora acuta* Gregory
3. *Stephanopyxis turris* (Greville) Ralfs
4. *Actiniscus pentasterias* Ehrenberg
5. *Thalassiosira gravida* Cleve
6. *Amphora costata* W. Smith
7. *Campylodiscus clypeus* Ehrenberg
8. *Distephanus speculum* (Ehrenberg) Haeckel
9. *Dictyocha fibula* Ehrenberg
10. *Nitzschia scalaris* W. Smith

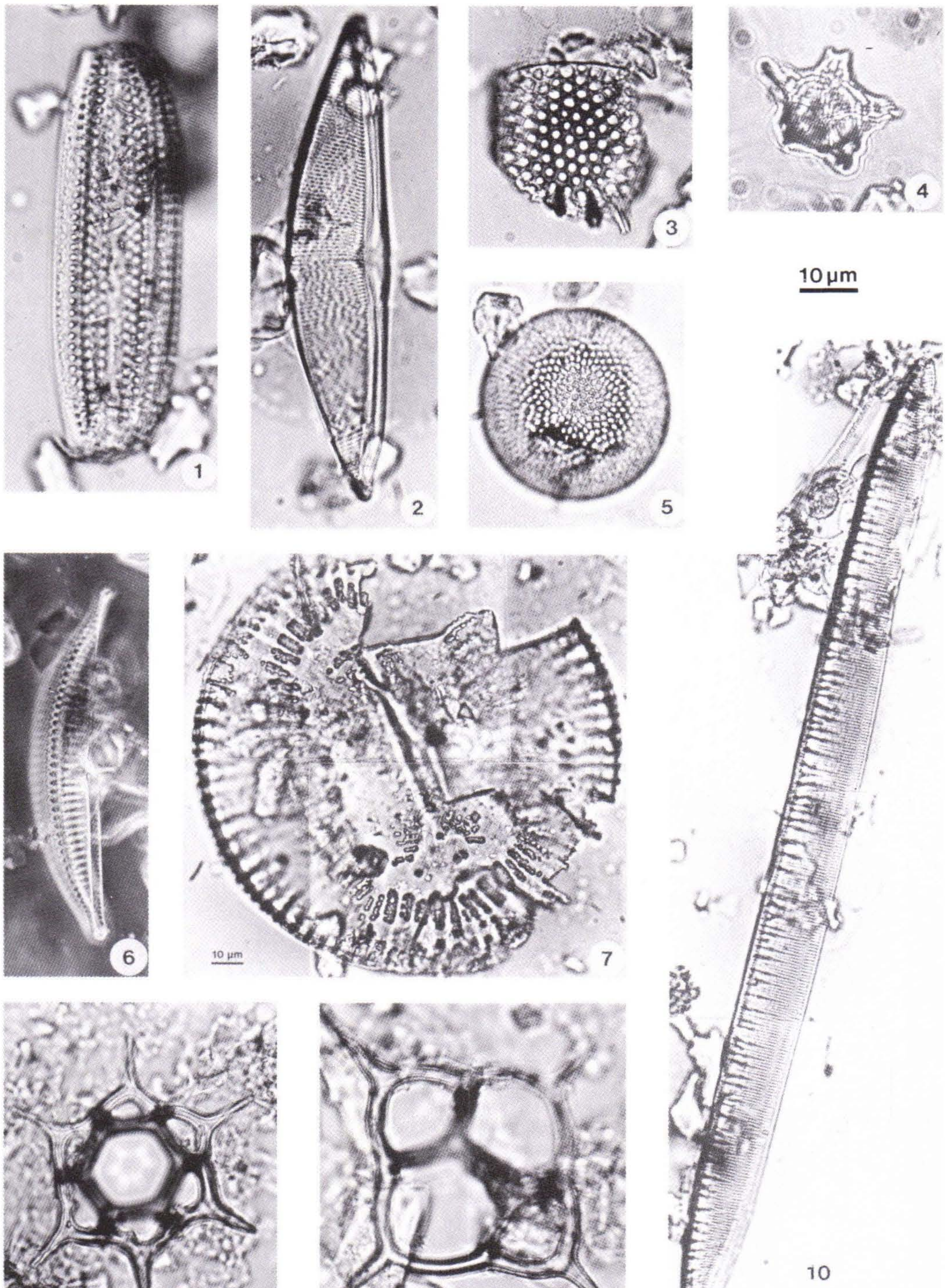
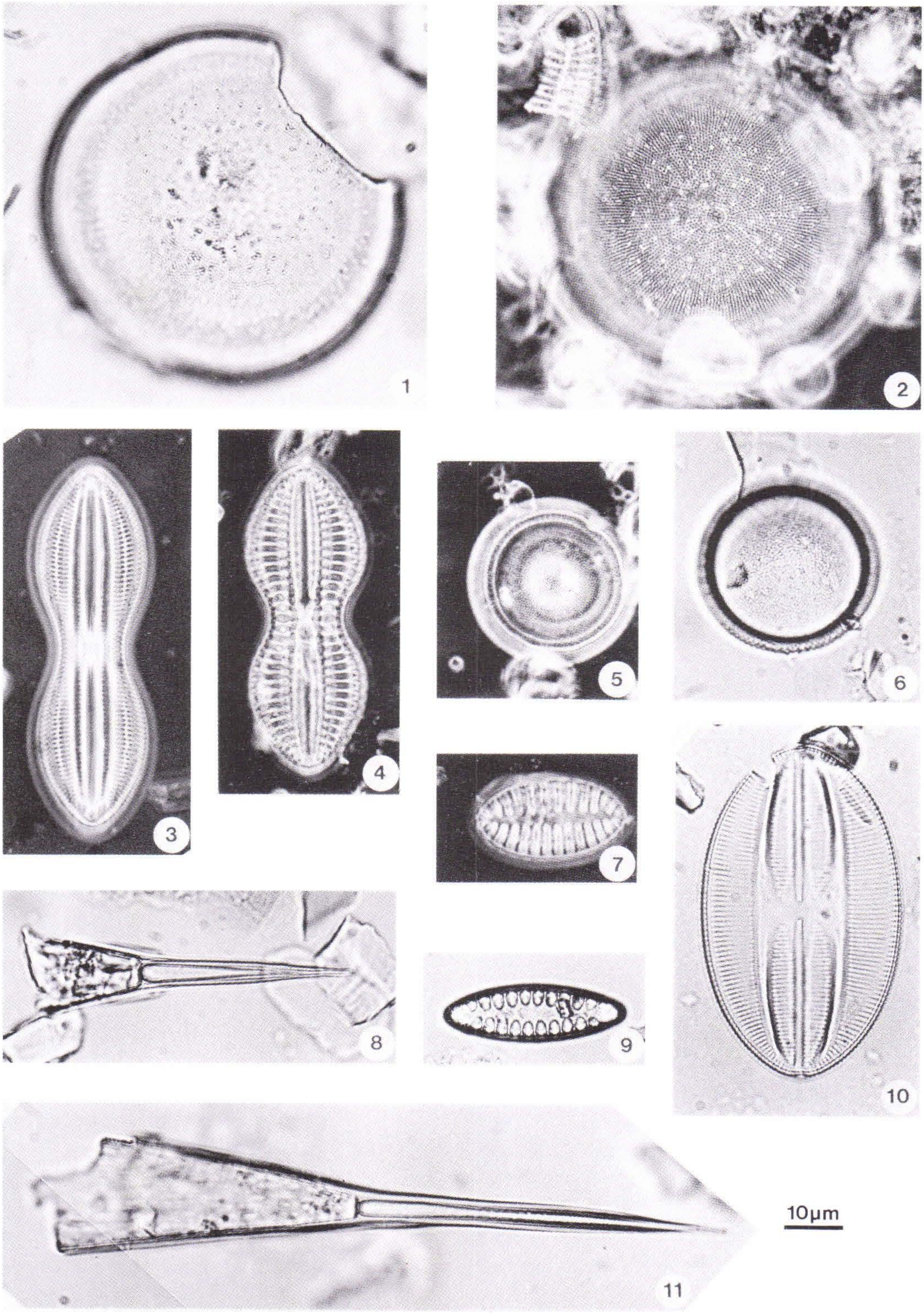

1
2
3
4
10 µm
5
6
10 µm
7
8
9
10
10 µm

Plate II

Fig. 1. *Podosira hormoides* (Montagne) Kützing
2. *Podosira hormoides* (Montagne) Kützing
3. *Diploneis chersonensis* (Grunow) Cleve
4. *Diploneis crabro* Ehrenberg
5. *Podosira montagnei* Kützing
6. *Podosira montagnei* Kützing
7. *Cocconeis costata* Gregory
8. *Rhizosolenia hebetata for. hiemalis* Gran
9. *Glyphodesmis distans* (Gregory) Grunow
10. *Navicula opuntioides* Simonsen
11. *Rhizosolenia hebetata for. hiemalis* Gran


1
2
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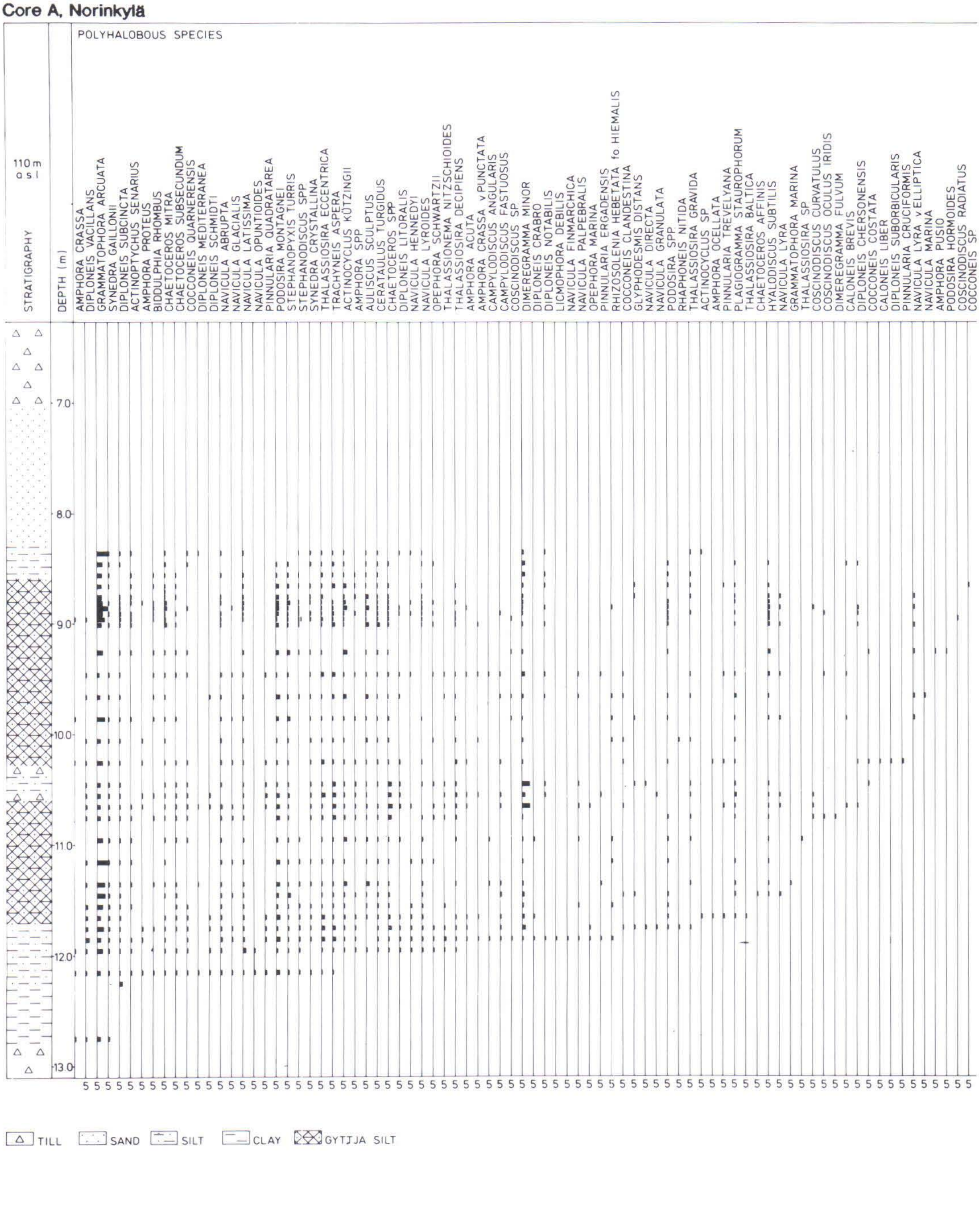
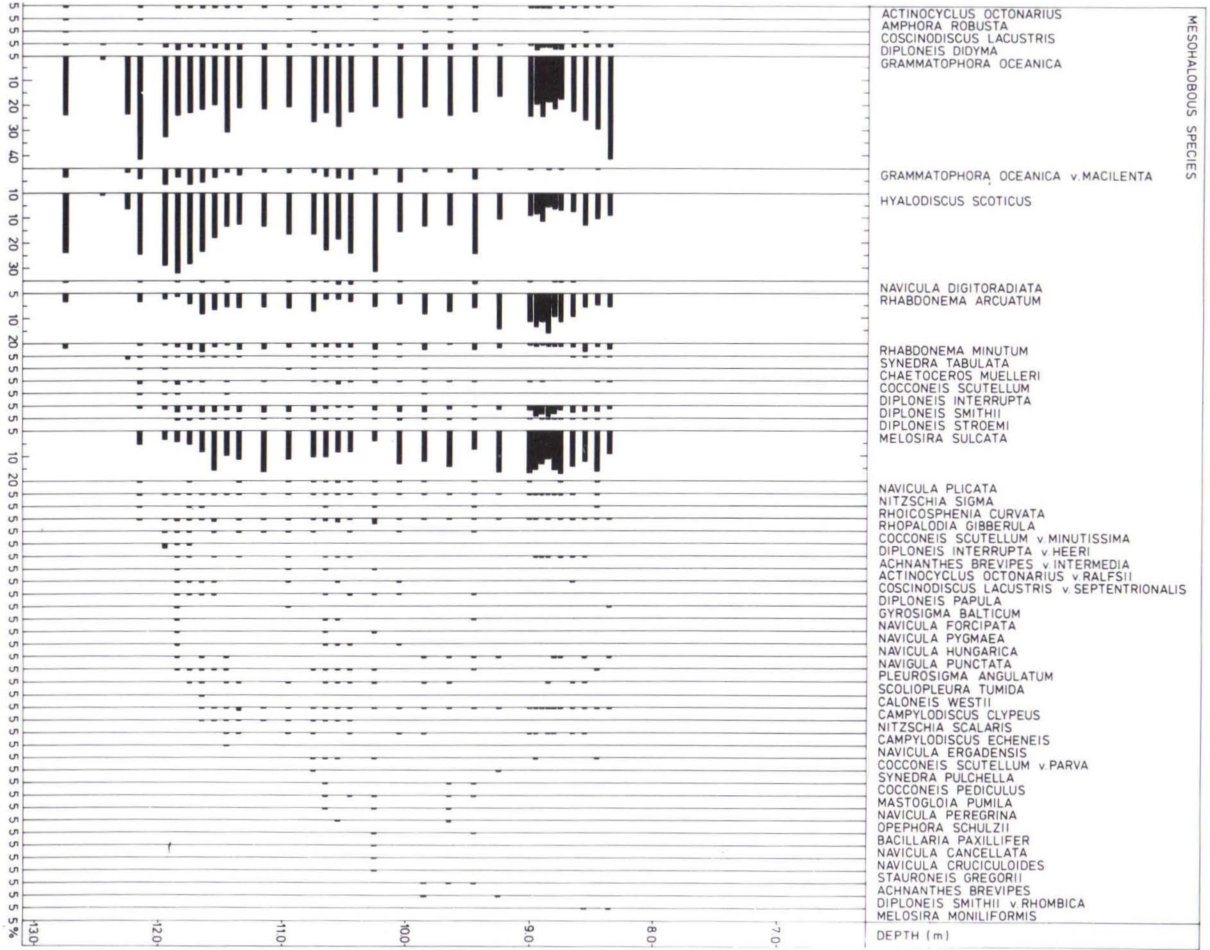
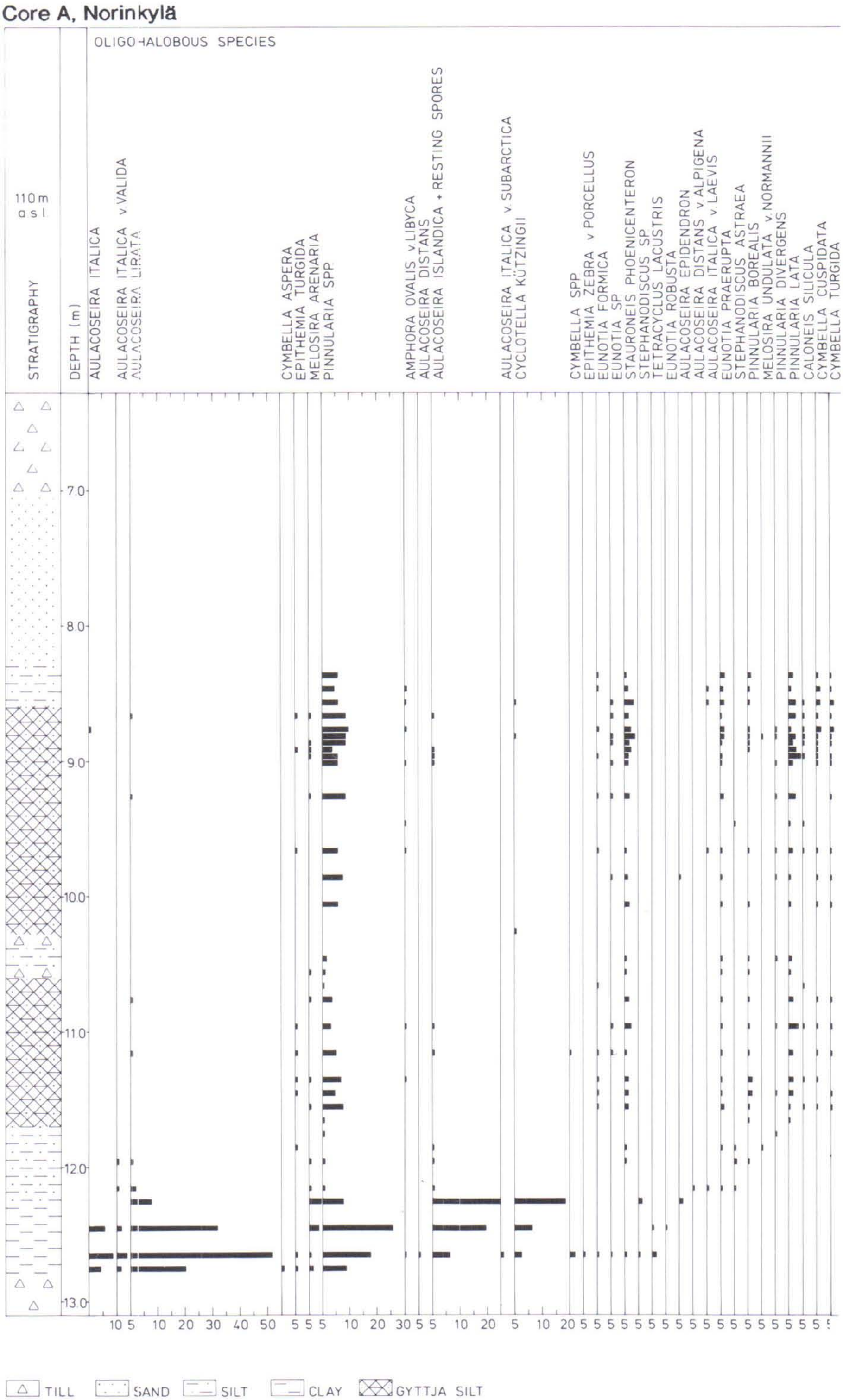
11
10μm

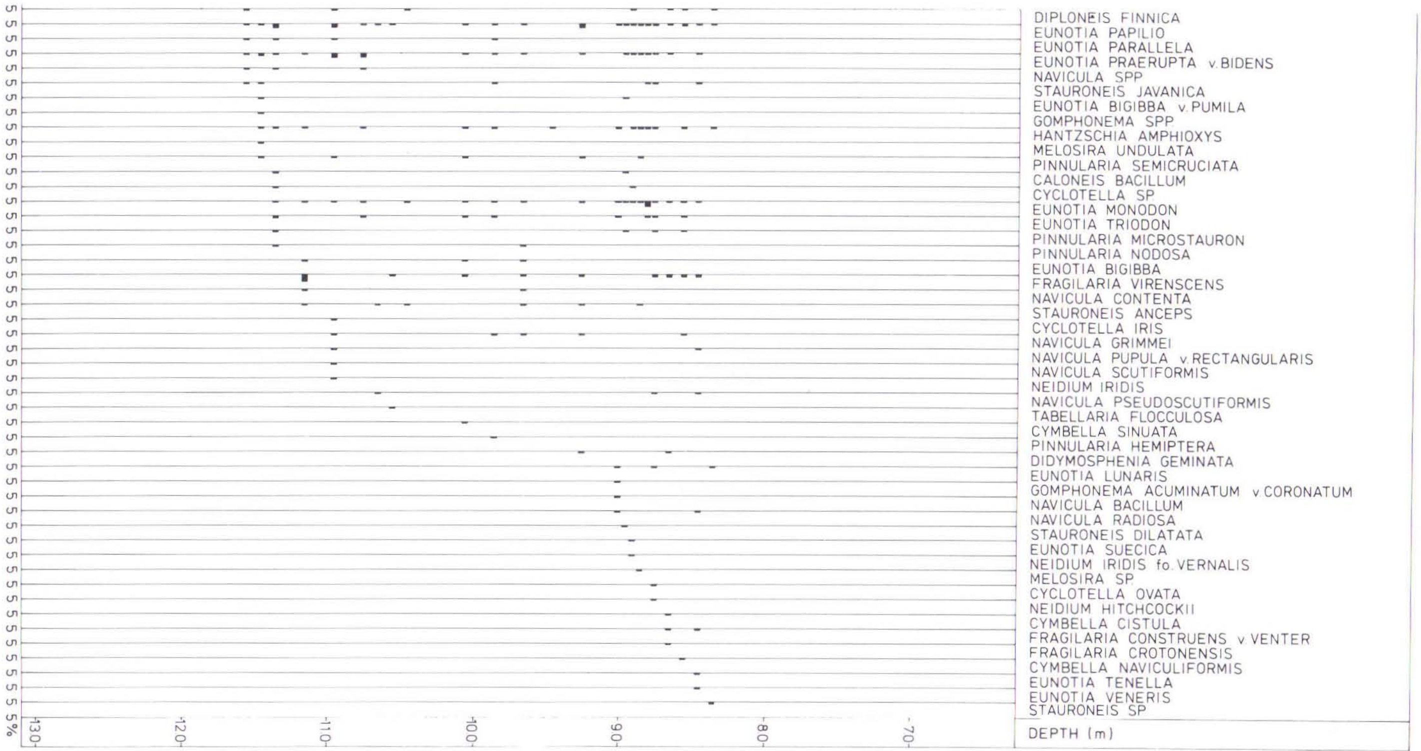
APPENDIX 1. The succession of polyhalobous and mesohalobous diatom taxa in core A from the Norinkylä site.




ACTINOCYCLUS OCTONARIUS
AMPHORA ROBUSTA
COSCINODISCUS LACUSTRIS
DIPLONEIS DIDYMA
GRAMMATOPHORA OCEANICA
GRAMMATOPHORA OCEANICA v. MACILENTA
HYALODISCUS SCOTICUS
NAVICULA DIGITORADIATA
RHABDONEMA ARCUATUM
RHABDONEMA MINUTUM
SYNEDRA TABULATA
CHAETOCEROS MUELLERI
COCCONEIS SCUTELLUM
DIPLONEIS INTERRUPTA
DIPLONEIS SMITHII
DIPLONEIS STROEMI
MELOSIRA SULCATA
NAVICULA PLICATA
NITZSCHIA SIGMA
RHOICOSPHENIA CURVATA
RHOPALODIA GIBBERULA
COCCONEIS SCUTELLUM v. MINUTISSIMA
DIPLONEIS INTERRUPTA v. HEERI
ACHNANTHES BREVIPES v. INTERMEDIA
ACTINOCYCLUS OCTONARIUS v. RALFSII
COSCINODISCUS LACUSTRIS v. SEPTENTRIONALIS
DIPLONEIS PAPULA
GYROSIGMA BALTICUM
NAVICULA FORCIPATA
NAVICULA PYGMAEA
NAVICULA HUNGARICA
NAVIGULA PUNCTATA
PLEUROSIGMA ANGULATUM
SCOLIOPLEURA TUMIDA
CALONEIS WESTII
CAMPYLODISCUS CLYPEUS
NITZSCHIA SCALARIS
CAMPYLODISCUS ECHENEIS
NAVICULA ERGADENSIS
COCCONEIS SCUTELLUM v. PARVA
SYNEDRA PULCHELLA
COCCONEIS PEDICULUS
MASTOGLOIA PUMILA
NAVICULA PEREGRINA
OPEPHORA SCHULZII
BACILLARIA PAXILLIFER
NAVICULA CANCELLATA
NAVICULA CRUCICULOIDES
STAURONEIS GREGORII
ACHNANTHES BREVIPES
DIPLONEIS SMITHII v. RHOMBICA
MELOSIRA MONILIFORMIS
MESOHALOBOUS SPECIES
DEPTH (m)
130
120
110
100
90
80
70
%

APPENDIX 2. The succession of freshwater diatom taxa in core A from the Norinkylä site.




DIPLONEIS FINNICA
EUNOTIA PAPILIO
EUNOTIA PARALLELA
EUNOTIA PRAERUPTA v.BIDENS
NAVICULA SPP
STAURONEIS JAVANICA
EUNOTIA BIGIBBA v.PUMILA
GOMPHONEMA SPP
HANTZSCHIA AMPHIOXYS
MELOSIRA UNDULATA
PINNULARIA SEMICRUCIATA
CALONEIS BACILLUM
CYCLOTELLA SP
EUNOTIA MONODON
EUNOTIA TRIODON
PINNULARIA MICROSTAURON
PINNULARIA NODOSA
EUNOTIA BIGIBBA
FRAGILARIA VIRENSCENS
NAVICULA CONTENTA
STAURONEIS ANCEPS
CYCLOTELLA IRIS
NAVICULA GRIMMEI
NAVICULA PUPULA v.RECTANGULARIS
NAVICULA SCUTIFORMIS
NEIDIUM IRIDIS
NAVICULA PSEUDOSCUTIFORMIS
TABELLARIA FLOCCULOSA
CYMBELLA SINUATA
PINNULARIA HEMIPTERA
DIDYMOSPHENIA GEMINATA
EUNOTIA LUNARIS
GOMPHONEMA ACUMINATUM v.CORONATUM
NAVICULA BACILLUM
NAVICULA RADIOSA
STAURONEIS DILATATA
EUNOTIA SUECICA
NEIDIUM IRIDIS fo.VERNALIS
MELOSIRA SP
CYCLOTELLA OVATA
NEIDIUM HITCHCOCKII
CYMBELLA CISTULA
FRAGILARIA CONSTRUENS v.VENTER
FRAGILARIA CROTONENSIS
CYMBELLA NAVICULIFORMIS
EUNOTIA TENELLA
EUNOTIA VENERIS
STAURONEIS SP
DEPTH (m)
130
120
110
100
90
80
70
5%

Tätä julkaisua myy

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Denna publikation säljes av

GEOLOGISKA FORSKNINGSCENTRALEN (GFC)
Publikationsförsäljning
02150 Esbo
☎ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GFC, Mellersta Finlands distriktsbyrå
Biblioteket
PB 1237
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Biblioteket
PB 77
96101 Rovaniemi
☎ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

This publication can be obtained from

GEOLOGICAL SURVEY OF FINLAND (GSF)
Publication sales
SF-02150 Espoo, Finland
☎ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GSF, Regional office of Mid-Finland
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P.O. Box 1237
SF-70101 Kuopio, Finland
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GSF, Regional office of Northern Finland
Library
P.O. Box 77
SF-96101 Rovaniemi, Finland
☎ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

ISBN 951-690-417-3
ISSN 0367-522-X

Vammala 1991
Vammalan Kirjapaino Oy