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Sediments from interglacial sites in Ostrobothnia, western Finland have been investigated for their diatom content. All the sites are correlated with the Eemian interglacial stage.

The diatom successions of two of the sites, Norinkylä (Teuva) and Viitala (Peräseinäjoki), begin with freshwater diatoms indicating deposition in a freshwater (great lake) basin. A rich marine diatom flora is found overlying the sediments with freshwater diatoms. The other sites Evijärvi, Ollala (Haapavesi) and Ukonkangas (Kärsämäki), have also a similar marine flora with *Grammatophora oceanica, Hyalodiscus scoticus, Paralia sulcata* and *Rhabdonema arcuatum* as dominant species. The flora also includes many diatoms that mainly thrive in highly saline water and have not been found in Finland earlier. In the Ollala and Norinkylä deposits, there is a transition from marine to freshwater diatoms implying isolation from the sea. The marine deposits at the sites are interpreted as having been deposited in the Eemian Baltic Sea, and the freshwater sediments found beneath the marine deposits in a lake which occupied the Baltic basin and preceded the Eemian Baltic Sea.

The history of the Eemian Baltic Sea is discussed and a comparison is also made with the Holocene Baltic basin.

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

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The thesis is based on the following papers:

I **Eriksson, B., Grönlund, T. & Kujansuu, R. 1980.** Interglasiaalikerrostuma Evijärvellä, Pohjanmaalla. Summary: An interglacial deposit at Evijärvi in the Pohjanmaa region, Finland. Geologi 32, 65—71.

II **Forsström, L., Eronen, M. & Grönlund T. 1987.** On marine phases and shore levels of the Eemian interglacial and Weichselian interstadials on the coast of Ostrobothnia, Finland. *In* Perttunen, M. (editor): Fennoscandian land uplift. Proceedings of a symposium at Tvärminne, April 10—11, 1986, arranged by Finnish National Committee for Quaternary Research. Geological Survey of Finland, Special Paper 2, 37—42.

III **Forsström, L., Aalto, M., Eronen, M. & Grönlund, T. 1988.** Stratigraphic evidence of the Eemian crustal movement and relative sea-level changes in Eastern Fennoscandia. Palaeogeography, Palaeoclimatology, Palaeoecology 68, 317—335.

IV **Grönlund, T. 1988.** The diatom flora of the Eemian deposit at Haapavesi, western Finland. Geological Survey of Finland, Report of Investigation 79, 14 p.

V **Nenonen, K., Eriksson, B. & Grönlund, T.** The till stratigraphy of Ostrobothnia, western Finland, with reference to new Eemian interglacial sites. *In* Andersen, B.G. & Königsson L.-K. (editors): Late Quaternary Stratigraphy in the Nordic Countries 150.000—15.000 B.P. Striae 34, in press.

VI **Grönlund. T.** The lagoonal diatom flora of the Holocene Baltic Litorina Sea in comparison with the Eemian Baltic Sea flora. Proceedings of the Eleventh International Diatom Symposium San Francisco, California, August 12—17, 1990, in press.

VII **Grönlund, T. 1991.** New cores from Eemian interglacial marine deposits in Ostrobothnia, Finland. Geological Survey of Finland, Bulletin 352 23 p.

CONTENTS

INTRODUCTION

The evolution of the present Baltic Sea, which is one of the largest brackish water basins in the world, has been a subject of numerous studies in the countries bordering it. The Holocene history of the Baltic Sea is indeed well established (e.g. Backman & Cleve-Euler 1922, Backman 1937, Florin 1946, 1957, Cleve-Euler 1951—55, Sauramo 1958, Simonsen 1962, Mölder & Tynni 1967—73, Alhonen 1971, 1979, Eronen 1974, 1983, Tynni 1975—80, Miller & Robertsson 1979, Hyvärinen & Eronen 1979, Gudelis 1979, Winterhalter *et al.* 1981, Hyvärinen 1980, 1984, Paabo 1985 and Donner & Raukas 1989), and its stages have been dated by the ^{14}C method. However, the history of the Baltic Sea before the latest glacial stage, the Weichselian, is less well known, particularly with respect to Fennoscandia.

Some marine deposits of the Holsteinian interglacial, which preceded the Saalian glaciation, are known, e.g. in Denmark (Madsen 1928, Andersen 1963, 1965) and Germany (Königsson 1979), but neither the depth nor the extent of the Baltic Sea basin at that time have been established in detail (Königsson 1979).

Miller (1977) has correlated mainly lacustrine diatom spectra from Hyby, southern Sweden, with the Holsteinian interglacial and Robertsson (1988a) presents the Eemian or possibly Holsteinian sediments also with freshwater diatom flora from Öje, central Sweden.

Somewhat more information is available about the Eemian Baltic Sea, which existed during the Eemian interglacial, between the Saalian and Weichselian glaciations (cf. Fig. 1). The term Eemian (Eem) for the sea gained currency after three Danes, V. Madsen, V. Nordmann and N. Hartz, who had introduced it in a joint paper in 1908. The interglacial was named after the small Dutch river on which the stratotype of the Eemian interglacial lies.

Eemian pollen assemblages found in Fennoscandia clearly indicate a warmer climate than that which prevailed during the Holocene climatic optimum. Considering geographic position, the assemblages correlate with those of mainland Europe (cf. Andersen 1961, Menke 1985, Behre & Lade 1986, Liivrand 1984). The pollen diagrams indicate a well differentiated flora, the evolution of vegetation in northwestern Europe being broadly as follows: the initial birch and pine prevalence was followed by mixed-oak-forest characterized by great amounts of hazel and later also by alder. The late-temperate substage was characterized by hornbeam and later by spruce. Pine and birch dominated during the post-temperate substage. In Finnish material the succession is the same but hornbeam pollen occur only sporadically (Brita Eriksson, oral communication, cf. also Donner 1971).

In the deep sea oxygen isotope ($^{18}O/^{16}O$) curve, the Eemian interglacial has been correlated with stage 5, which is composed of several substages (Fig. 2) (Shackleton 1969, Mangerud in press). The oldest of them, 5e, represents the interglacial stage of true continental areas. The thermal maximum of the Eemian interglacial has been dated between 125 000—128 000 B.P. (Shackleton & Obdyke 1973, Martinson *et al.* 1987).

In the areas south of the present Baltic Sea palaeoenvironments of the Eemian Baltic Sea has been studied mainly with the aid of fauna remains (e.g. Madsen *et al.* 1908). Those encountered in the Eemian Baltic Sea deposits are very homogeneous, comprising only marine species. Since the fauna includes several thermophilous, Lusitanian species (Lusitania = Portugal) (Nilsson 1983) it is assumed that the Eemian Baltic Sea was warmer than the present North Sea. It is further assumed that the sea was in open connection with the Atlantic Ocean through the English Channel. The marine diatoms found in the Eemian deposits imply that the water approached the ocean salinity during the Eemian interglacial stage and it was more saline than in the Baltic Sea during any of its postglacial stages (cf. Brockmann 1928, Brander 1937a and b, Cheremisino-

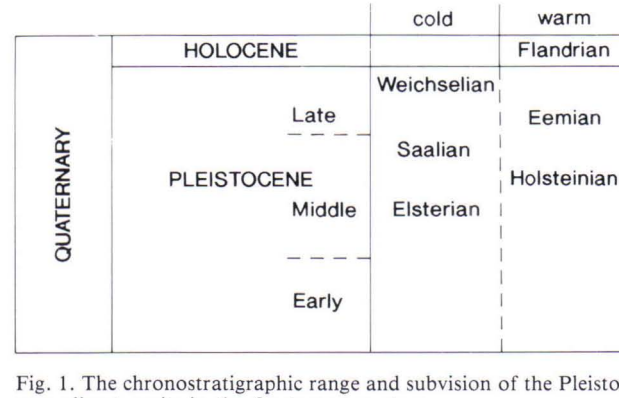

Fig. 1. The chronostratigraphic range and subvision of the Pleistocene climate units in the Quaternary system.

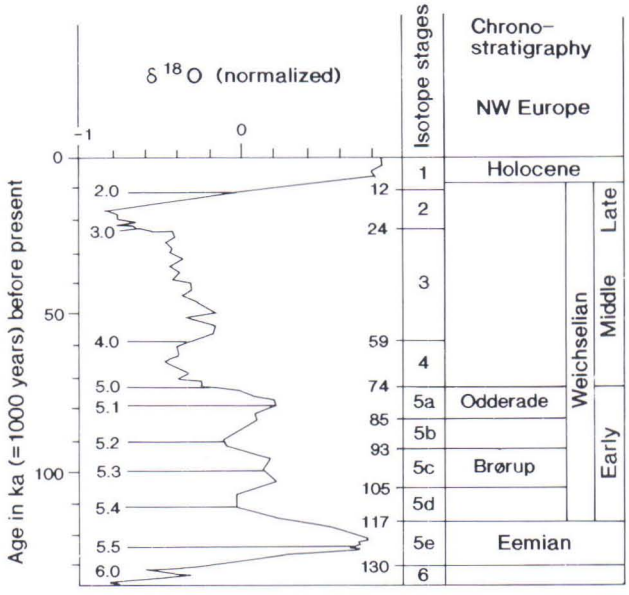

Fig. 2. The oxygen isotope curve, the last six oxygen-isotope stages of a generalized palaeotemperature record and the chronostratigraphy in northwestern Europe modified after Mangerud (in press).

va 1961, Niemelä & Tynni 1979, Eriksson *et al.* 1980, Forsström *et al.* 1987 and Grönlund 1988).

In the Eemian time (5e), the sea level was a few metres higher than it is at present (Bloom *et al.* 1974). The highest shore line of the Eemian Baltic Sea is not known in eastern Fennoscandia, but it is likely that immediately after deglaciation the sea reached the highest level similarly as the Weichselian glaciation. The occurrence of molluscs that thrive in cold water, e.g. Portlandia (Yoldia) arctica, among species favouring warm water has led to the distinction of a separate Portlandia Sea phase in the Eemian interglacial sea (Fig. 3) (Zans 1936). During this phase the sea extended from the Baltic to the White Sea. Its chronological position and age in relation to the Eemian Baltic Sea are disputed, and it has been correlated with either the initial or final stages of the Eemian Baltic Sea. Older interpretations (Zans 1936 and Brander 1937b) ascribe it to the end of the Eemian interglacial. According to Zans, the warm Eemian transgression took place during the first half of the Eemian interglacial and the cool Portlandia transgression during its second half. Gross (1967) considers it slightly older than the Eemian Baltic Sea, while Cleve-Euler (1940) holds it synchronous with the Eemian Baltic Sea. Cheremisinova (1965) too, places it in the Eemian warm stage, suggesting that the cold molluscs were transported from the Arctic Ocean by sea currents.

The first sediments containing marine diatoms related to the northern and northeastern parts of the Eemian Baltic Sea were found in the Karelian Isthmus (Brander 1937a and b, 1943) (Fig. 4). Since then, sediments containing diatoms interpreted as having depo-

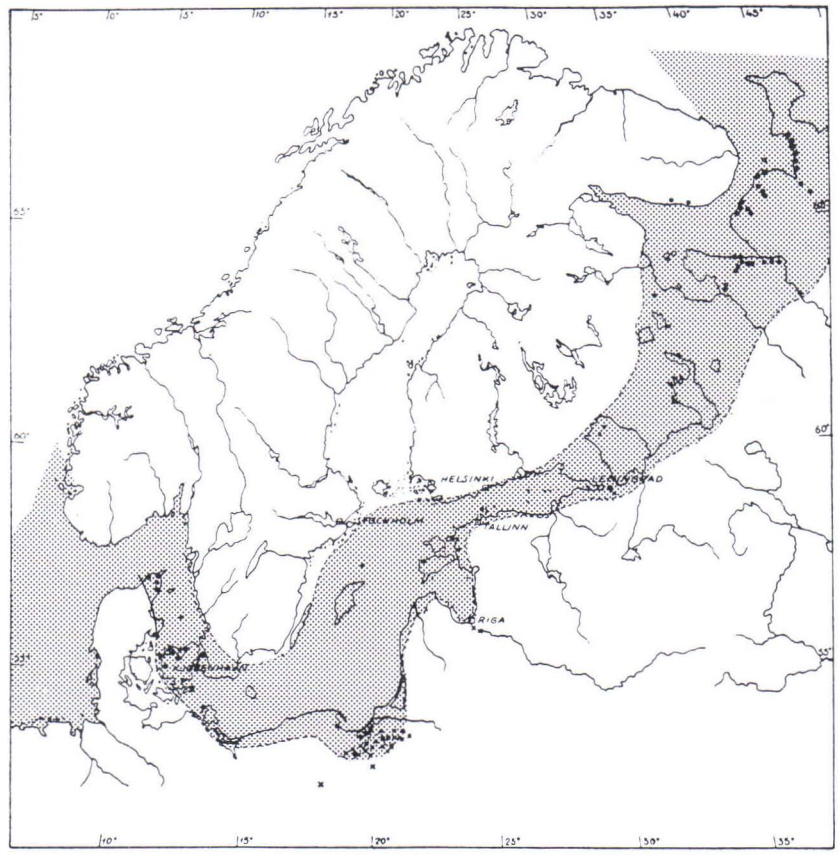

Fig. 3. Eemian and Portlandia Seas in the Baltic basin and the northwestern Russia according to Zans (1936 Fig. 1, p. 247).

Fig. 4. The map showing localities with Eemian marine diatom bearing sediments from northern Europe, this study based on the sites marked with ringed dots.

sited in the Eemian Baltic Sea, but in fact often redeposited, have been found in Finland (Niemelä & Tynni 1979). Redeposited diatoms of the Eemian Baltic Sea have also been encountered in late-glacial clay in Somero southwestern Finland (Tynni 1971) and in till at several localities in Ostrobothnia (e.g. Niemelä & Tynni 1979, Gibbard *et al.* 1989). It is highly probable that the marine diatoms of the Holocene Yoldia Sea also include a number of redeposited Eemian species (Eronen 1974). Several of deposits of the Eemian Baltic Sea have been found in Ostrobothnia (Niemelä & Tynni 1979, Eriksson *et al.* 1980, Forsström *et al.* 1987, 1988, Nenonen *et al.* in press) (Fig. 4), the most important sites being Evijärvi (Eriksson *et al.* 1980) and Ollala in Haapavesi (Forsström *et al.* 1987, 1988, Grönlund 1988). The Evijärvi site (Eriksson *et al.* 1980) has been proposed as the Eemian stratotype in Finland (Donner *et al.* 1986).

Sediments with less abundant Eemian Baltic Sea diatoms have been reported from the western and southern parts of the present Baltic Sea (Fig. 4). In Sweden they have been encountered in Bollnäs and Nyköping (Halden 1915, Miller & Persson 1973, Miller 1986, García Ambrosiani 1990). The sequence from Margareteberg, southwestern Sweden, (Påsse *et al.* 1988) tentatively correlated with the later part of the Eemian interglacial, contains also redeposited marine Eemian diatoms. Eemian Baltic Sea diatom flora from at a depth of 60—70 m below the present sea level on the island of Prangli (earlier Suur-Prangli) on the coast of northern Estonia, in the southern part of Gulf of Finland, was first presented by Cheremisinova (1961) and later by Liivrand (1984, 1987, in press) on the basis of the studies of Cheremisinova. Liivrand (1987) proposed the Eemian Baltic Sea deposit at Prangli as the stratotype for the western part of the northern Baltic.

Kosack and Lange (1985) presented the Eemian strata from Offenbüttel and Schnittlohe in Schleswig-Holstein, northern Germany and demonstrated a connection between the Eemian North Sea and the Baltic Sea with the aid of borehole cores. The Eemian diatom data in brackish-marine sediments from Husum, Schleswig-Holstein, have also been investigated by Tynni (in Menke 1985).

A rich Eemian marine diatom flora has also been presented from Kady (Elblag Heights) near the Gdansk Bay, Poland by Cheremisinova (1965). Elsewhere in Poland the marine deposits of the Eemian interglacial occur in the Lower Vistula river valley (Mojski 1985). These deposits have been investigated by means of their mollusc fauna (e.g. Galon 1938, Makowska 1979, 1980).

The till-covered deposits encountered in Ostrobothnia with diatom flora indicating saline or brackish water environment have been interpreted as having deposited in the Eemian Baltic Sea. No interstadial saline water deposits have been met, but several deposits containing exclusively freshwater diatoms and covered by one till bed have been reported. The most important sites are Oulainen (Forsström 1982), Vimpeli I and II (Aalto *et al.* 1983, 1989) and Marjamurto (Peltoniemi *et al.* 1989). The dates of the first two are still disputed. The sites have been dated mainly by pollen analysis. The Oulainen site (80 m a.s.l.) was originally interpreted as being of interglacial character (Forsström 1982), but later on it was shown to represent an interstadial interval (Donner 1983, Hyvärinen 1985, Forsström *et al.* 1987, Donner 1988, Forsström 1988). Donner *et al.* (1986) correlates it with the Early Weichselian Brörup Interstadial. From the Vimpeli sites (125 m a.s.l.), Vimpeli I was initially correlated with the Eemian interglacial stage (Aalto *et al.* 1983) and later with an Early Weichselian interstadial (Aalto *et al.* 1989). The Marjamurto site (95 m a.s.l.), which appears to be located in the same till-covered esker chain as the Oulainen site, resembles it in lithostratigraphy and biostratigraphy and is thus correlated with the Early Weichselian interstadial, probably the Brörup (Peltoniemi *et al.* 1989).

Harrinkangas, another site in Ostrobothnia, was recently investigated by Gibbard *et al.* (1989) and found to contain freshwater diatom flora. This site, too, is situated on the till-covered esker and is considered late Saalian in age. On the basis of pollen content, the lake sediments have tentatively been interpreted as representing the end of an interglacial, possibly the Eemian stage. Redeposited marine diatoms are also found at the Harrinkangas site. This marine material is intermixed with till in various sections of the lake sediment. As some of the species are the same as those in the Eemian diatom flora of Ostrobothnia, at least part of the material may originate from the Eemian stage.

Interstadial deposits with marine diatoms in the Göta river valley, western Sweden, have been studied by Miller (1964). In Sweden the sequences from Pilgrimstad (Robertsson 1986) and Boliden (Robertsson & García Ambrosiani 1988) with freshwater diatoms are correlated with the Weichselian interstadial whereas the sequence from Seitevare (Robertsson 1988b, Robertsson & Rohde 1988) also containing freshwater diatoms is tentatively correlated with the later part of the Eemian interglacial.

The purpose of this study is to report the latest discoveries on the Eemian Baltic Sea with the aid of diatoms from deposits found in Finland, from the western part of the country, Ostrobothnia, in particular. The main Eemian marine sites studied by means of diatoms and discussed here are Evijärvi (Eriksson *et al.* 1980), Ollala (Haapavesi) (Forsström *et al.* 1987, 1988 and Grönlund 1988), Viitala (Peräseinäjoki) (Nenonen *et al.* in press), Norinkylä (Teuva) (Niemelä & Tynni 1979, Donner 1988 and Grönlund 1991) and Ukonkangas (Kärsämäki) (Grönlund 1991). These papers are summarised in the following. A diatom check-list of the polyhalobous and mesohalobous taxa of the northeastern coastal areas of the Eemian Baltic Sea is also included.

SAMPLING AND METHODS

At Evijärvi, Norinkylä and Viitala the samples were taken with a driven percussion drill fitted with a flow-through bit sampler. At Ukonkangas the samples were taken by spade, as were most of those collected at Ollala.

The samples were bleached in diluted H_2O_2 for 24 h at 50°C, and then subjected to repeated suspension and decantation. The mounting medium was Hyrax Liquid with a refractive index of 1.65.

Whenever possible at least 500 diatom valves were identified in each subsample. The diatoms of all the above sites were classified by salinity preference as polyhalobous (salinity in the habitat 35—17 parts per mille), mesohalobous including meso- and pleioeuryhaline polyhalobous (salinity in the habitat 35—3 parts per mille) and oligohalobous, which are freshwater species. The grouping is that of Simonsen (1962) as applied to Finnish conditions by Tynni (Niemelä & Tynni 1979).

EEMIAN INTERGLACIAL SITES

The locations of the five sites discussed in this thesis are marked in Figure 4. The Evijärvi site is dealt with in paper I, Ollala in papers II, III, and IV, Viitala in paper V, Norinkylä in papers VI and VII and Ukonkangas in paper VII. A silt deposit in a open section of Haapalankangas, the adjacent till-covered esker at Teuva situated only 12 km north of the Norinkylä site, was also studied (paper VII). The silt is in the same stratigraphical position as that in the Norinkylä drill profiles and in the section investigated by Niemelä and Tynni (1979) and Donner (1988). Interglacial diatom flora occurs in gyttja, gyttja silt, silt or clay. At each of the above sites, these sediments are overlain by only one till unit. The following are brief summaries of these sites.

The Evijärvi site (67 m a.s.l.)

The Evijärvi site is situated in central Ostrobothnia (63°26' N, 23°20'E). The interglacial deposits at the Evijärvi site consist of gyttja-silt (at a depth of 7.5 m to 6.4 m) and clay-gyttja (at a depth of 9.0 m to 8.0 m) overlain by till and sand deposits (Fig.5). The upper surface of the gyttja layer is at about 61 m above sea level. These deposits are underlain by till antedating the last interglacial. Radiocarbon dating of the gyttja-silt layer gave an age of > 41 ± 200 BP (Su-736 A) for the NaOH-insoluble fraction, and > 51 ± 800 BP (Su-736 B) for the humus fraction. The pollen assemblage of the silt and the lower part of the gyttja reflects original interglacial flora with an abundance of hazel and oak. The pollen flora of the upper part of the gyttja layer indicates a cooling climate.

The silt layer contains an exclusively marine diatom flora dominated by the mesohalobous *Grammatophora oceanica, G. oceanica* var. *macilenta, Hyalodiscus scoticus, Paralia (Melosira) sulcata* and *Rhabdonema arcuatum*. Several polyhalobous species interpreted typical of Eemian Baltic Sea diatom flora, are also present. Lagoonal diatom flora, including *Amphora robusta, Campylodiscus clypeus* and *Nitzschia scalaris,* were encountered in the lower part of the gyttja layer, which represents a later stage in the history of the basin. The layer had deposited in a shallow marine bay that included a considerable proportion of cool freshwater.

The Ollala site, Haapavesi (124 m a.s.l.)

The location of the Ollala site is 64°10' N, 25°21.5' E, and its deposits consist of a layer of silt (at a depth of 8.7 to 8.1 m) and of gyttja (at a depth of 8.1 to 7.9 m) overlain by a till bed (Fig. 6). The upper surface of the gyttja layer is at about 116 m above sea level. The pollen flora of the site shows that the sediment deposited during an interglacial period.

A rich marine diatom flora was found in the Ollala deposits. The main part of the silt deposit shows a diatom flora of the marine stage proper, dominated by the mesohalobous species *Grammatophora oceanica, Hyalodiscus scoticus* and *Paralia sulcata*. Also present are species typical of the Eemian Baltic Sea and diatoms alien to the postglacial Baltic Sea.

The diatom assemblages from the gyttja layer show that the water in the basin changed from saline to fresh, indicatig that the basin was isolated from the sea.

The Viitala site, Peräseinäjoki (89 m a.s.l.)

The Viitala site is situated (62°36' N, 23°00' E) in southern Ostrobothnia. The site is one of the southernmost interglacial deposits encountered in Finland. The deposit at the site is a clay layer of about half a metre thick (at a depth of 7.5 to 7.1 m), the top of which is at about 82 m above sea level (Fig. 7). The pollen flora of the basal part of the clay layer refers to the beginning of a vegetation cycle dominated by birch. This was followed by pine and oak indicating a warmer climate.

The diatom succession of the clay layer begins with freshwater diatoms but the diatom flora soon changes radically, and diatoms characterizing marine conditions are found. *Grammatophora oceanica, Hyalodiscus scoticus, Paralia sulcata* and *Rhabdonema minutum* dominate. Several other diatoms considered to be Eemian Baltic Sea species are present. The lower part of the clay deposited in fresh, possibly cool, mineral bearing water. The upper part of the clay deposited in the Eemian Baltic Sea during the littoral phase.

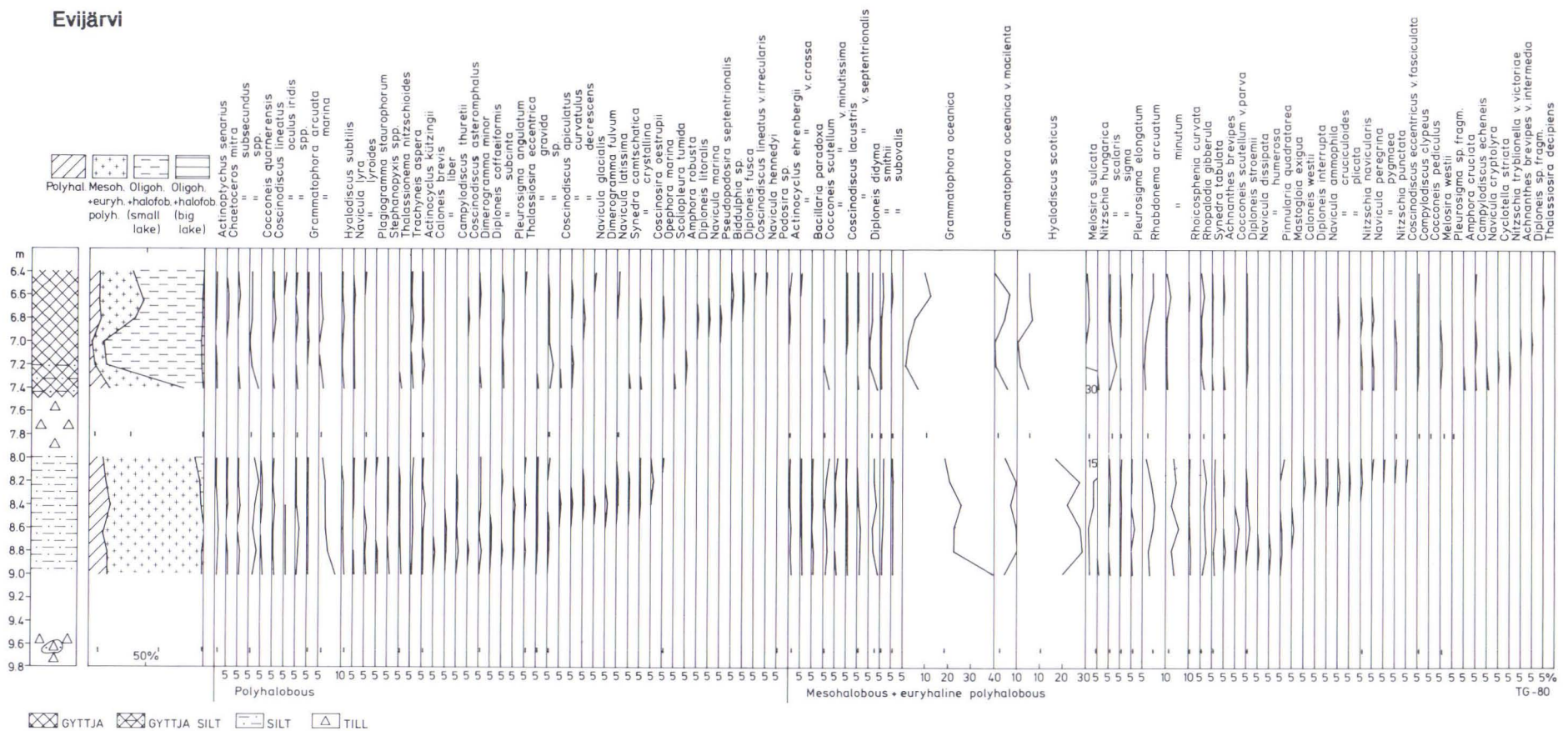

Fig. 5. Diatom groups after salinity and the succession of the polyhalobous and mesohalobous diatom taxa from the Evijärvi site (Eriksson, B. *et al.* 1979, Fig. 5., p. 68).

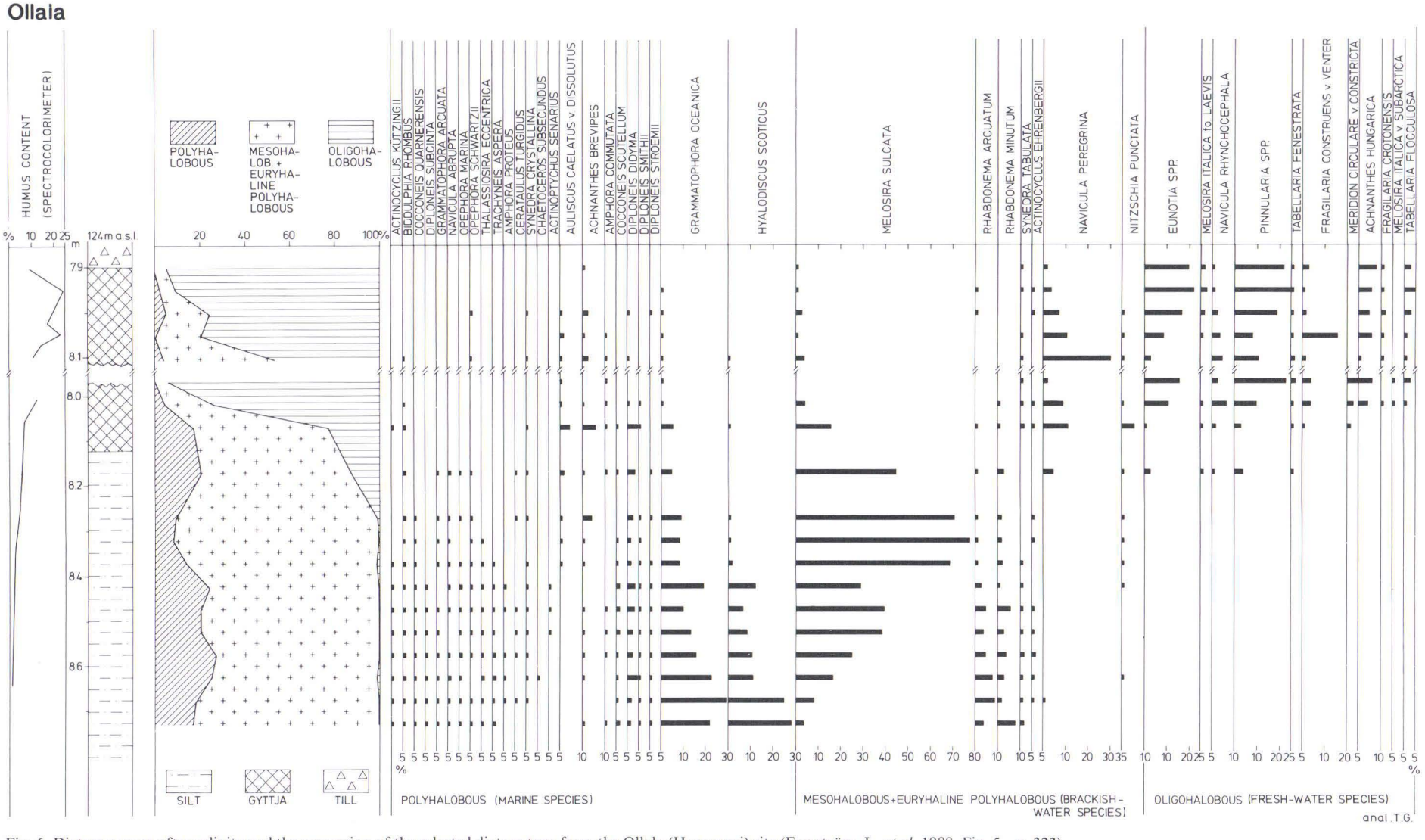

Fig. 6. Diatom groups after salinity and the succession of the selected diatom taxa from the Ollala (Haapavesi) site (Forsström, L. *et al.* 1988, Fig. 5., p. 323).

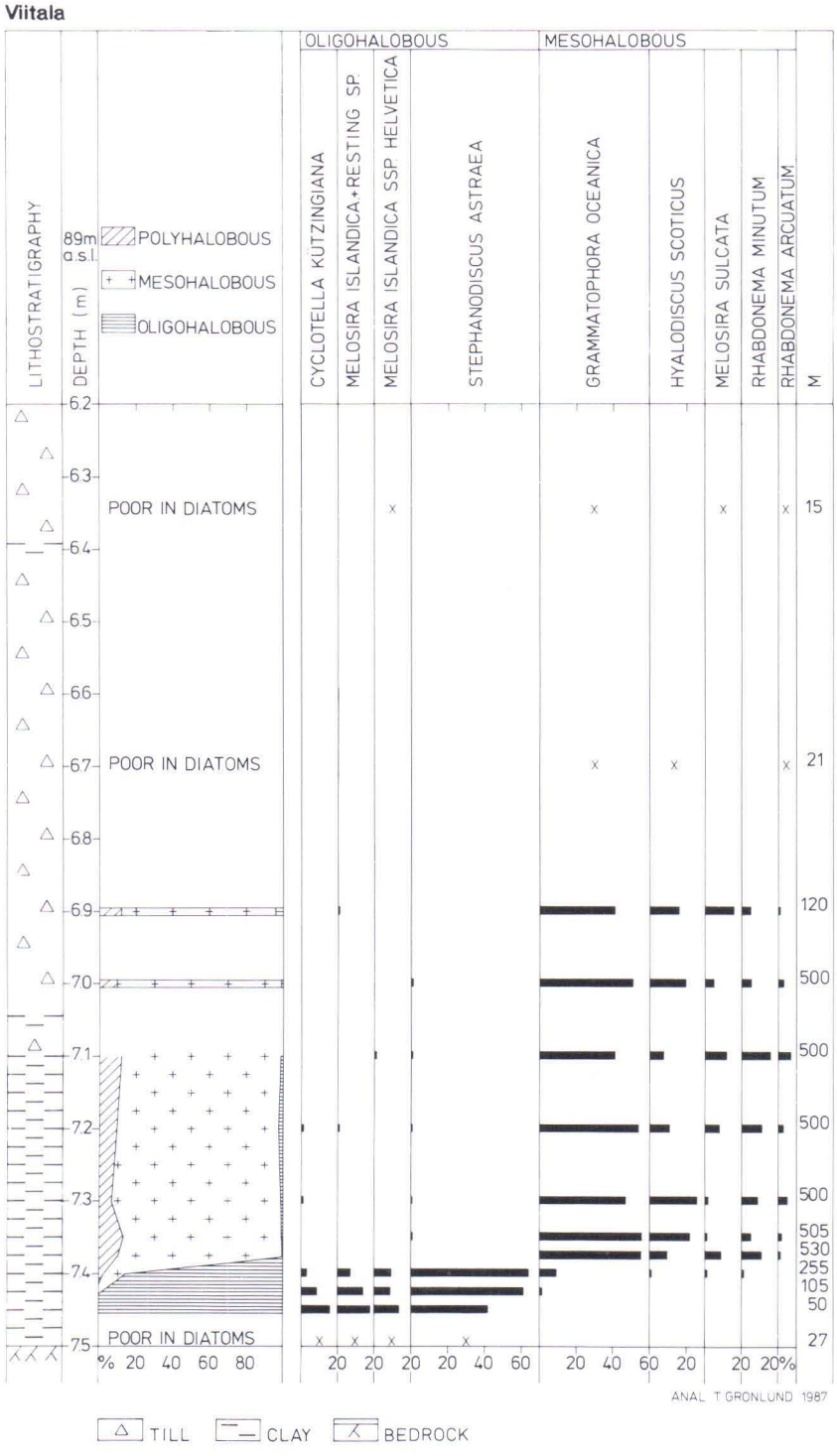

Fig. 7. Diatom groups and the succession of the selected diatom taxa from Viitala (Peräseinäjoki) site (Nenonen, K. *et al.* in press).

The Norinkylä site, Teuva (110 m a.s.l.)

The Norinkylä site is located in Teuva (63°55'N and 25°52'E) (Fig. 4), and was first studied by Niemelä & Tynni (1979) and Donner (1988). The section they studied was within a tillcovered esker. Four new cores (A—D, Figs. 8—11) were now studied from Rahkaneva mire on the western side of the esker in the direction from which the glacier approached. The elevation of Rahkaneva mire is 110 m a.s.l. The peat layer above the

till deposits is 0—3 m thick at the sites of the cores studied. There are silt and gyttja silt deposits in all the cores between the two till deposits.

Lowermost in the three of the sequences studied from Norinkylä is a layer containing freshwater diatoms (Figs. 8, 9 and 10). Freshwater diatom flora, including several Holocene Ancylus Lake species, was also encountered in the silt in the Haapalankangas section at Jurva. Above the freshwater deposit in Norinkylä is a diatom flora with abundant saline water diatoms (Figs. 8—11). *Grammatophora oceanica, G. oceanica* var. *macilenta, Hyalodiscus scoticus, Rhabdonema arcuatum* and *Paralia sulcata* prevail, but diatoms alien to the Holocene Baltic Sea are also present. A couple of sequences contain species of the *Clypeus* flora typical of the Holocene Litorina Sea, indicating the lagoonal phase and approaching isolation of the basin.

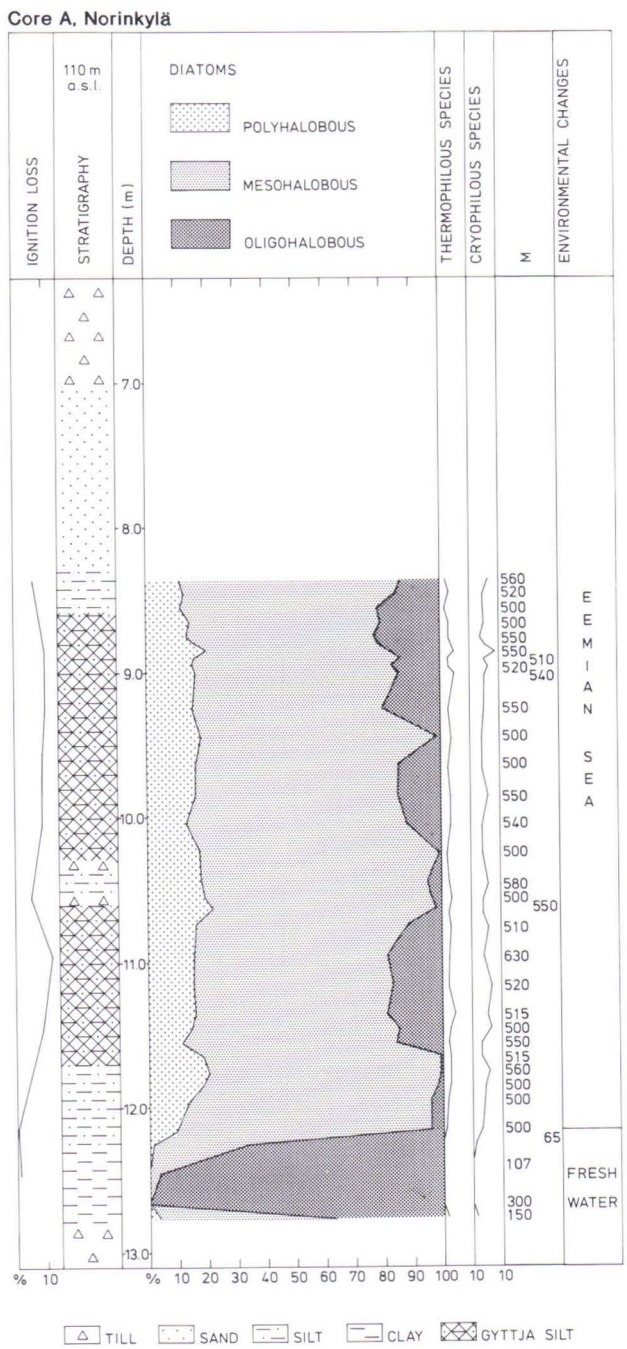

Fig. 8. Diatom groups after salinity and environmental changes according to diatom spectra in the core A in the Norinkylä (Teuva) site (Grönlund 1991, Fig. 3., p. 8).

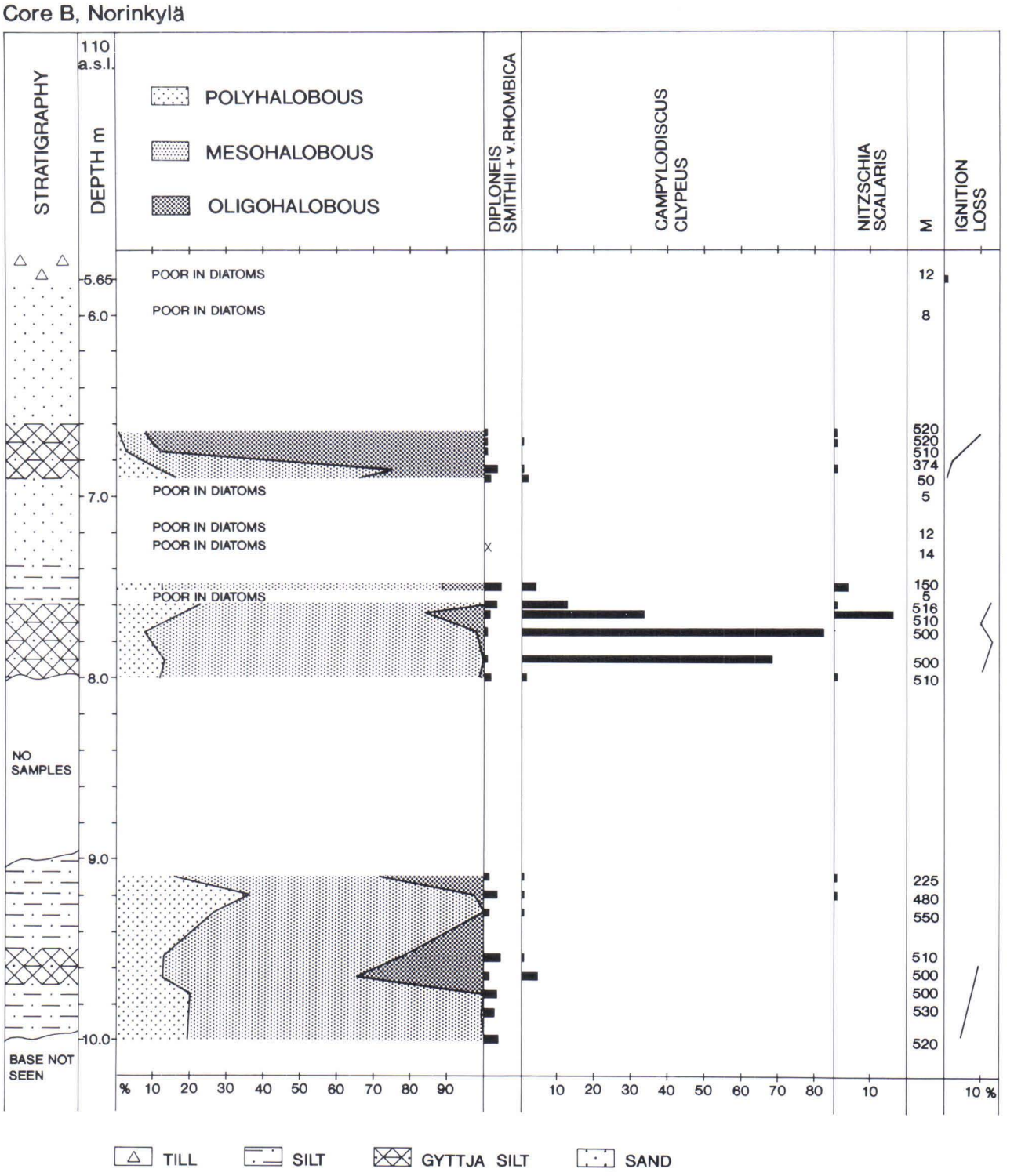

Fig. 9. The diatom groups after salinity and the lagoonal species from the core B in the Norinkylä site (Grönlund 1991, Fig. 4., p. 11).

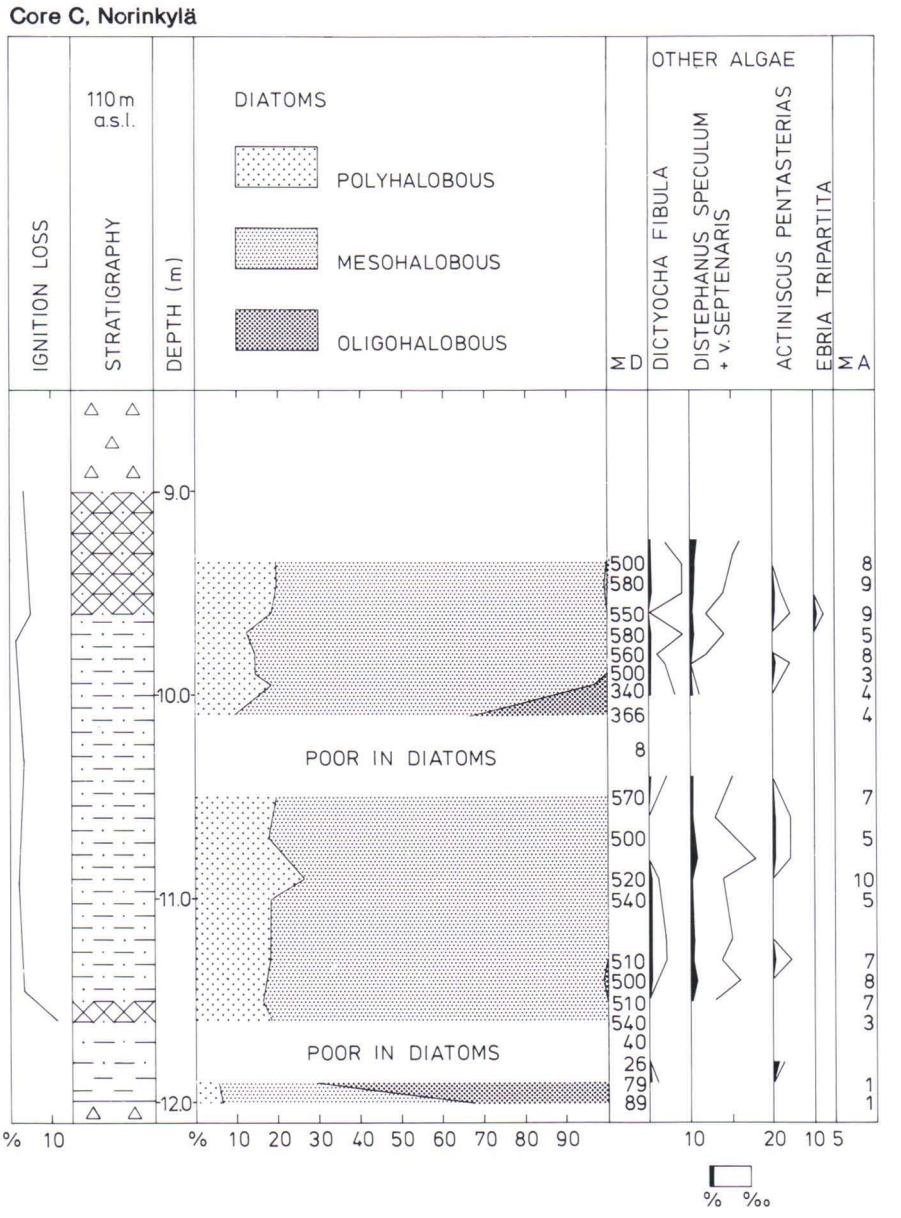

Fig. 10. The diatom groups after salinity and investigated silicoflagellates, *Actiniscus pentasterias* and *Ebria tripartita* from the core C in the Norinkylä site (Grönlund 1991, Fig. 5., p. 12). Sediment symbols as in Figure 8.

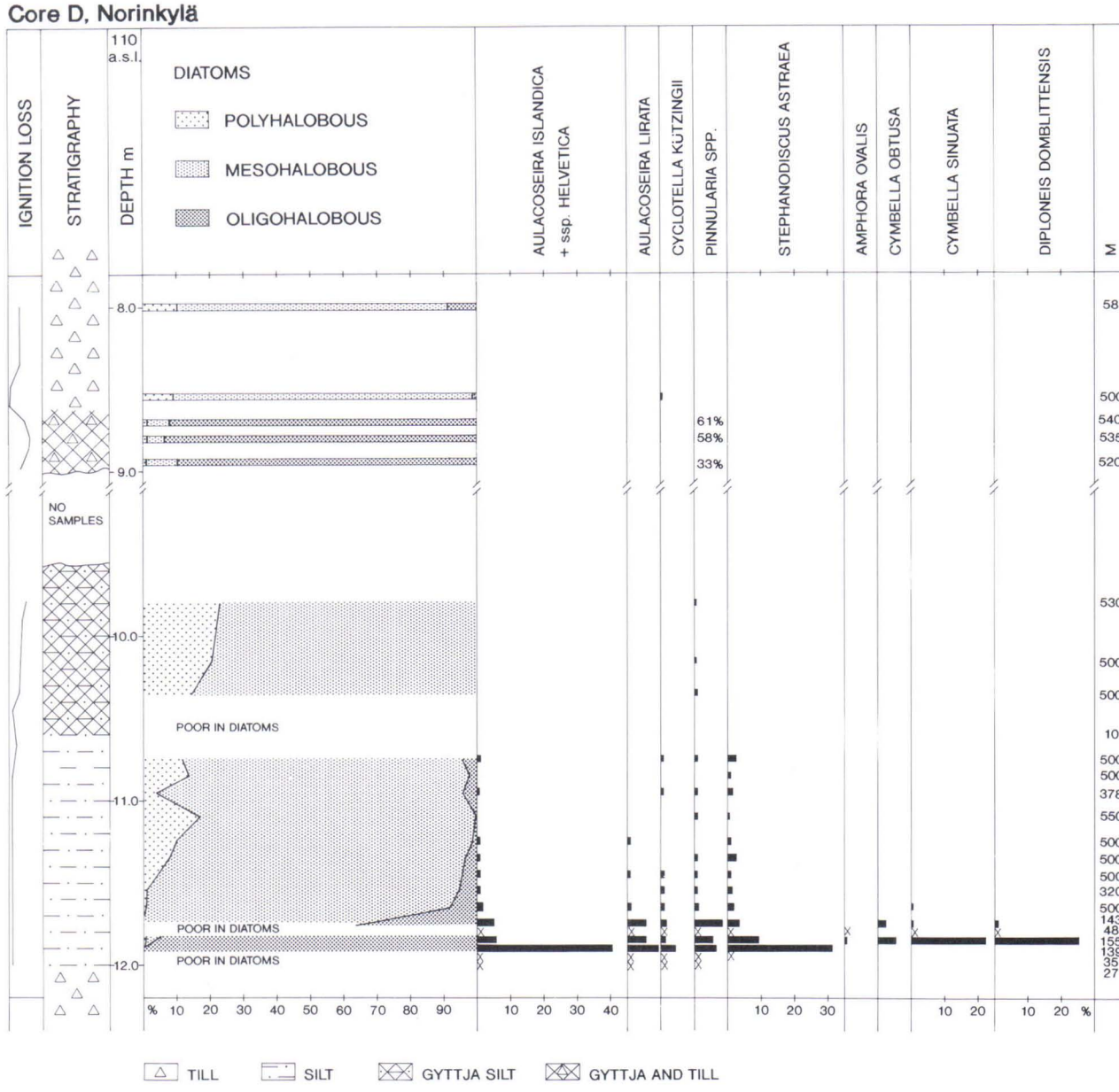

Fig. 11. The diatom groups after salinity and some selected freshwater species from the core D in the Norinkylä site (Grönlund 1991, Fig. 6., p. 14).

The Ukonkangas site, Kärsämäki (110 m a.s.l.)

The Ukonkangas site is a gravel pit in a till covered esker (63°55'N, 25°52'E) at an elevation of 110 m a.s.l. The stratigraphy of the pit is as follows. Lowermost there is gravel followed by obviously *in situ* blue silt overlain by laminated sand and gravel and uppermost is about 2 m of till (Fig. 12). The silt layer was submitted to diatom analysis at a spot where it was about half a metre thick.

The silt contained diatom flora typical of the Eemian Baltic Sea, with the mesohalobous *Grammatophora oceanica, Hyalodiscus scoticus, Paralia sulcata* and *Rhabdonema arcuatum* as dominant species. The *Clypeus* flora is weakly developed. The taxa include several species indicating high salinity.

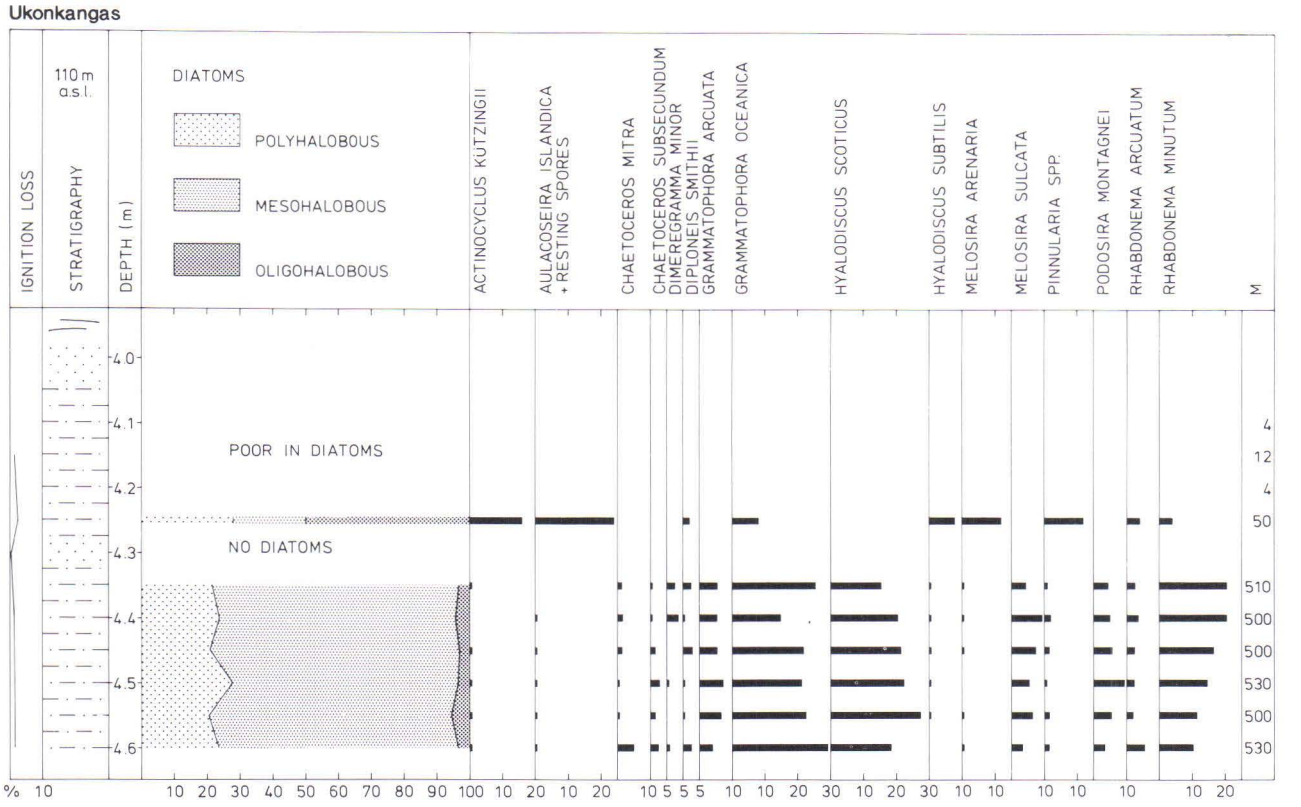

Fig. 12. The diatom groups after salinity and some selected species in the Ukonkangas (Kärsämäki) site (Grönlund 1991, Fig. 8., p. 16). Sediment symbols as in Figure 8.

CONCLUSIONS

The numerous till-covered deposits with marine diatoms presented above, and which have been interpreted as having deposited in the Eemian Baltic Sea, were correlated and dated on a lithostratigraphical and pollen stratigraphical basis. They are too old for radiocarbon dating. All the sites are covered with till and their pollen assemblages, above all the abundance of *Corylus* pollen, are characteristic of the Eemian stage. Figure 13 depicts the northern part of the Eemian Baltic Sea in the light of present understanding. Figures 14 and 15 summarize the stages of the Eemian Baltic Sea deduced from data on the deposits in Ostrobothnia described in the present work. Figure 14 shows four new sequences from Norinkylä and those from Viitala, Evijärvi, Ukonkangas and Ollala plotted in accordance with their elevations (67—125 m a.s.l.) and locations from south to north. In Figure 15 the same sites are projected according to the stages of the Eemian Baltic Sea.

It seems highly probable that before the Eemian Baltic Sea the Baltic basin was occupied by a lake with diatom flora similar to that of the Holocene Ancylus Lake: *Amphora ovalis* Kützing, *Aulacoseira islandica* (O. Müller) Simonsen, *A. islandica* subspec. *helvetica* (O. Müller) Simonsen, *Cymbella aspera* (Ehrenberg) H. Peragallo, *C. sinuata* Gregory, *Diploneis domblittensis* (Grunow) Cleve, *Melosira arenaria* Moore and *Stephanodiscus astraea s.l.* (Ehrenberg) Grunow. The species of the genus *Aulacoseira* often occur as resting spores, indicating adverse, probably cold, conditions. According to available data, the sediments in the lake preceding the Eemian Baltic Sea occur immediately below Eemian marine deposits only in southern Ostrobothnia at Norinkylä in Teuva and at Viitala in Peräseinäjoki. Species indicating cool, freshwater mixed with the flora of the Eemian Baltic Sea have been encountered on island of Prangli below the Eemian Baltic Sea deposits that Cheremisinova (1961) attributes to a glacial lake (see also Liivrand 1987) invaded by the Eemian Baltic Sea. This glacial lake encompassed the Gulf of Finland, Ladoga and Onega. Its diatom flora contained not only some of the species encountered in a freshwater deposit overlain by Eemian sediments in Ostrobothnia but also some cold water diatoms. The greatest difference between the two sites is that *Aulacoseira islandica,* which is common in Ostrobothnia, is absent from the Prangli deposit. When the diatom stratigraphy in Ostrobothnia and Prangli

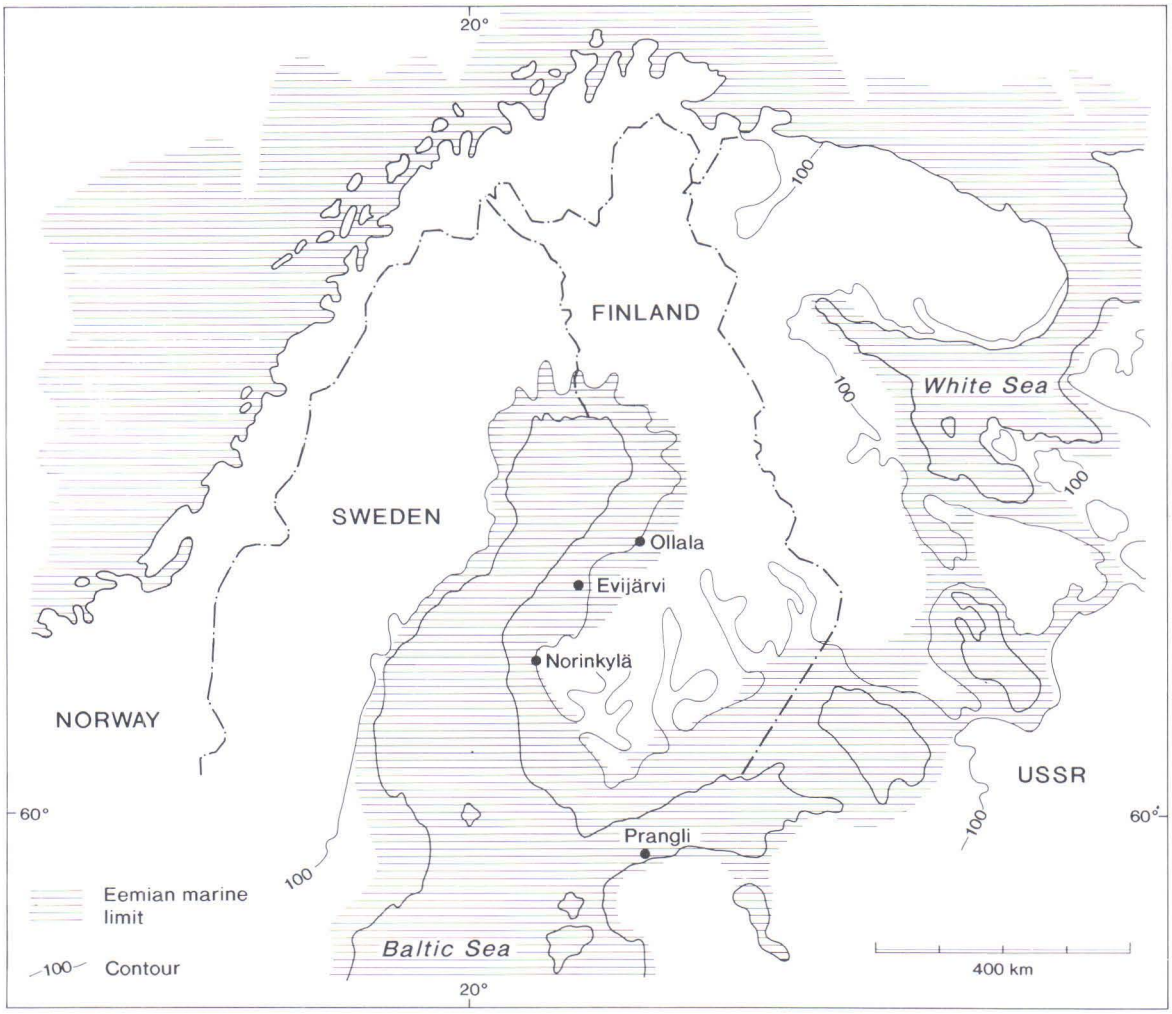

Fig. 13. The extend of the Eemian Baltic Sea and northwestern part of the Soviet Union, the main study sites are marked.

are compared, the evolution of the Baltic basin during the Eemian and Holocene stages was surprisingly similar; a freshwater lake was replaced by a marine stage. The freshwater species in Prangli listed by Cheremisinova (1961) are partly same as those interpreted Ancylus species. There is every probability that, the freshwater sediments encountered in Ostrobothnia and Prangli deposited in the same basin, which resembled the Holocene Ancylus Lake rather than a glacial lake. There is insufficient material for us to establish either the size of the lake preceding the Eemian Baltic Sea or its northern extent.

The pollen assemblage in the deposit attributed to the lake stage preceding the Eemian Baltic Sea at Viitala indicates *Betula*-dominant forests, with *Pinus* accounting for less than 15 % and *Alnus* for about 10 % of the tree taxa. Some *Corylus* pollen grains also occur (Nenonen *et al.* in press). According to preliminary pollen studies on profile D at Norinkylä, the pollen spectra of the lake stage preceding the Eemian Baltic Sea correlates with the corresponding pollen spectra at Viitala (Eriksson, oral communication). The birch-pine forests thus herald the beginning of a vegetation cycle but do not indicate a particularly cold climate.

The deposits of the Eemian Baltic Sea proper in Ostrobothnia represent littoral areas. The diatom flora of all the above sites is rich in species and very similar. The number of polyhalobous species is higher than that of mesohalobous ones, but mesohalobous diatoms predominate at all sites. Most of the samples or subsamples include freshwater species. Littoral diatoms dominate and pure planktonic diatoms are rare. East of Prangli island the water was deeper and more favourable for planktonic species (Liivrand 1987). The mesohalobous *Grammatophora oceanica, G. oceanica* var. *macilenta, Hyalodiscus scoticus, Rhabdonema arcuatum* and *Paralia sulcata* are predominant. In addition to them, the flora contains many species alien to or very rare among Holocene Baltic Sea diatoms, such as *Amphora acuta, Diploneis chersonensis, D. crabro, D. mediterranea* and *D. schmidti*, which show that the water was more saline than during the Holocene. The

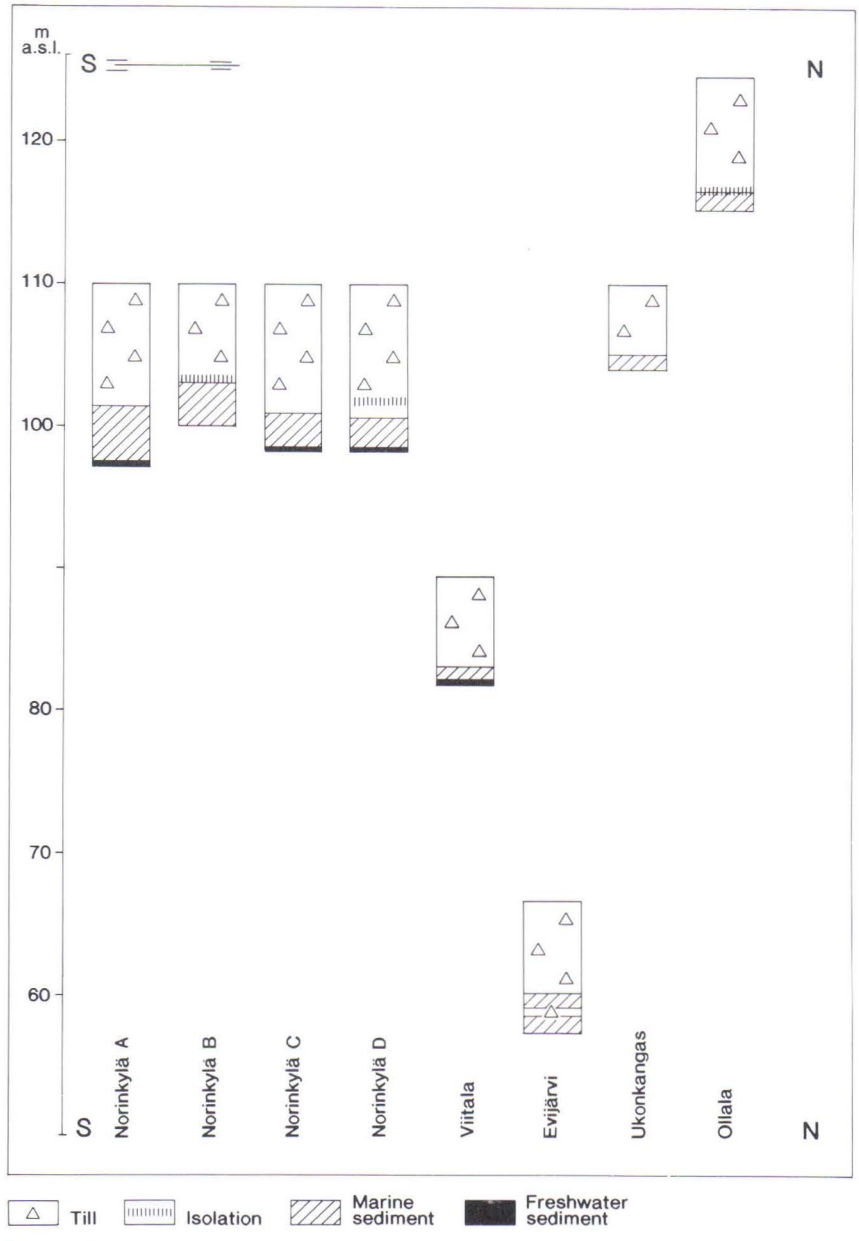

Fig. 14. The studied cores based on the altitude above sea level in direction from south to north.

salinity is also indicated by the presence of some silicoflagellates and *Ebria tripartita* (Schumann) Lemmermann and *Actiniscus pentasterias* Ehrenberg. Many of the species favour a warm water habitat, although cold water species are also encountered, thus corroborating the contention that the Eemian Baltic Sea was connected with the Atlantic Ocean in the west and with the White Sea in the east. The proportions of thermophilous and cryophilous in the diatom flora are very similar and differ little within the deposits. The available data suggest that both oceanic connections contributed to the formation of the diatom flora.

The formation of the flora was also clearly affected by the proximity of the coast. In terms of diatom flora, the situation was similar to that of the present-day Gulf of Bothnia in relation to the Baltic Sea proper. During the pelagic phase of the Eemian Baltic Sea proper the diatom flora was probably quite different from that in the littoral phase presented here from Finnish Ostrobothnia. The proportion of polyhalobous and plankton diatom species was very likely much higher there. Diatoms indicating the lagoonal phase, with the same species as those in the *Clypeus* flora in the Holocene Litorina Sea, are most distinct at Norinkylä, although they also occur at Evijärvi and Ukonkangas, although rarely at the latter. The basin became progressively less saline and was finally isolated from the sea as an independent freshwater basin in much the same way as later from the Litorina Sea and the present Baltic Sea. The isolation event is best recorded at the Ollala and Norinkylä sites, although signs of incipient isolation are also evident at Evijärvi.

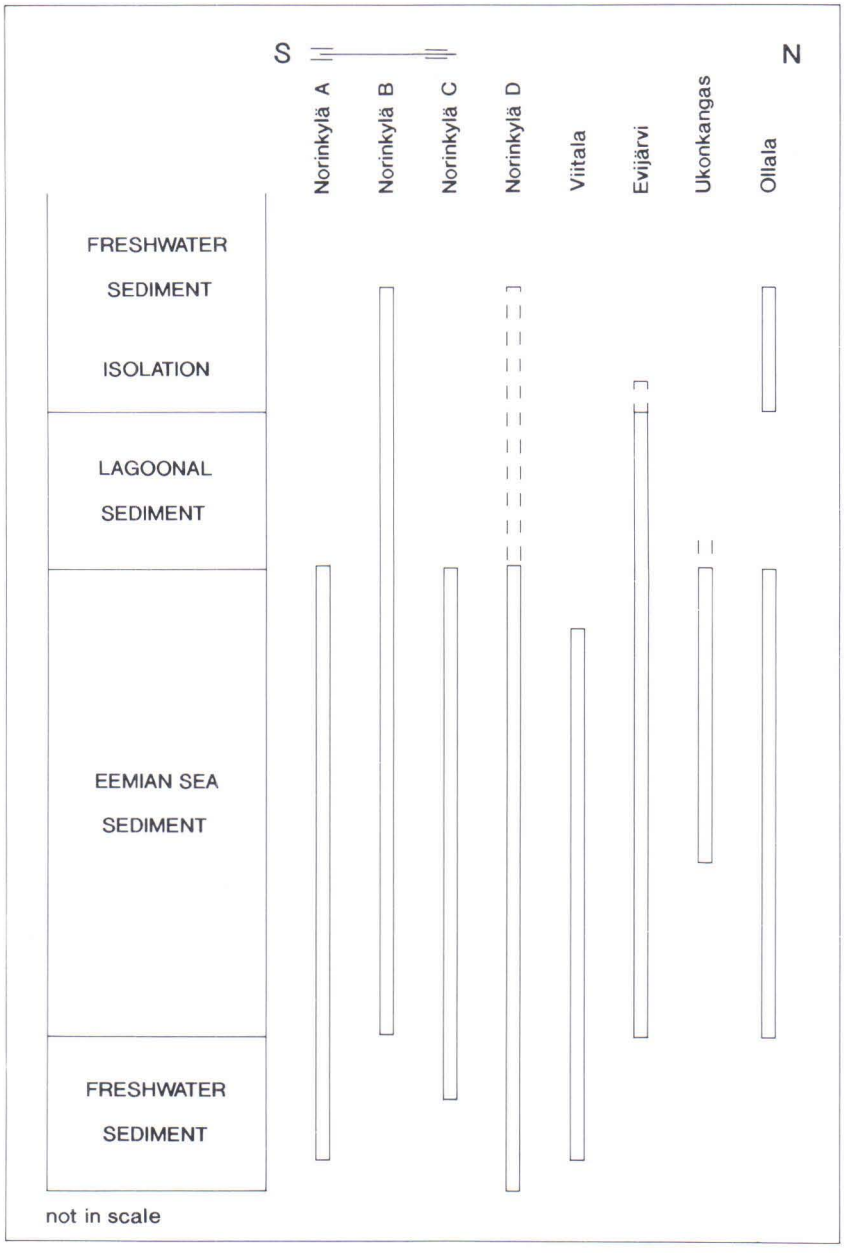

Fig. 15. Schematic stratigraphic sequences after environmental changes of the Eemian Baltic Sea based on sediment cores of the studied sites.

The deposits of the Eemian Baltic Sea proper are characterized by deciduous mixed forest, initially dominated by birch, pine, and, at least in southern Ostrobothnia, oak, and later increasingly by alder and hazel. This vegetation reflects the climatic optimum, which was characterized by an abundance of hazel. In places, its abundance even exceeds that during the Holocene thermal optimum by a factor of ten (Eriksson, oral communication). Spores of Osmunda are also typical of the Eemian interglacial deposits in Ostrobothnia.

Despite the gaps in our knowledge concerning the evolution of the Baltic Sea during the Eemian interglacial, Figure 16 is an attempt to compare schematically the events in the basin of the Baltic Sea during the Eemian interglacial and the Holocene. It is very unlikely that the Baltic Sea basin always evolved in a similar way during the early post-glacial stages of the various interglacials. The course of deglaciation, uplift and the elevation of the ocean surface together with modifications to the topography all contributed to the connection between the basin and the ocean. Nonetheless, the above findings suggest that the evolution of the Baltic Sea basin during the early stages of the Eemian interglacial was largely similar to that during the Holocene. Both times a freshwater basin preceded the marine stage. As far as is currently known these chains of events were separated by over 100 000 years. This reconstructed course of events of the emergence history of the Baltic basin is contrary to what was suggested in paper III (Forsström *et al.* 1988).

Fig. 16. Schematic model of the history of the Baltic basin during the Holocene stage and the Eemian interglacial.

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Check-list of diatom taxa of the northern Eemian Baltic Sea, littoral phase; the grouping according to Simonsen (1962) applied to Finnish conditions by Tynni (Niemelä & Tynni 1979).

Polyhalobous taxa

Actinocyclus kützingii (A. Schmidt) Simonsen
Actinoptychus senarius Ehrenberg
Amphora acuta Gregory
A. arenaria Donkin
A. angusta Gregory
A. coffeaeformis (Agardh) Kützing
A. costata W. Smith
A. crassa Gregory
A. crassa var. *punctata* A. Schmidt
A. ocellata Donkin
A. proteus Gregory
A. pusio Cleve
A. wisei Simonsen ?
A. spp.
Auliscus sculptus (W. Smith) Ralfs
— syn. *A. caelatus* var. *dissolutus* Halden
Biddulphia rhombus (Ehrenberg) W. Smith
Caloneis brevis (Greville) Cleve
C. liber (W.Smith) Cleve
Campylodiscus angularis Gregory
C. fastuosus Ehrenberg
— syn. *C. thuretii* Brébisson
Cerataulus turgidus Ehrenberg
Chaetoceros affinis Lauder
C. mitra (Bailey) Cleve
C. subsecundus (Grunow) Hustedt
C. spp.
Cocconeis clandestina A. Schmidt
C. costata Gregory
C. quarnerensis (Grunow) A. Schmidt
C. sp.
Coscinodiscus apiculatus Ehrenberg
C. asteromphalus Ehrenberg
C. centralis Ehrenberg
C. curvatulus Grunow
C. decrescens Grunow
C. lineatus Ehrenberg
C. obscurus A. Schmidt
C. oculus iridis Ehrenberg
C. radiatus Ehrenberg
C. sp.
Coscinosira oestrupii Ostenfeld
Dimeregramma fulvum (Gregory) Ralfs
— syn. *Dimerogramma fulvum* (Gregory) Ralfs
D. minor (Gregory) Ralfs
— syn. *Dimerogramma minor* (Gregory) Ralfs
Diploneis chersonensis (Grunow) Cleve
D. coffaeiformis (A. Schmidt) Cleve
D. crabro Ehrenberg
D. fusca (Gregory) Cleve
D. lineata (Donkin) Cleve
D. litoralis (Donkin) Cleve
D. mediterranea (Grunow) Cleve
D. notabilis (Greville) Cleve
D. schmidti Cleve
D. subcincta (A. Schmidt) Cleve
D. suborbicularis (Gregory) Cleve
D. vacillans (A. Schmidt) Cleve
Glyphodesmis distans (Gregory) Grunow
Grammatophora arcuata Ehrenberg
G. oceanica var. *subtilissima* (Bailey) De Toni
G. marina (Lyngbye) Kützing
Hyalodiscus obsoletus Scheschukova
H. subtilis Bailey
Licmophora debilis (Kützing) Grunow
L. distans (Gregory) Grunow
Navicula abrupta (Gregory) Donkin
N. ammophila Grunow
N. arenaria Donkin
N. atlantica (A. Schmidt) Peragallo
N. cancellata Donkin
N. directa W. Smith
N. finmarchica Cleve & Grunow
N. forcipata Greville
N. glacialis (Cleve) Grunow
N. granulata Bailey
N. hennedyi W. Smith
N. humerosa Brébisson
N. latissima Gregory
N. lyra Ehrenberg
N. lyra var. *elliptica* A. Schmidt
N. lyroides Hendey
N. marina Ralfs
N. monilifera Cleve
N. opuntioides Simonsen
N. palpebralis Brébisson
N. ramossima (Agardh) Cleve
Nitzschia acuminata (W. Smith) Grunow
N. constricta (Gregory) Grunow
Opephora marina (Gregory) Petit
O. schwartzii Petit
Pinnularia cruciformis (Donkin) Cleve
P. ergadensis Gregory
P. quadratarea A. Schmidt
P. trevelyana (Donkin) Rabenhorst
Plagiogramma staurophorum (Gregory) Heiberg
Podosira hormoides (Montagne) Kützing
P. montagnei Kützing
P. spp.
Porosira glacialis (Grunow) Jorgensen
Pseudosira septentrionalis Loseva
Rhaphoneis nitida (Gregory) Grunow
Rhizosolenia hebetata for. *hiemalis* Gran
R. sp.
Stephanopyxis turris (Greville) Ralfs
S. spp.
Synedra chamtschatica Grunow
S. chamtschatica var. *finnmarchica* Grunow
S. crystallina (Agardh) Kützing
S. gaillonii (Bory) Ehrenberg
Thalassionema nitzschioides Grunow
Thalassiosira eccentrica (Ehrenberg) Cleve
T. gravida Cleve
T. sp.
Trachyneis aspera (Ehrenberg) Cleve
Tropidoneis vitrea (W. Smith) Cleve

Mesohalobous (+ meso- and pleioeyryhaline polyhalobous) taxa

Achnanthes brevipes Agardh
A. brevipes var. *intermedia* (Kützing) Cleve
A. delicatula (Kützing) Grunow

A. longiceps Agardh
Actinocyclus ehrenbergii var. *minuta* Pantocsek
A. octonarius Ehrenberg
— syn. *A. ehrenbergii* Ralfs
A. octonarius var. *grassus* (W. Smith) Hendey
— syn. *A. ehrenbergii* var. *crassa* (W. Smith) Hustedt
A. octonarius var. *ralfsii* (W. Smith) Hendey
— syn. *A. ehrenbergii* var. *ralfsii* (W. Smith) Hustedt
A. octonarius var. *sparsus* (Gregory) Hendey
— syn. *A. ehrenbergii* var. *sparsa* (Gregory) Hustedt
Amphora commutata Grunow
A. cruciata Brander
Amphora robusta Gregory
Bacillaria paxillifer (O. Müller) Hendey
Caloneis westii (W. Smith) Hendey
Campylodiscus clypeus Ehrenberg
C. echeneis Ehrenberg
Chaetoceros muelleri Lemmermann
Cocconeis pediculus Ehrenberg
C. peltoides Hustedt
C. scutellum Ehrenberg
C. scutellum var. *minutissima* Grunow
C. scutellum var. *parva* Grunow
C. sp.
C. striata (Kützing) Grunow
Diploneis didyma (Ehrenberg) Cleve
D. interrupta (Kützing) Cleve
D. interrupta var. *clancula* (A. Schmidt) Cleve
D. interrupta var. *heeri* (Pantocsek) Hustedt
D. papula (A. Schmidt) Cleve
D. smithii (Brébisson) Cleve
D. smithii var. *rhombica* Mereschkowsky
D. stroemii Hustedt
Grammatophora oceanica Grunow
G. oceanica var. *macilenta* (W.Smith) Grunow
Gyrosigma balticum (Ehrenberg) Rabenhorst
Hyalodiscus scoticus (Kützing) Grunow
Mastogloia elliptica (Agardh) Cleve
M. exigua Lewis
M. pumila (Grunow) Cleve
Melosira moniliformis (O. Müller) Agardh
M. westii W. Smith
Navicula crucicula (W. Smith) Donkin
N. cruciculoides Brockmann
N. cryptolyra Brockmann
N. digitoradiata (Gregory) A. Schmidt
N. dissipata Hustedt
N. elegans W. Smith
N. gregaria Donkin
N. peregrina (Ehrenberg) Kützing
N. plicata Donkin
N. pygmaea Kützing
N. rostellata Kützing
N. salinarum Grunow
Nitzschia filiformis (W. Smith) Hustedt
N. hungarica Grunow
N. navicularis (Brébisson) Grunow
N. punctata (W. Smith) Grunow
N. scalaris (Ehrenberg) W. Smith
N. sigma (Kützing) W. Smith
N. tryblionella var. *victoriae* Grunow
N. spp.
Opephora schulzii (Brockmann) Simonsen
Paralia sulcata (Ehrenberg) Cleve
— syn. *Melosira sulcata* (Ehrenberg) Kützing
Pleurosigma angulatum (Quekett) W. Smith
P. elongatum W. Smith
Rhabdonema arcuatum (Lyngbye) Kützing
R. minutum Kützing
Rhoicosphenia curvata (Kützing) Grunow
Rhopalodia gibberula (Ehrenberg) O. Müller
R. operculata (Agardh) Håkansson
Scoliopleura peisonis Grunow
S. tumida (Brébisson) Rabenhorst
Stauroneis gregorii Ralfs
Surirella striatula Turpin
Synedra pulchella (Ralfs) Kützing
S. tabulata (Agardh) Kützing
Thalassiosira baltica (Grunow) Ostenfeld
T. decipiens (Grunow) Joergensen
T. hyperborea var. *lacunosa* (Berg) Hasle
— syn. *Coscinodiscus lacustris* var. *septentrionalis* Grunow
T. hyperborea var. *pelacica* (Cleve-Euler) Hasle
— syn. *Coscinodiscus lacustris* Grunow

The check-list contains the diatoms from the Evijärvi, Ollala, Viitala and Ukonkangas sites (Grönlund 1991) and the Norinkylä site (Niemelä & Tynni 1979 and Grönlund 1991).

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