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Cover: Lake Onega in Russian Karelia was connected with the Baltic Sea and White Sea basins during the Eemian.
Photograph M. Saarnisto 1992

Ykkös-Offset Oy
Vaasa, 2001

Abstract

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Pollen, diatom and foraminiferal analyses of a nearly complete Mikulino/ Eemian interglacial marine sequence in Petrozavodsk, Russian Karelia, is presented together with a comprehensive literature review of Mikulino biostratigraphical data in NW Russia earlier published mostly in Russian. Mikulino interglacial deposits have been investigated in numerous sites, and, similarly, palaeohydrology and duration and correlation of different phases of the Mikulino marine submergence in this region have also been under discussion in several papers.

On the basis of the Petrozavodsk sequence, the marine phase proper began in the Lake Onega basin in pollen zones M_2-M_3 (*Pinus-Betula*) and continued until the upper part of the M_6 (*Picea-Alnus-Carpinus*) zone, when the regression began. Isolation of the Onega basin from the sea occurred at the beginning of the *Picea-Pinus*/M_7 zone, when the connection to the White Sea was closed suggesting that the marine phase covers a considerable part of the Mikulino interglacial. There was an open passage between the White Sea and the Baltic Sea through the Onega and Ladoga basins.

Key words: Mikulino interglacial, Eemian interglacial, biostratigraphy, pollen, diatoms, marine submergence, Lake Onega, White Sea, North West Russia.

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CONTENTS

INTRODUCTION

Studies of Mikulino/Eemian interglacial deposits from the northwestern part of Russian plain have been published mainly in the Russian language. The limited availability of the original articles and the poor knowledge of Russian language in the west have meant that most of these studies have been remained unknown outside Russia.

Deposits of the Mikulino/Eemian interglacial have been investigated in a great number of sites in northwestern part of Russia (Fig. 1) and knowledge of the general vegetational development in the area is widely understood. The palynological data indicates that the initial birch and pine forest substage was followed by a temperate substage characterised by large amounts of alder and hazel and a succession of temperate deciduous trees including *Quercus*, *Ulmus* and *Carpinus*. The post-temperate substage is characterised by spruce and

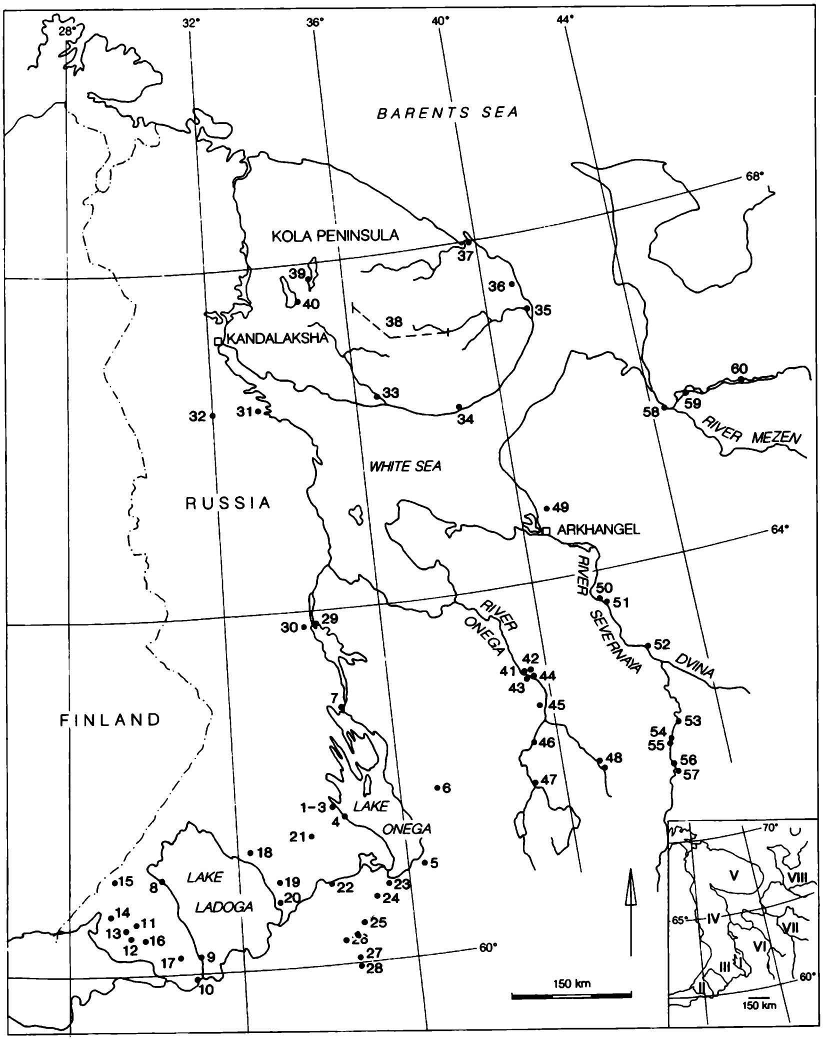


Fig. 1. Locality map. Numbers refer to the site descriptions in the text. Insert: Location of the geographical areas discussed in the text. I Lake Onega, II Karelian Isthmus, III Ladoga-Onega isthmus, IV Area between Lake Onega and the White Sea, V Kola Peninsula, VI Onega river area, VII Severnaya Dvina and Vaga river area and VIII Mezen and Pyoza river area.

pine and the end of Mikulino interglacial is marked by a decline of coniferous forest in favour of birch. However, at many sites interglacial deposits represent only a part of the whole succession or the interpretation of the sequences are based on faunal data, therefore severely complicating regional correlations.

The palaeohydrology and the duration and the correlation of different phases of marine evolution in this region have also been under discussion in numerous papers. Thus, for example, the Mga deposit, that includes cold water mollusc fauna, was assumed to represent the *Portlandia* transgression. It was placed at the end of the interglacial, while the Eemian transgression was placed at the warmer early part of the interglacial (Zans 1936). In addition Pokrovskaya (1947 in Biske 1959) assumed that the Mga deposit is younger than those recovered at Severnaya Dvina and assigned it to the Valdai Stage. According to Lavrova (1948 in Biske 1959), the deposits in Karelia, at Mga and at Severnaya Dvina were deposited during the Boreal transgression. Later the *Portlandia* sea phase was regarded as being older than the Eemian Sea and corresponding to the lateglacial substage, preceding the Mikulino Interglacial (Gross 1967).

In Karelia, marine Mikulino interglacial units are mainly composed of greenish grey and dark grey clays and sandy silts containing vivianite and abundantly remains of marine fauna and plant debris in some places. The Mikulino units are often underlain by glaciolacustrine and glaciofluvial sandy clay or pure clay and till bed of the Moscovian glacial stage and covered by lake sediments and till bed of Valdaian age.

The interglacial deposits in Karelia are rather frequent, but only two complete sections of the interglacial deposits have been detected in the area, which offers the possibility of resolving the question concerning the connection and duration of the Eemian Baltic Sea with the White Sea. The deposits are often eroded by glacial erosion and consequently the duration of the transgression has not been possible to resolve.

Discovery of an Eemian interglacial marine deposit in Petrozavodsk was made during the construction of a pumping station for a new draining system in the city and was preliminarily introduced at the 11th INQUA Congress in Karelia in 1982. Ekman & Lak (1986) and Yelovicheva, Lak and Ekman (1989) published the first brief reports on the deposit.

The Petrozavodsk section has proved to be an important biostratigraphical key site in the Lake Onega area, hence a more detailed study concerning the lithostratigraphy and pollen, diatom and foraminiferal analysis has been completed, but so far only results of the pollen analyses have been partially published. The aim of the present paper is to discuss and interpret the history of this sequence and correlate it with previously published diagrams from northwestern Russia. The interglacial unit of the Petrozavodsk site provides a further link in the reconstruction of the history of the Eemian Baltic Sea in the periphery of the Fennoscandian shield.

In addition to the Petrozavodsk key locality a comprehensive review has been made of the Mikulino biostratigraphical studies in NW Russia mostly published in Russian.

PETROZAVODSK SITE

The city of Petrozavodsk lies in a tectonic depression that extends westwards from the central part of the Onega-Ladoga isthmus to Lake Svyatozero and continues as a more extensive depressional basin connected with the ancient valley of the river Svir and the Lake Ladoga basin. The tectonic depression is infilled by preglacial, Lower, Middle and Upper Pleistocene and Holocene deposits. The thickness of sediments is 120-150m and include continental (glacial, lacustrine, alluvial, deltaic and peat) and marine sediments. Towards the lake shore, beneath the Petrozavodosk terrace, the Quaternary strata decrease to 30-60 m thick (Ekman 1982). The lake shore altogether exhibits four ancient Late Valdai and Holocene shoreline terraces with altitudes of 80-85 m, 60-75 m, 45-58 m, and 35 m, respectively. The study site is situated on the lowest, Holocene terrace of the Lake Onega, at an elevation of 35 m above sea level. The present Lake Onega is at 32 m a.s.l.

In terms of forest vegetation, the Petrozavodsk area lies today within the southern boreal vegetation zone (middle taiga in the Russian classification). The forests in the area consist mainly of birch and pine-birch forests.

The core (C-EK-82-2) was taken within the city, 500 m from the mouth of Neglinka River, in the lakeside Varkaus Street (Fig. 2).

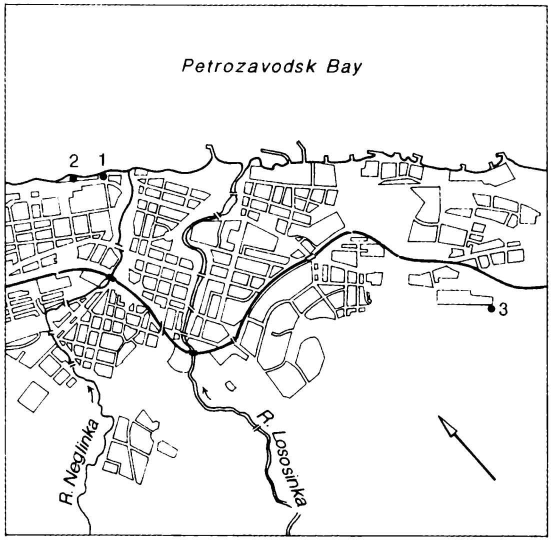


Fig. 2. The map of the Petrozavodsk city. Numbers 1 -3 refer to the sites described in the text

Methods

Pollen analysis was carried out from the sediments recovered by Dr. Yadviga Yelovicheva, diatoms by Dr. Garry Lak and foraminefera by Dr. Marina Bylinskaya.

The pollen diagram (Fig. 4) was redrawn on the basis of the preliminary diagram drawn by the analyst. Pollen analyses have been made from the entire sediment sequence (82 samples) at intervals of 20-25 cm. The sums from which the percentages of the pollen and spore types were calculated are indicated in the diagram. The pollen assemblage zones have been named according to the main tree species occurring in each zone.

The diatom analyses were made from the same depths as those used for the pollen diagram and the main results of the diatom analyses are indicated in figures 5 and 6. The nomenclature of the diatom species used by Dr. Lak, and the changes made according to recent practise in the study profile are listed in the Appendix 1.

Foraminifera were studied from the deposit between 12.3-7.1 m; a total of 25 samples were analysed. The samples were washed through sieves with mesh sizes of 100 and 50μm. The samples were dried and weighed. The fractions, >50μm, 50-100μm and <100μm were separated with heavy liquid. Foraminifera were found in samples, 12, 14-19 and 21-25 (see Table 1). The amount of foraminifera ranged from one to 197 specimens in 100 g dry sediment. A total amount of 19 species were identified, 1-11 species per sample.

Lithology	Depth m	SiO_2	TiO_2	Al_2O_2	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	P_2O_5	S	loss-on-ign.	
sand, gravel	2.5	71.20	0.47	10.96	1.01	2.51	0.060	1.56	2.24	2.90	2.00	0.72	0.16	0.03	4.2	
fine and coarse silt	3.5	69.90	0.48	11.74	0.97	2.73	0.061	1.61	2.31	2.93	2.14	0.66	0.16	0.06	4.3	
	4.5	70.96	0.47	10.69	0.97	2.73	0.063	1.66	2.31	2.87	2.15	0.60	0.18	0.09	4.2	
silty clay sand	5.5	70.60	0.50	10.67	1.29	2.44	0.051	1.56	2.24	2.96	2.15	0.64	0.16	0.19	4.4	•
	6.6	74.38	0.41	10.74	1.70	1.44	0.044	1.06	2.38	3.19	2.12	0.19	0.14	0.09	2.1	
	7.6	69.76	0.47	10.96	1.80	2.16	0.070	1.31	2.31	2.90	2.17	0.72	0.17	0.96	5.1	
silty clay	8.5	63.76	0.51	11.72	1.61	2.87	0.049	1.92	2.38	2.41	2.30	0.48	0.19	0.81	9.4	Mikulino/ Eemian
	9.5	62.94	0.54	12.49	0.69	3.88	0.052	2.02	2.24	2.40	2.45	0.50	0.18	0.95	9.3	
	10.5	63.80	0.53	12.49	1.41	3.23	0.056	2.12	2.17	2.50	2.42	0.40	0.20	0.97	8.5	
	11.5	67.60	0.52	13.03	2.40	2.16	0.052	1.97	2.10	2.62	2.50	0.86	0.21	0.50	3.6	•
coarse silt	12.5	69.60	0.53	13.28	2.24	1.94	0.048	1.71	2.17	3.13	2.60	0.58	0.22	-	1.9	
	13.5	61.38	0.69	15.52	3.07	2.73	0.101	3.23	2.17	2.62	3.50	0.97	0.22	-	3.3	
	14.5	66.02	0.58	13.77	2.40	2.16	0.071	2.57	2.38	2.96	3.14	0.56	0.23	0.02	2.6	
varved clay	15.5	67.60	0.58	13.51	2.20	2.16	0.071	2.22	2.80	3.13	2.52	0.28	0.19	0.01	2.6	
	16.5	66.16	0.60	14.02	2.65	2.30	0.080	2.21	3.08	3.18	2.79	0.37	-	-	2.7	
	17.5	68.78	0.58	13.12	2.50	1.80	0.071	1.81	3.08	3.34	2.58	0.25	-	-	2.0	
gravel	18.5	66.72	0.65	13.73	2.37	2.73	0.088	2.27	3.08	3.00	2.61	0.22	-	-	2.7	Moscowian/ Saalian
	18.8	72.70	0.42	11.78	2.20	2.15	0.053	1.36	2.17	2.63	2.38	0.34	-	-	2.1	
	19.0	52.08	0.83	19.52	5.71	3.84	0.089	4.09	1.58	1.38	3.76	(2.80)	-	-	7.2	
varved clay	20.0	50.66	0.86	20.40	5.94	3.98	0.093	4.09	1.58	1.20	3.72	(2.60)	0.22	0.22	7.0	
	21.0	51.19	0.83	20.11	5.81	4.27	0.093	3.93	1.58	1.40	4.03	(2.45)	-		7.1	

Table 1. Chemical composition of sediments in the Petrozavodsk deposit.

Fig. 3. Marine silty clay with mollusc shells from the Petrozavodsk deposit (site 1).

Lithostratigraphy

The sediment sequence is 21 m thick in this borehole. The fine-grained till at the base is overlain by a 8.4 m thick varved clay unit, which contains a thin gravel layer at the depth of 18.8-18.5 m. The clay sequence, below the gravel, is dark grey in colour with 1-2 mm thick varves (total = 1200). In the upper clay, brown in colour, the varves (total = 3000) are 2-5 mm thick. The upper clay contains much more sand and less clay material than that below. The chemical content and loss-on-ignition of the clays suggests different provenance for upper and lower clays (Table 1). The varved clay sequence is overlain by dark grey, finely laminated coarse silt at 12.6-12.2 m.

The sediment sequence comprises the following units:

0.0-2.2 m	made ground
2.2-2.5 m	sand and gravel
2.5-5.0 m	fine and coarse silt with interbedded with thin sand layers, dark grey and greenish grey, bituminous, plant debris scattered or occurring in layers
5.0-6.5 m	silty clay with vivianite
6.5-7.0 m	sand, grey with some plant debris
7.0-10.5 m	silty clay, dark grey, bituminous with molluscs (Fig. 3)
10.5-12.2 m	silty clay, dark grey, bituminous with plant debris
12.2-12.6 m	coarse silt
12.6-18.5 m	varved clay
18.5-18.8 m	gravel
18.8-21.0 m	varved clay
>21.0 m	till

An upper till bed is absent in the section having been removed by subsequent intense lacustrine abrasion, but it is found west from the shore of the Lake Onega.

Pollen stratigraphy

Pollen counts show that the strata can be divided into two parts (Fig. 4). The varved clay and interbedded sand layer have a low pollen content, whereas in the marine silty clay pollen grains are more abundant.

The lower part is mainly characterised by *Artemisia*, reaching a maximum value of 100 %, although its percentages are generally in the range of 38-88 %. *Betula nana* also has high values. The other important families are Caryophyllaceae, Chenopodiaceae, Gramineae, Asteraceae, Cichoriaceae and Ericaceae. The frequency of tree pollen is in the range 12-96 %. Reworked (Quaternary and Tertiary) pollen types and sporomorphs (Carboniferous) are principally concentrated in this lower part. On the basis of changes in the composition of tree taxa, ten pollen assemblage zones (p.a.z.) can be distinguished:

Pinus-Picea-NAP p.a.z. (21.0-18.6 m). In this zone the percentage of tree pollen is 55-96 %; the dominant tree species being *Pinus* and *Picea*. The values of NAP and spores are 2-36 % and 2-19 % respectively. Small quantities of redeposited old Quaternary pollen were also found. The upper limit of the zone is placed at the level where the *Betula* curve begins to rise.

Betula-NAP p.a.z. (18.6-13.3 m). The tree pollen values in this zone are 42-86 % of which *Betula* pollen are dominant. The abundances of NAP and spores are 14-46 % and 2-20 % respectively. Reworked Carboniferous spores and degraded Quaternary and Tertiary pollen are found in both the lower and upper parts of the zone. Towards the upper boundary of the zone the *Pinus* curve rises.

Pinus-Betula-NAP p.a.z. Subzone a (13.3-12.2 m). The zone is defined by the rise of NAP values, 33-85%. The abundance of tree pollen is 12-52 % and the proportion of spores ranges from 5-15 %.

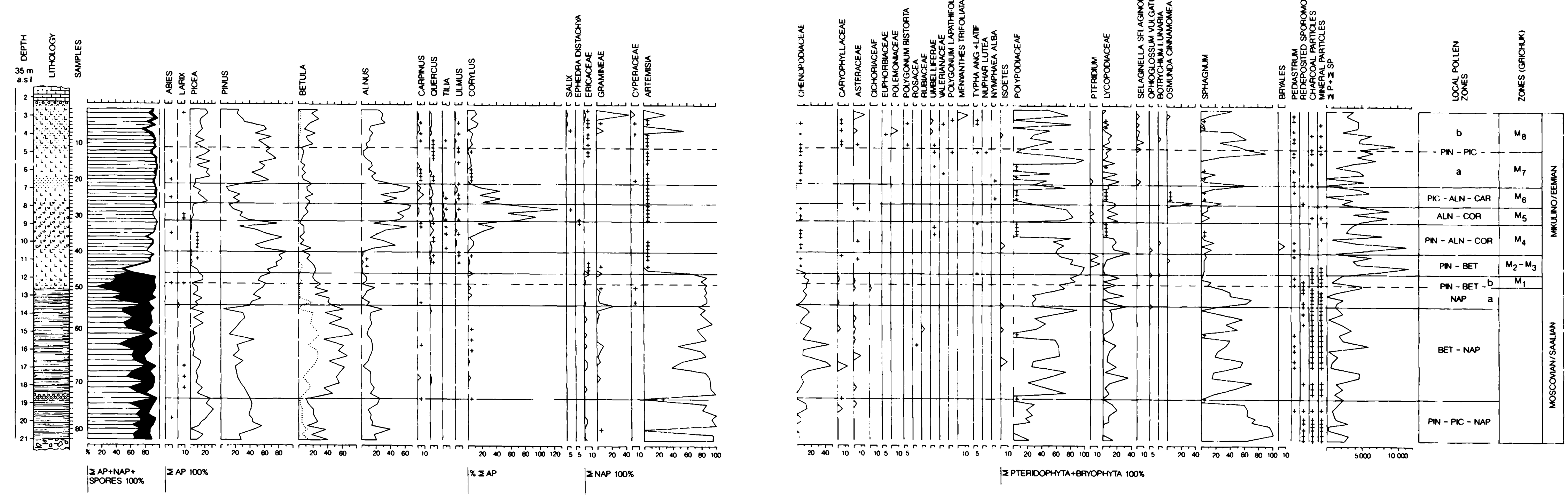


Fig. 4. Pollen diagram from Petrozavodsk site 1. Anal. Y. Yelovicheva.

Pinus-Betula-NAP p.a.z. Subzone b (12.2-11.6 m). The zone is defined by gradual increase of tree pollen, 40-55 %. *Pinus* dominates over the other trees, ranging between 52-65 %. The *Picea* and *Betula* values are 17-19 % and 8-30 % respectively. *Betula nana* has pollen values of 1-4 %. *Abies* and *Larix* pollen were also found. NAP frequences are high (> 52 %), but decrease distinctly towards the end of the zone (2 %). *Artemisia* is very abundant in the lower part (88 %) but decreases sharply at the upper level of the zone. The other families present are Chenopodiaceae 10-17 %, Ericaceae and Caryophyllaceae 1 %. The abundance of spores is 8-43 % of which the proportion of Polypodiceae, Lycopodiaceae and *Sphagnum* is 64-96 %, 18-22 % and 4-13 % respectively. The first occurrence of sponge spicules was detected at the upper boundary of the subzone.

Pinus-Betula p.a.z. (11.6-10.4 m). In this zone tree pollen increases to 47-91 %. The *Pinus* frequences are very high (76-91 %) and increase towards the latter part of the zone. *Picea* is still present but at low values. The percentage of *Betula* is 8-21 %. *Betula nana* disappears during this zone. The proportion of *Alnus* is below 2 %. The first occurences of *Quercus* and *Ulmus* are recorded and NAP values are low 1-5 %. The proportion of spores is 8-48 %.

Pinus-Alnus-Corylus p.a.z. (10.4-8.7 m). Tree pollen values remain high 80-94 %. The proportion of *Pinus* is 26-85 %. *Picea* is found only sporadically. *Betula* values are very low 1-17 %. The main change is the increase of *Alnus* pollen, accompanied by the simultaneous onset of a continuous *Corylus* curve and of the first occurrence of *Tilia*. NAP pollen remains present at low frequencies as in the previous zone.

Alnus-Corylus p.a.z. (8.7-7.6 m). *Alnus* and *Corylus* pollen reach the maximum values 50-68 % and 58-123 % respectively. The proportion of temperate broad-leaved tree pollen increases to 7 %. *Carpinus* appears as scattered finds whilst the proportion of *Pinus* is low. *Picea* begins to appear regularly, although at very low frequencies.

Picea-Alnus-Carpinus p.a.z. (7.6-6.6 m). *Alnus* remains practically unchanged, while *Corylus* decreases substantially in this zone. *Carpinus* pollen reaches its maximum 9 %. *Pinus* values remain low, while *Picea* shows a further increase. *Osmunda cinnamomea* maximum (36 %) is recorded in the lower part of the zone.

Pinus-Picea p.a.z. Subzone a (6.6-4.6 m). The zone is defined by the rise in *Pinus* (maximum 77 %) and the subsequent abrupt decrease of *Alnus*, *Picea* values fluctuate within the range 8-28 %. The continuous occurrence of temperate deciduous trees is interrupted at the upper boundary of the zone. *Corylus* remains at low but regular values (0.5-5 %). *Sphagnum* starts to rise in the upper part of the zone, where also Ericaceae pollen and *Selaginella selaginoides* spores are recorded.

Pinus-Picea p.a.z. Subzone b (4.6 m-2.2 m) *Betula* and *Alnus* percentages increase gradually, while *Pinus* declines gradually to 22 % in the upper part of the zone. The continuous curve of *Betula nana* starts at the lower boundary of the zone. Temperate broad-leaved trees are found sporadically. *Corylus* has a low but almost continuous occurrence. *Artemisia*, Asteraceae, Ericaceae and Gramineae pollen increase. In the uppermost section *Menyanthes* (14 %), *Typha latifolia* pollen and *Osmunda cinnamomea* (3 %) spores were found.

Vegetational history

The reworked and long-distance transported pollen flora in the lower varved clay section obscure the interpretation of the true vegetation cover in the area. Reworked Quaternary and Tertiary pollen are also found in the basal clay section. The isolated *Carpinus*, *Quercus* and *Corylus* finds suggest an interglacial origin, while the other component consisting of *Artemisia*, *Betula nana*, Chenopodiaceae, Caryophyllaceae, Gramineae and Ericaceae characterizes an periglacial vegetation. The continuous occurrence of *Picea* and *Alnus* pollen, which is interrupted in the transition from the Moscovian to the Mikulino Stage also suggest long-distance transport of these trees. However, the climate was probably fairly warm at the end of the Moscovian (Saalian) lateglacial and birch forest formed the pioneering vegetation with periglacial herbs and shrubs communities. The field layer appears to have been rich in ferns and clubmosses.

The transition from the Moscovian (Saalian) to Mikulino (Eemian) is reflected in the lower part of the silt layer (*Pinus-Betula*-NAP subzone b), where the amount of tree birch and also *Betula nana* decrease. A periglacial flora is still present. The increase of *Pinus* pollen indicates that a few scattered pine stands were probably established in the area and that pine forests were present in the vicinity. In the following successional phase boreal forests became common and the first scattered stands of *Ulmus* and *Quercus* appeared (*Pinus-Betula* zone). *Pinus* expanded quickly and it maintained its dominance on dry places.

A simultaneous abrupt rise of the *Alnus* and *Corylus* pollen curves and a small increase of mesophilous deciduous taxa such as *Ulmus*, *Quercus* and *Tilia* characterise a marked change in climatic conditions. During the maximum of the temperate deciduous forest (*Alnus-Corylus* zone), with abundant *Corylus* in the field layer, the area of pine forests were reduced. Spruce expanded during the subsequent *Corylus* decline and at the same time *Carpinus* became more common (*Picea-Alnus-Carpinus* zone). The maximum occurrence of the thermophilous fern, *Osmunda cinnamomea* on the moist field layer is concentrated in this period indicating that the climate was still favourable.

The end of climatic optimum is marked by an abrupt simultaneous decrease of *Alnus* and *Corylus* pollen (*Pinus-Picea* subzone a). The area of temperate deciduous forests was reduced and coniferous forests expanded subsequently. The continuation of the climatic deterioration is manifested by an increase of *Betula* in boreal forests (*Pinus-Picea* subzone b). A further signal, a new expansion of *Betula nana*, Gramineae, *Artemisia* and Ericaceae indicates substantial opening of the woodland.

A slight increase of *Corylus* and *Alnus* pollen is detected in the uppermost layers, where simultaneously a new expansion of open-ground species and families, including *Selaginella selaginoides* spores, occurs. This vegetational combination is inconsistent and argues in favour of redeposition of temperate taxa. The thin sand layers in the uppermost silt sequence imply possible erosion in the surroundings and an influx of secondary material from eroded Mikulino interglacial sediments.

Diatom stratigraphy

According to diatom counts the strata can be divided in two parts similar to the pollen data (Fig. 5). The varved clay sections have a low diatom count (80-2000 specimens/slide), whereas the diatom frequencies increase in the silty clay (maximum 147 000 specimens/slide at depth of 11.6 m). The upper, black, varved clay (18.5-12.6 m) contains diatoms in moderate abundance (80-2000 specimens/slide), but none were found in the lower varved clay (21.0-18.8 m). This lack of diatoms in itself implies that conditions were unfavourable to the diatom growth probably as a result of disturbed cold water. It is possible that turbid water derived from the thawing ice was a limiting factor on the growth of diatoms, although dissolution of diatoms cannot be excluded.

The dominant species in the upper clay sequence is *Aulacoseira islandica* (including the morphotype *helvetica*), which is a typical planktonic diatom in oligotrophic large lakes such as in the present Lake Onega, (Lak, unpublished report) and in the Ancylus Lake of the Holocene Baltic basin (Mölder&Tynni 1967). It is also the most common diatom in the Baltic Ice Lake sediment and was also common in the Yoldia phase of the Baltic basin (Grönlund 1991). Embryonic forms of this species are abundant, especially in the lowermost samples 50-100%. In the upper part of the sequence their percentages vary from 0-34 %. *A. italica* and *A. ambiqua* are also fairly common. The other *Aulacoseira* species encountered are: *A. distans* v. *alpigena*, *A. subarctica*, *A. granulata*, *A. granulata* v. *angutissima*, *A. valida* and *A. tenuissima*. Species such as *Cyclotella comta*, *Stephanodiscus rotula* et varieties and different *Diatoma* and *Tabellaria* species are also fairly abundant. Most of these species are widespread in the deposits of large lakes such as the Holocene Ancylus Lake and many of them thrive in the present Lake Onega (Mölder & Tynni 1967 and Devyatova et al. 1968). A small amount (1-22%) of redeposited saline water species were also found in the lower part of the clay sequence.

The diatom flora in the coarse silt above the varved clay, at depths of 12.6-12.2 m, consists for

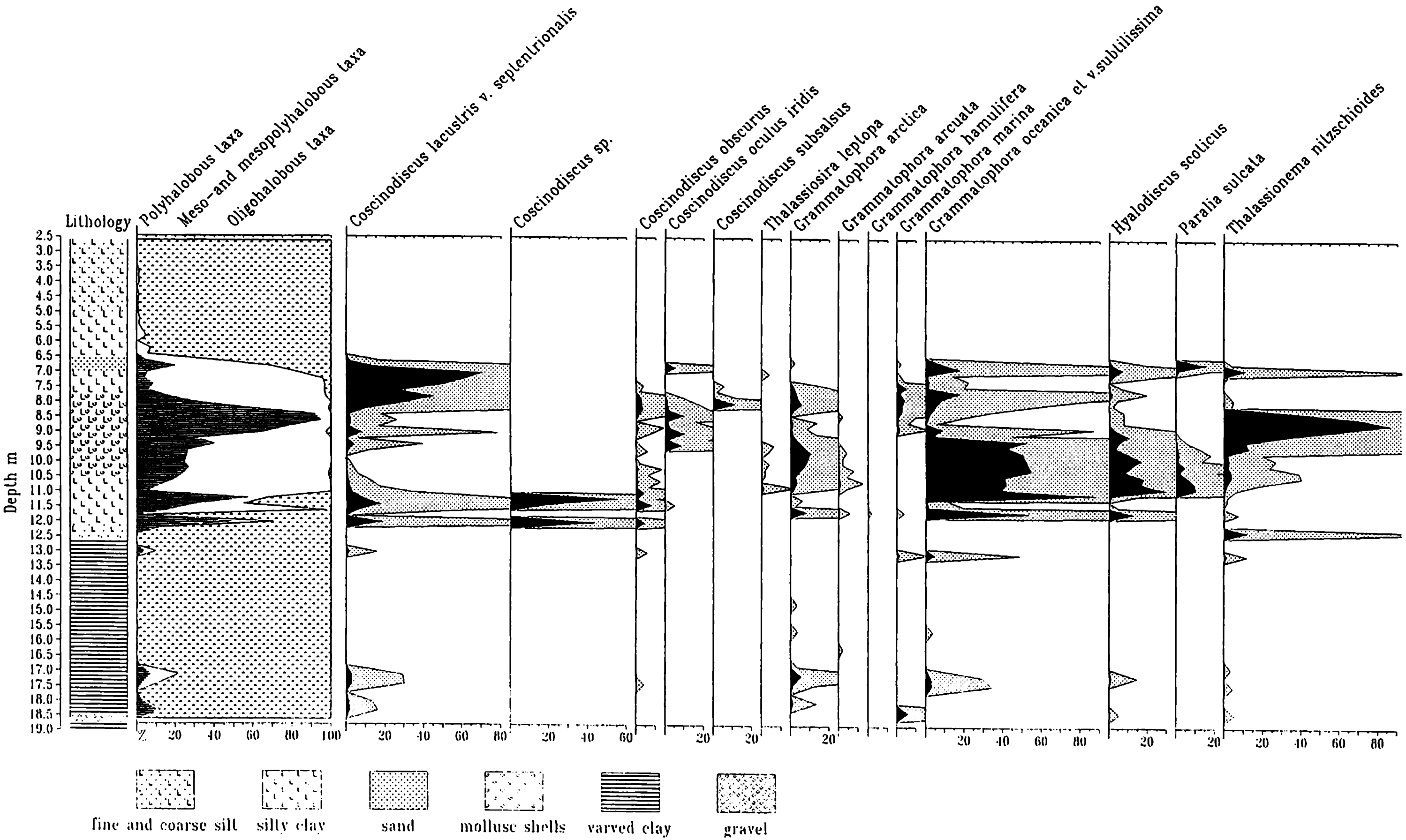
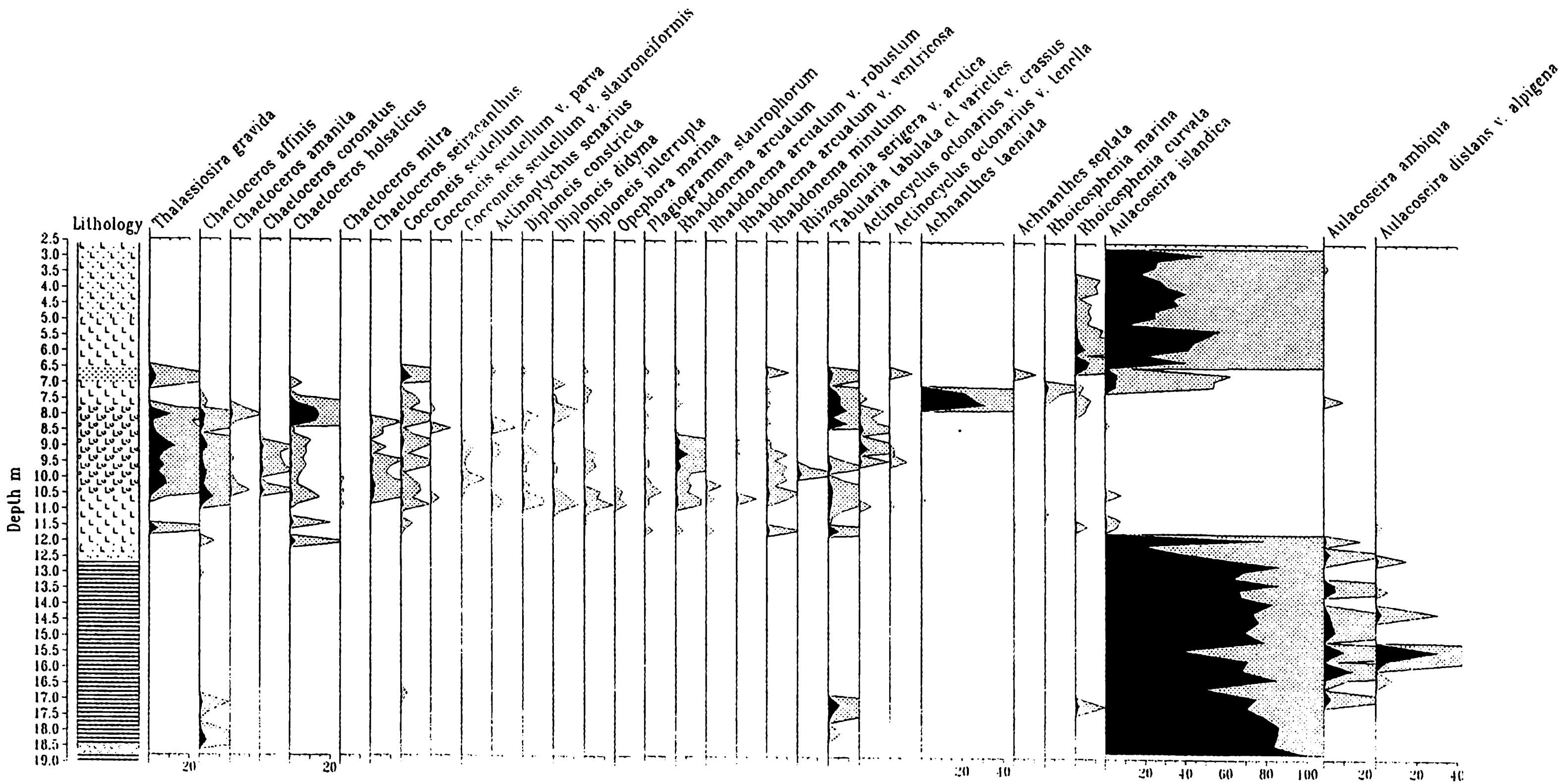
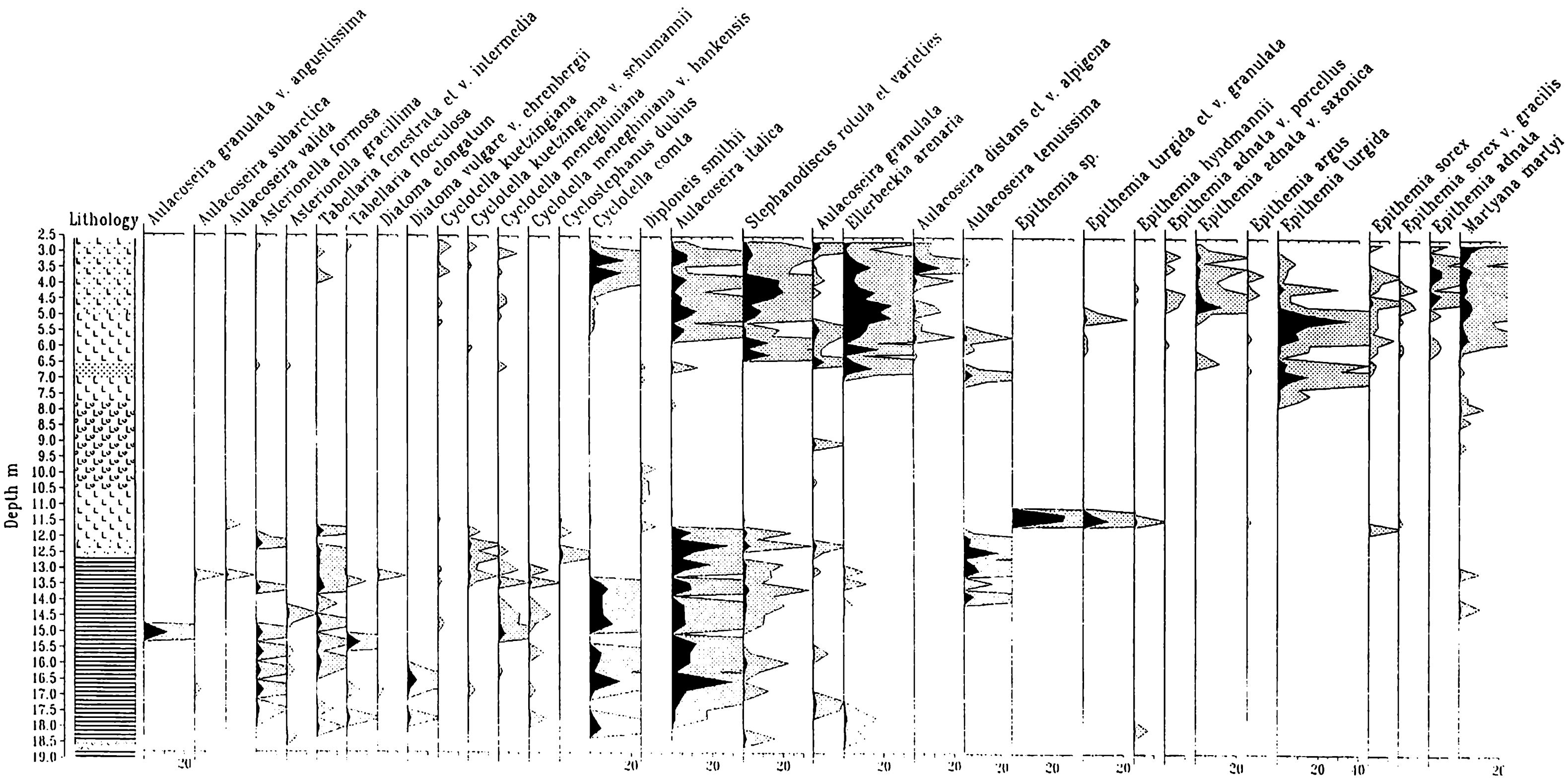
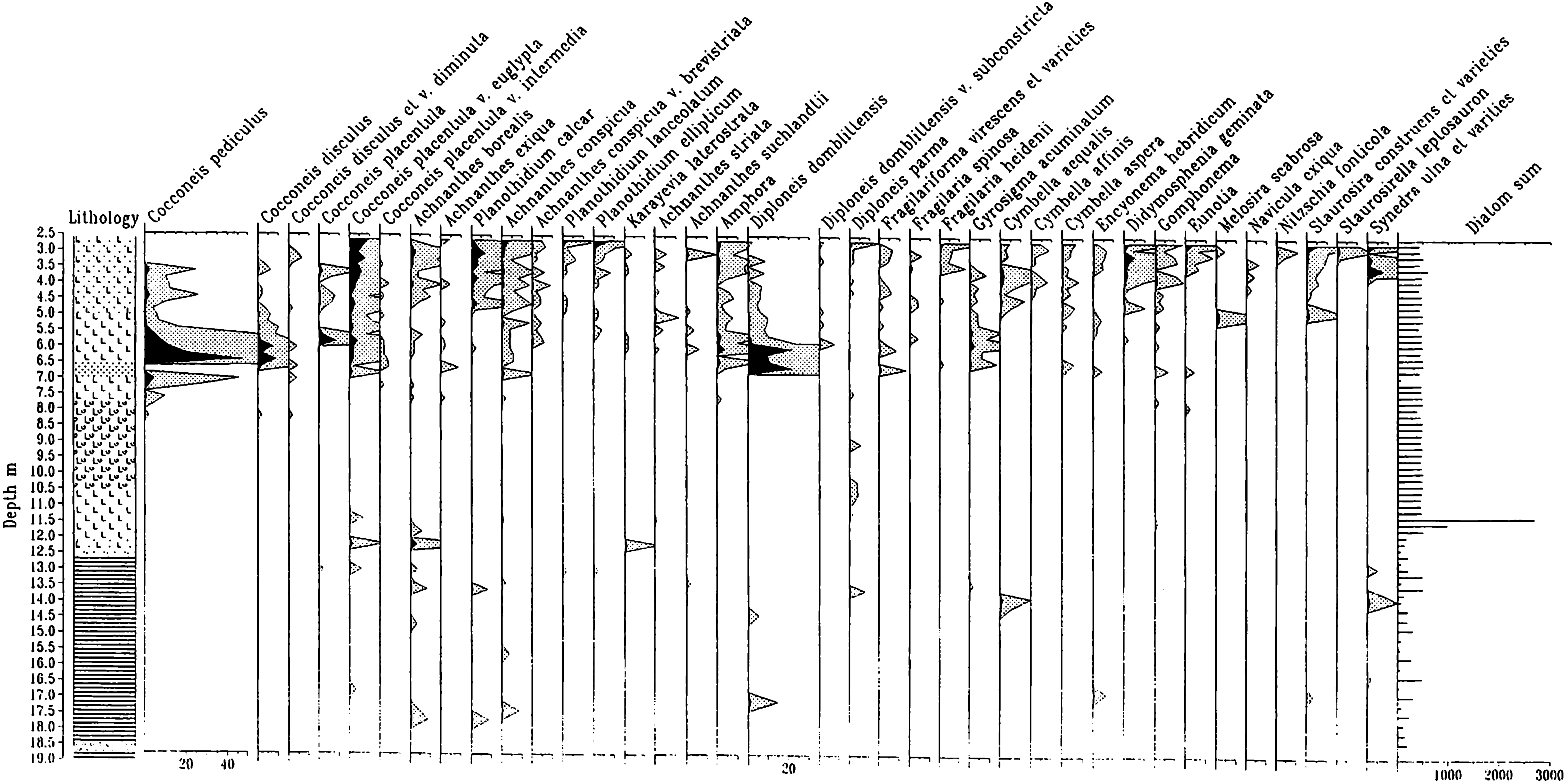


Fig. 5. Diatom diagram from site 1 at Petrozavodsk. Anal. G. Lak.



Lithology
Depth m
Thalassiosira gravida
Chaetoceros affinis
Chaetoceros amanita
Chaetoceros coronatus
Chaetoceros holsaticus
Chaetoceros mitra
Chaetoceros seiracanthus
Cocconeis scutellum
Cocconeis scutellum v. parva
Cocconeis scutellum v. stauroneiformis
Actinoptychus senarius
Diploneis constricta
Diploneis didyma
Diploneis interrupta
Opephora marina
Plagiogramma staurophorum
Rhabdonema arcuatum
Rhabdonema arcuatum v. robustum
Rhabdonema arcuatum v. ventricosa
Rhabdonema minutum
Rhizosolenia setigera v. arctica
Tabularia tabulata et varieties
Actinocyclus octonarius v. crassus
Actinocyclus octonarius v. tenella
Achnanthes taeniata
Achnanthes septata
Rhoicosphenia marina
Rhoicosphenia curvata
Aulacoseira islandica
Aulacoseira ambigua
Aulacoseira distans v. alpigena


Lithology
Aulacoseira granulata v. angustissima
Aulacoseira subarctica
Aulacoseira valida
Asterionella formosa
Asterionella gracillima
Tabellaria fenestrata cf v. intermedia
Tabellaria flocculosa
Diatoma elongatum
Diatoma vulgare v. ehrenbergii
Cyclotella kuetzingiana
Cyclotella kuetzingiana v. schumannii
Cyclotella meneghiniana
Cyclotella meneghiniana v. hankensis
Cyclostephanus dubius
Cyclotella comta
Diploneis smithii
Aulacoseira italica
Stephanodiscus rotula cf varieties
Aulacoseira granulata
Ellerbeckia arenaria
Aulacoseira distans cf v. alpigena
Aulacoseira tenuissima
Epithemia sp.
Epithemia turgida cf v. granulata
Epithemia hyndmannii
Epithemia adnata v. porcellus
Epithemia adnata v. saxonica
Epithemia argus
Epithemia turgida
Epithemia sorex
Epithemia sorex v. gracilis
Epithemia adnata
Martyana martyi
Depth m
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
20
40



Lithology
Depth m
Cocconeis pediculus
Cocconeis disculus
Cocconeis disculus el v. diminula
Cocconeis placenlula
Cocconeis placenlula v. euglypla
Cocconeis placenlula v. inlermedia
Achnanlhes borealis
Achnanlhes exiqua
Planolhidium calcar
Achnanlhes conspicua
Achnanlhes conspicua v. brevislriala
Planolhidium lanceolalum
Planolhidium ellipticum
Karayevia laleroslrala
Achnanlhes slriala
Achnanlhes suchlandlii
Amphora
Diploneis domblillensis
Diploneis domblillensis v. subconslricla
Diploneis parma
Fragilariforma virescens el varielies
Fragilaria spinosa
Fragilaria heidenii
Gyrosigma acuminalum
Cymbella aequalis
Cymbella affinis
Cymbella aspera
Encyonema hebridicum
Didymosphenia geminala
Gomphonema
Eunolia
Melosira scabrosa
Navicula exiqua
Nilzschia fonlicola
Slaurosira construens el varielies
Slaurosirella leplosauron
Synedra ulna el varilies
Dialom sum
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
20
40
20
1000
2000
3000

the most part of oligohalobous species in low numbers (180-800 specimens/slide). *Aulacoseira islandica* is dominant (36-86%), but other *Aulacoseira* species present include *A. italica* (5-27 %) and *A. tenuissima* (2-18 %). The first appearance of marine influence is found at 12.2 m where a minor peak of *Thalassiosira nitzschioides* is detected.

The initial marine phase in the silty clay sequence, at depths of 12.0-11.0 m is demonstrated by the fluctuation in the abundance of a marine diatom floral assemblage. At a depth of 12.0 m the proportion of polyhalobous and meso-polyhalobous taxa is already 70 %. *Coscinodiscus* is a dominant genus, but the specimens are mostly fragments, as is the case with *Chaetoceros* species. Unbroken specimens are rare and they are represented by *Coscinodiscus lacustris* v. *septentrionalis* and *C. obscurus*. At the same depth freshwater species, of which *Aulacoseira* species are dominant, are unbroken. It seems that the freshwater species are autochtonous, but the marine species are allochtonous (i.e. they were carried by currents) and therefore largely broken (Lak, unpublished manuscript). At depths of 11.8 - 11.6 m *Aulacoseira islandica* (79%) dominates, but there is still some marine species remaining.

At depth 11.6 - 11.4 m the percentage of oligohalobous taxa is only 3 %. The dominant species are polyhalobous *Grammatophora oceanica* and v. *subtilissima* (53%), *Grammatophora arctica* (8%) and *Thalassiosira gravida* (4%) and mesopolyhalobous *Hyalodiscus lacustris* (13%) and *Coscinodiscus lacustris* v. *septentrionalis* (6%). The latter species has been found abundantly in the Holocene Litorina Sea deposits in Finland (Mölder & Tynni 1968). Arctic forms include, besides *T. gravida*, species such as *Achnanthes septata*, *Grammatophora arcuata* and *Trachyneis aspera*. The occurrence of arctic species in the flora implies that the basin had a connection to the White Sea (Niemelä & Tynni 1979, Grönlund 1991). One *Grammatophora hamulifera* specimen was found at a depth of 11.6 m. This species is included with the southern boreal forms in the Vaga deposits south of the White Sea (Loseva 1992).

In the subsequent levels, at depths of 11.4-11.2 m, the flora is composed of both marine (55-68%) and freshwater (32-45%) species. The dominant marine species are *Coscinodiscus* sp. (20-55%) and *Coscinodiscus lacustris* v. *septentrionalis* (9-17%) and the dominant oligohalobous species are *Epithemia* sp. (25%) and *Epithemia turgida* and v. *granulata* (5-13%). It is particularly worth noting that throughout the section, the diatoms are mostly fragmental.

The diatom flora changes radically from a depth of 11.0 m, where a decrease of oligohalobous species is initiated. Freshwater species are totally replaced by brackish and saline species at a depth of 11.0 m and between 10.0-8.2 m. According to Lak (unpublished report), the deficiency of freshwater diatoms in the marine silty clay is a rare phenomenon. In several Holocene and Pleistocene diatom lists from Karelia this type of phenomenon is not seen. Usually the proportion of freshwater species comprises 22-28 % of the flora (Poretskaya 1955, Lak 1959 and 1976).

The diatom flora at depths 11.0-9.0 m indicate a marine littoral environment, where *Grammatophora oceanica* v. *subtilissima* is dominant (41-88%). Other main species are mesopolyhalobous *Hyalodiscus scoticus* (2-29 %) and *Paralia sulcata* (1-10 %). The former, epiphytic, marine species with brackish-water affinity is almost absent in the present Baltic Sea, but have been found in the Holocene Yoldia and Litorina Seas. The latter species is a common bottom or pelagic form everywhere in the Baltic Sea, but according to Mölder (1962), seldom occurs on the coast of Finland. It is also found in Yoldia and Litorina sediments. All the three species are common in the Eemian interglacial diatom flora of Ostrobothnia in Finland (Grönlund 1991), in the Eemian clay at Rouhiala on the Karelian Isthmus, in Russia (Brander 1943) and in the Eemian deposits at Prangli, in Estonia (Liivrand 1991), where *Grammatophora* is indicated only as a genus. Other marine diatoms found in small abundances are as follows: *Tabularia fasciculata* and some *Coscinodiscus*, *Cocconeis* and *Rhabdonema* species. The abundance of dominant pelagic species are as follows: *Thalassionema nitzschioides* 0.5-13%, *Thalassiosira gravida* 1-9% and *Chaetoceros* species 3-10%. In the Eemian interglacial deposit from Ostrobothnia, Finland, the proportion of polyhalobous planktonic species is lower than at Petrozavodsk. In the Prangli deposit marine planktonic species also occur only sporadically

(Liivrand 1987). Arctic species include *Thalassiosira gravida*, *Grammatophora arcuata*, *Trachyneis aspera* and also an arctic neritic species *Chaetoceros mitra*, which is widespread in polar seas, the North Sea and the North Atlantic (Grönlund & Ikonen 1996 and references therein). The low abundance of silicoflagellates that favour the plankton of saline waters is concentrated in this section. *Distephanus speculum* (Ehrenberg) Haeckel, a cold-water species is more common reaching a maximum (10-18 specimens/sample) at depth 9.4-9.6 m. *Dichtyocha fibula* Ehrenberg prefers warm water but is detected only at depths 9.4 m and 10.2 m.

The marine flora includes three species which occur nowadays in many places along the western coast of Europe, but are not found in less saline areas of the Baltic Sea. These species include *Cocconeis quarnerensis* (at depths of 9.8 m, 9.2 m and 8.8 m), *Opephora marina* (at depths 10.4-10.8 m) and *Coscinodiscus granulosus* (at a depth of 11.2 m). This species have also been found in the interglacial deposits of Ostrobothnia, Finland (Niemelä & Tynni 1979). *Actinoptychus senarius*, which is alien to the postglacial Baltic Sea and yet occurs in the interglacial flora in Ostrobothnia, Finland and at Rouhiala, Karelian Isthmus (Grönlund 1991), was detected at depths of 10.6-10.8 m, 9.0-9.4 m, 8.2-8.4 m and 6,6 m. Another species, *Thalassiosira leptopa*, which does not belong to the modern Baltic Sea assemblages but to more southern seas (Hendey 1937) but has been found at Rouhiala, in the Karelian Isthmus (Mölder & Tynni 1968), has a continuous occurrence at depths of 9.4 m-10.8 m.

Above the depth of 9.0 m the abundance of *Grammatophora oceanica* v. *subtilissima* decreases abruptly, while those of marine pelagic polyhalobous species *Thalassionema nitzschioides* (maximum 86% at a depth of 8.6 m) and *Thalassiosira gravida* (maximum 13% at a depth of 9.0 m) increase. The pelagic polyhaloboys *Coscinodiscus oculus iridis* is also concentrated in this phase. From a depth of 8.2 m the abundances of *Coscinodiscus lacustris* v. *septentrionalis* and *C. subsalsus* and of a pelagic cold-water species *Chaetoceros holsaticus* increase, while the proportion of *Thalassionema nitzschioides* decreases.

At depths of 7.8-6.6 m the dominant marine species is *Coscinodiscus lacustris* v. *septentrionalis*. The other main marine species include *Grammatophora oceanica* v. *subtilissima*, *Tabularia tabulata* and in smaller numbers *Chaetoceros holsaticus*, *Cocconeis scutellum*, *Hyalodiscus scoticus* and *Paralia sulcata*. A pelagic, cold-water species *Achnanthes taeniata* reaches a maximum between 7.2 m to 7.6 m. A species, *Coscinodiscus apiculatus*, which does not belong to the flora of the Baltic Sea proper and which has been seldom found in Holocene Yoldia and Litorina sediments (Mölder & Tynni 1968), was detected at a depth of 7.2 m. A warmer-water species *Thalassiosira leptopa* was found for the last time at a 7.0 m. The occurrence of an arctic species *Thalassiosira gravida* is terminated at a depth of 6.6 m. The main oligohalobous species are: *Epithemia turgida*, *Aulacoseira islandica*, *Ellerbeckia arenaria* and *Cocconeis pediculus*. In the sand layer, at depths 6.8-6.6 m the proportion of oligohalobous species is already 31-59%.

In the upper silt interbedded with thin sand layers and including plant debris, at depths of 6.6-2.6 m, saline-water species are replaced almost totally by freshwater species (Figs. 6 and 7). The only marine species is *Rhoicosphenia curvata*. The succession from a marine to a freshwater diatom flora unambiguously indicates the isolation of the basin from an interglacial sea. The diatom flora consists for the most part of alkaliphilic species. Planktonic diatoms are quantitatively dominant, but in terms of the number of species epiphytic forms dominate. Dominant species are *Aulacoseira islandica*, *A. italica*, *Ellerbeckia arenaria*, *Cyclotella comta*, *Stephanodiscus rotula* and varieties, *Cocconeis pediculus*, *Diploneis domblitenssis* and *Epithemia turgida*. Other species found comprise genera f.e. *Achnanthes*, *Amphora*, *Eunotia*, *Fragilaria* and *Cymbella*. North-alpine cold water species found include *Achnanthes borealis*, *Planothidium calcar*, *Karayevia laterostrata*, *Diploneis parma*, *Eunotia monodon*, *Navicula galikii* and *Staurosirella leptosauron*.

The abundance of three genera follows an order *Cocconeis*, *Epithemia* and *Achnanthes*. The abundance of *Cocconeis* species, of which *C. pediculus* is dominant, decreases from base upwards while that of *Achnanthes* increases upwards. The maximum of *Epithemia* species is at depths 5.6-4.6 m. *Eunotia* species have their maximum in the uppermost part of the sequence indicating lowering of the water level in the basin.

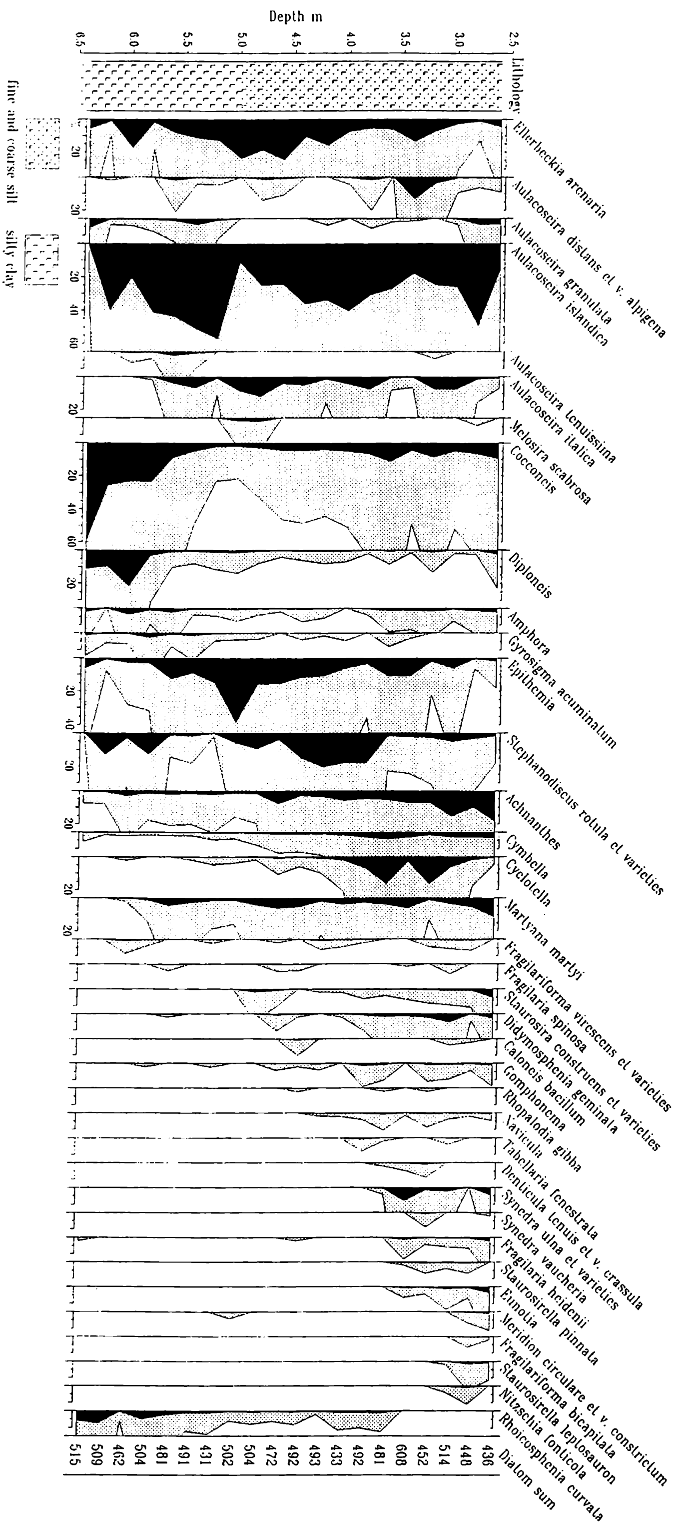


Fig. 6. Diatom diagram showing the succes-
sion of species in the lake phase at Petoza-
vodsk site 1. Anal. G. Lak.

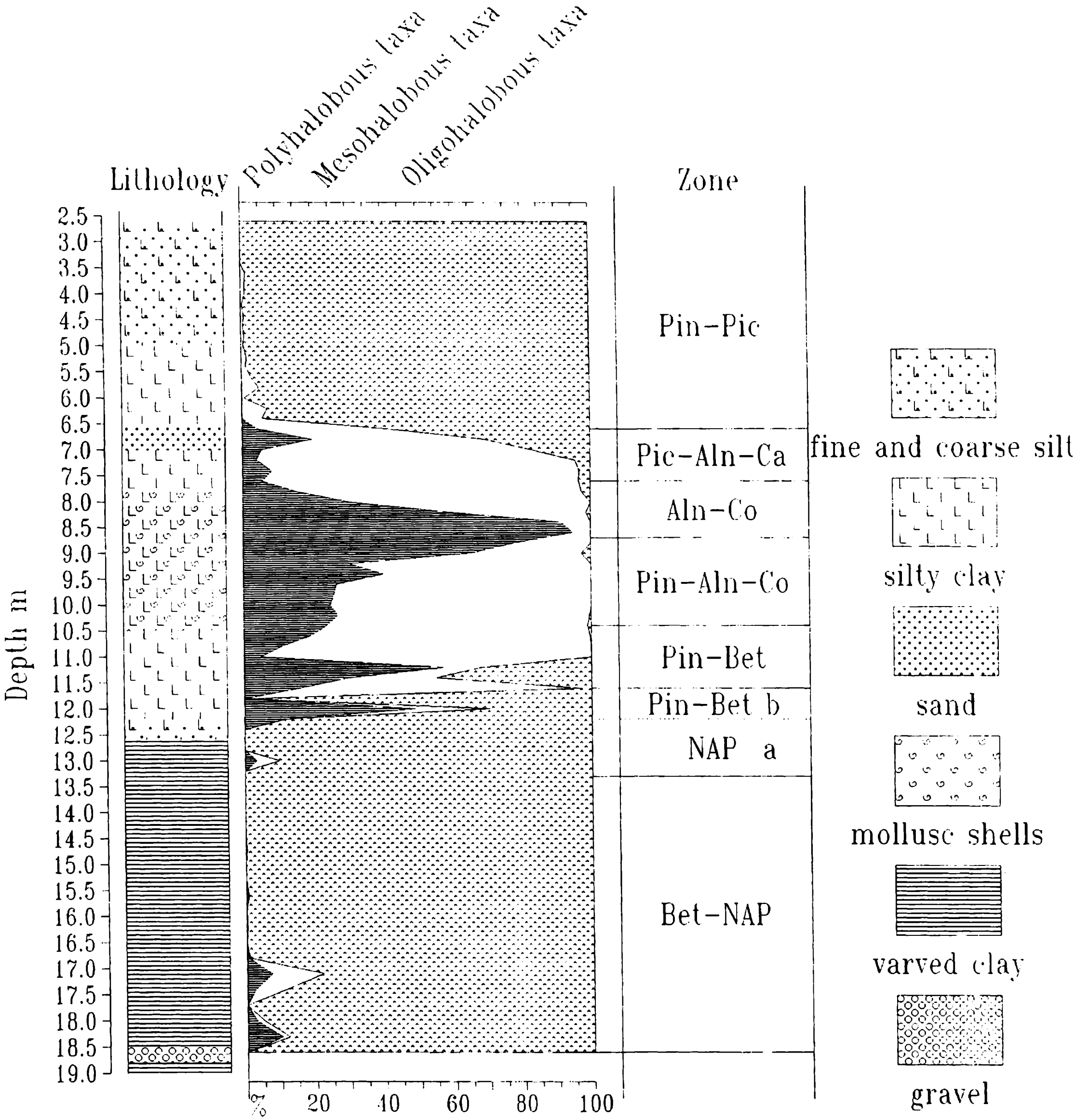


Fig. 7. The diatom groups after salinity and the pollen assemblage zones at site 1 in Petrozavodsk.

Foraminifera stratigraphy

Foreminifera are found between depths 7.1- 12.3 m. The number of species and their amount are limited. The fauna includes species such as *Buccella tenerimma*, *Retroelphidium clavatum*, *Protelphidium pauciloculum albiumbilicatum*, *Cibicides lobatulus*, *Protelphidium orbiculare*, *Astrononion gallowayi*, *Guttulina lactea*, *Cassidulina carinata*, *C. subacuta*, *Cassandra teretis*, *Islandiella sulcata* and *Islandiella* sp. (Table 2.). The first three species mentioned above are more abundant than the rest. The species have not been listed in the faunal assemblages of Kola, Onega and Mezen' interglacial deposits (according to the data in Legkova 1966, Abrukina & Krasilnikova 1972, Gudina & Yevzerov 1973). *C. lobatulus* is an arctic species indicating strong currents. A. *gallowayi* can be found both in arctic and subarctic assemblage. *Cibicides lobatulus*, *Astrononion gallowayi* and *Buccella tenerimma* have been found in bottom samples from shallow waters around western Svalbard (Nagy 1965) and in Svalbard fjords (Hald & Korsun 1997). *Guttulina lactea* and *Cassidulina subacuta* and *C. carinata* represent boreal-subarctic species of which the two first mentioned have been encountered in Ponoi and Strel'na deposits in the Kola Peninsula (according to data in Gudina & Yevzerov 1973).

Cassandra teretis is found livng on the

Sample	12	14	15	17	18	19	21	22	23	24	25
Depth m	7.1	7..9	8.3	9.1	9.5	9.9	10.7	11.1	11.5	11.9	12.3
1. *Guttulina lactea* Walker et Jacob								2			
2. *Buccella tenerrima* Bandy	54			109	12	93	5				
3. *Cibicides lobatulus* Walker et Jacob		1		1			6	2	1		1
4. *Astrononion gallowayi* Loebelich et Tappan							2		1		
5. *Retroelphidium clavatum* Cushman	13			64		9	1				
6. *Protelphidium orbiculare* Brady							10			1	
7 *Protelphidium pauciloculum albiumbilicatum* Weiss		68	2								
8. *Cassidulina carinata* Silvestry				1							
9. *Cassidulina subacuta* Gudina							1				
10. *Cassidulina teretis* Tappan							3		1		1
11. *Islandiella sulcata* Voloshinova		1									
12. *Islandiella* sp			1								
13. *Globigerina pachyderma* Ehrenberg				1			7				2
14. *Globigerina bulloides* d'Orbigny				14							
15. *Globigerinita glutinata* Egger				3							1
16. *Globigerinoides ruber* (pink) d'Orbigny		1		2		1		1			
17. *Globigerinella siphonifera* d'Orbigny						1					
18. *Globorotalia inflata* d'Orbigny				1							
19. *Orbulina universa* d'Orbigny				1							

Table 2. Numbers of foraminiferal species per 100 g sediments.

continental slope off the Barents Sea (Mackensen 1985 in Hald & Aspeli 1997) and it also appears to be related at present to Atlantic water masses in the Barents and Kara Seas. It seems to require cold saline bottom water (Steinsund et al. in press, in Hald & Aspeli 1997). The species has been found in abundance in the deposits of Boreal transgression in the lower course of the river Mezen' (Legkova 1966). It is included in the fauna from both the Ponoy and Strel'na beds on the Kola Peninsula (Gudina & Yevzerov 1973) and also in the Mikulino deposits of the Onega river (Abrukina & Krasilnikova 1972).

Planktic species, which prefer warm water conditions, were only found in low frequences. They include the genera such as *Globigerina*, *Globigerinita*, *Globigerinoides*, *Globigerinella*, *Globorotalia* and *Orbulina*. *Globigerina bulloides* d'Orbigny is a subarctic species, which tolerates rather low salinity and temperature, and lives in relatively deep water (around 100 m), at least at the adult stage (Be 1977). *Globigerina pachyderma* Ehrenberg is subarctic and widely distributed in the cold waters of the North Atlantic. The species has also been found in the Ponoi beds of the Kola Peninsula (Gudina & Yevzerov1973). *Globigerinita glutinata* Egger, the recent habitat of which is in northern parts of the Atlantic Ocean, has been recorded in the Ponoi Bed at Svyatonosski bay (Gudina & Yevzerov 1973).

Recently, a similar exotic faunal assemblage has been found in the bottom sediments of the Barents Sea. These sediments were laid down during the deglaciation of the last glaciation and at the beginning of Holocene (L. V. Polyak, in the Bylinskaya manuscript, unpublished). According to Bylinskaya, no other source of redeposition from older sediments with the similar warm water planktic assemblage is known from the study area and adjacent areas. Moreover, the contamination of samples is also not possible.

The only explanation for the presence of foraminifera indicating warmer waters in the Petrozavodsk deposit might be that during the Boreal transgression the current system of Atlantic Ocean was different from that today. The relatively warm Atlantic water was transported northward to the shelf areas of the southern Barents Sea (Gudina & Yevzerov 1973, Yevzerov & Koshechkin 1982, Raukas 1991, Mangerud et al. 1999). In this way, planktic foraminifera were able to reach the Barents Sea shelf areas and were transported further. During the period of high relative sea level, the channel between the Barents and the White Seas was wider and probably the current pattern in the White Sea and in the Onega bay were different from the present. This allowed the transport of planktic foraminifera, which were finally buried in the sediments. Consequently, the species are allochtonous, but contemporaneous with sediments.

However, the dominance of arctic-benthic species in the Petrozavodsk deposit indicates relatively shallow and cold waters. At present the species live on the arctic inner shelf and have been there throughout the Pleistocene. Thus temporal correlation on the basis of fauna is not possible. Foraminifera show no faunal succession either. Consequently, the question of the correlation of the marine deposits especially with the transgression phase of interglacial sea also remains open (Bylinskaya manuscript). However, the bulk of the marine planktic species coincides with the maximum occurrence of planktonic diatoms. Foraminifera disappear at the beginning of the regression, in the upper part of the *Picea-Alnus-Carpinus* pollen zone.

Oscillation of the ice margin during the Moscovian deglaciation is recorded in the basal sediments of the Onega basin. The thickness of the varves in clay sequences at Petrozavodsk show that sedimentation occurred under changing palaeohydrological conditions. During the sedimentation of the lower clay sequence, the ice margin stood north of the Lake Onega basin. Conditions were most probably unfavourable to the growth of diatoms, since none were found in the sequence. A gravelly sand unit interbedded between the varved-clays and the upper varved-clay sequence, with thicker varves, indicates a readvance of the ice margin. Diatom composition in the upper clay sequence shows that deposition occurred in a rather deep, cold freshwater basin. The large amount of embryonic *Aulacoseira islandica* forms, especially in the lower part of the clay, indicates that conditions were still unfavourable for the growth of diatoms. The pollen flora indicates late-glacial Moscovian (Saalian) vegetation around the glacial lake. Deposition of varved-clay ceased when the ice margin retreated north of the Lake Onega water divide and meltwater drainage was directed to the White Sea basin and/ or to the Baltic basin. In the late Valdaian, the deposition was halted when the ice margin was 200 kilometres northwest of Petrozavodsk (Saarnisto & Saarinen 1999). The glacial lake phase of the basin persisted for several thousand years. In the Lake Onega basin, the longest late Valdaian varved-clay deposition lasted 1300 years (Saarnisto & Saarinen 1999).

In the Moscow late-glacial time a lake phase continued during the period represented by the coarse silt sedimentation, from which a similar freshwater flora were found as in varved-clay sequences. In Ostrobothnia (Pohjanmaa), in western Finland the lake sediments preceding the Eemian Baltic Sea are also dominated by *A. islandica* and its morphotype *helvetica* and other *Aulacoseira* species. In Estonia at Prangli deposit proper *Aulacoseira* species are not found below the marine phase and the diatom flora is composed of a different type of cool freshwater species mixed with the marine flora of the Eemian Baltic Sea. According to Cheremisinova (1961), the diatom assemblage in the lower part of Prangli deposit characterises the initial pulse of marine waters into the glacial lake, which existed in the pheriphery of the Fennoscandian shield area. After the Moscovian deglaciation, isolated cold-freshwater basins were formed in the depressions of the Gulf of Finland, Lake Ladoga and Onega (Cheremisinova 1961). Cheremisinova (1961) correlates the lower part of Prangli deposit with the lower parts of the Mga and Sinyavino interglacial sequences, in which glaciomarine and lower lagoonal phases have been distinguished (Znamenskaya 1959, Cheremisinova 1960 and Znamenskaya & Cheremisinova 1962). According to Grönlund (1991), the freshwater species listed by Cheremisinova (1961) are partly the same as those interpreted as Ancylus species and therefore the freshwater sediments encountered in Ostrobothnia and Prangli were probably laid down in the same basin. The conditions in this lake resembled the conditions in the Holocene Ancylus Lake in the Baltic Basin with redeposited cold water species rather than conditions of a glacial lake.

As a result of continuous sea level rise as a consequence of climate warming and the downwasting of the continental ice sheet saline waters from the Barents Sea reached the White Sea basin into which warm, Atlantic waters also penetrated. The rise of sea level also lead to opening of a connection between the Onega basin and the White Sea. The connection between the Eemian Baltic Sea and the White Sea has been confirmed by numerous studies in Russia (Lavrova 1961, Znamenskaya & Cheremisinova 1962, Devyatova 1982).

After the formation of connections to the White Sea and the Baltic Sea, Fennoscandia became an island, which was separated from the rest of Europe by a wide channel.

The diatom flora shows that the marine phase in the Onega basin began with an abrupt discharge of saline water in two pulses. According to pollen stratigraphy, this occurred within a shift from Moscovian lateglacial to Mikulino (Eemian) interglacial type vegetation, in the *Pinus-Betula*-NAP zone (Fig. 7). The marine phase proper began in the *Pinus-Betula* zone with a littoral facies, in which *Grammatophora oceanica* et v. *subtilissima* became dominant. In the subsequent phase, during the *Pinus-Alnus-Corylus* and *Alnus-Corylus* zones planktic species dominated especially *Thalassionema nitzschioides*. The end of the marine phase is marked by dominance of the brackish water species *Coscinodiscus lacustris* v. *septentrionalis*. The regression began in the upper part of the *Picea-Alnus-Carpinus* zone. The connection to the north was closed and the basin finally became isolated from the White Sea basin as an independent freshwater basin in the beginning of *Picea-Pinus* zone. The subsequent freshwater diatom flora shows a progressive lowering of the water level in the Onega Basin.

Thus the onset of the marine phase already occurred in the *Pinus-Betula* NAP zone and continued into the post-temperate phase, when the vegetation of climatic optimum was replaced by boreal taiga. Hence, the passage between the Eemian Baltic Sea and the Barents Sea persisted for several thousand years.

The Mikulino history of the Onega basin water body differs from that during the Late Valdai (Late Weichselian), when no marine connection existed between the White and Baltic Sea basins. Lake Onega developed from an independent ice-dammed body to the present lake (Saarnisto et al. 1995).

Regional correlation

The terms for stratigraphical units used in Russian papers differ somewhat from those used in western countries. The terms, Boreal transgression, Mga Sea, Mga transgression and Boreal Sea imply the marine phase during the Mikulino interglacial. The terms have been used as a substitute for the term Eemian Sea. Two marine sequences on the Kola Peninsula: the Ponoy (lower) and Strel'na (upper) beds were previously correlated with an independent Middle Valdai transgression (Gudina & Yevzerov 1973, Yevzerov et al. 1976). At the end of the 1970s and the beginning of the 1980s, new uranium-thorium dates confirmed the Mikulinian age for the Ponoi beds and Middle Valdaian age for the Strel'na beds (Arslanov et al. 1981, Faustova 1984).

In the papers referred different types of names have been used to identify pollen zones. The zonation used by Devyatova (1982) includes zones KA_1-KA_9 and that by Grichuk (1961) M_1-M_8. The correspondence with the zonal types and the description by Grichuk (1961) are as follows:

KA_9/M_8	*Pinus* zone with *Picea* and *Betula* (M8a dominant *Picea*, M_{8b} dominant *Pinus*)
KA_8/M_7	*Picea* zone (upper maximum) with QM
KA_7/M_6	*Carpinus* zone with *Tilia*, *Quercus*, *Ulmus* (occasionally), *Corylus* and *Picea*
KA_6/M_5	*Tilia* zone (second *Corylus* maximum) with *Quercus*, *Ulmus* and *Carpinus*
KA_5/M_{4b}	*Quercus-Ulmus* zone (first *Corylus* maximum)
KA_4/M_{4a}	*Quercus-Ulmus* zone with *Corylus*
KA_3/M_3	*Pinus-Betula* zone with low frequneces of QM
KA_2/M_2	*Pinus-Betula* zone with low frequences of *Picea*
KA_1/M_1	*Picea* (lower maximum) with small abundance of *Betula* and *Pinus*

Further type of zonal names, V-XIII was used by Devyatova in 1972 and is included in the correlation scheme in Table 3.

The nomenclature of diatom species varies with individual authors. The author name after species is indicated in the text only when the species is not present in the Petrozavodosk flora and when it is mentioned for the first time.

Devâtova 1972		Ikonen & Ekman 2000		Grichuk 1961
Diatom zones	Pollen zones	Pollen zones	History of water basin	Pollen zones
4	XII-XIII	Pin-Pic b	Independent Lake	M_8
		Pin-Pic a		M_7
	XI	Pic-Aln-Car	⋀	M_6
3	X	Aln-Cor	Marine phase	M_5
	IX			
2	VIII	Pin-Aln-Cor		M_4
	VII	Pin-Bet		M_2-M_3
	VI			
1	V	Pin-Bet-NAPb		M_1
			Glacial lake	

⋀ beginning of regression

Table 3. Correlation of the pollen zones of two Mikhulinian profiles at Petrozavodsk and history of the water basin. Correlation to Grichuk's zonation according to the present authors.

LAKE ONEGA AREA

The following description is based on references by Zemlyakov (1936), Cheremisinova (1952, 1962a), Biske (1959), Biske & Devyatova (1965), Ekman (1968, 1972, 1987), Apukhtin & Ekman (1967), Devyatova et al. (1968), Devyatova (1972) and Abrukina & Krasilnikova (1972). Numbers in brackets refer to sites indicated in Figs 1 and 2.

Mikulino marine interglacial deposits in the Petrozavodsk area have been discussed in many boreholes on the northwestern shore of Lake Onega, north of the Neglinka river (Devyatova 1972). The top of interglacial units lies at 35-41 m above sea level. The units are overlain by till, but in places, especially towards the shore of Lake Onega this till bed has been eroded. Marine interglacial deposits have not been found south from the Neglinka river. The core site 3604 studied by Devyatova (1972) is situated 550 m north of the Petrozavodsk site 1 described above, at 35 m above sea level (Fig. 2). The interglacial sequence from the base consists of silt, clay and silt with horizontal sand layers. This sequence rests on Moscovian late-glacial sand-clay strata, which is in turn underlain by Moscovian till bed. The till bed overlying the interglacial unit has been eroded.

The difference in the calculation of the tree pollen percentages compared to the new Petrozavodsk profile causes some difficulties in correlation of the pollen zones. However, there are specific levels (the *Corylus-Alnus* maximum and *Alnus* decline) that allow correlation.

The diatom flora reflects four successional phases (Devyatova et al. 1968). During the first phase (1), that corresponds with the pollen zone V, diatoms are absent. The marine phase (2) at 8.4-7.5 m, during pollen zones VI-VIII, saline water species such as *Hyalodiscus scoticus*, *Opephora marina*, *Chaetoceros holsaticus*, *C. mitra*, *Thalassionema nitzschioides*, *Rhabdonema arcuatum*, *R. minutum*, *Grammatophora oceanica*, *Synedra tabulata*, *Cocconeis costata* Gregory and *C. scutellum* occur.

In the subsequent phase (3), at 7.5-5.5 m, the main species present are *Actinocyclus octonarius* and v. *intermedia* and v. *tenella*, *Coscinodiscus lacustris* v. *septentrionalis*, *Hyalodiscus scoticus* and *Thalassionema nitzschioides*. This phase falls mainly within the *Corylus* and *Alnus* maximum (the zones IX, X and half of zone XI). The diatom flora in the upper part of the core (4) at 5.5-3.5 m, consists of freshwater diatoms which are typical of the present-day Onega Lake, such as: *Melosira islandica* subsp. *helvetica*, *M. granulata*, *M. arenaria*, *Cyclotella comta*, *Opephora martyi* and *Cocconeis disculus* v. *diminuta* and others (Devyatova et al. 1968).

Molluscs were found between 5.50 m - 8.15 m, and are particularly abundant in the silt sequence between 5.50 m - 7.35 m (marine phase 3). The fauna includes arctic *Portlandia arctica* Gray, subarctic *Mytilus edulis* Linné and *Macoma baltica* Linné and ubiquitous *M. calcarea* Cheminitz and *Leda pernula* Müller (Lavrova 1961, Devyatova 1972). Of particular note is the find of the arctic *Cardium ciliatum* Fabricius, which is wide-spread in polar waters at present, but has seldom been encountered in the Atlantic Ocean (Lavrova 1961). This mollusc was found not only at Petrozavodsk but also at Mga and in Mikulino deposits of the River Onega (Tëksa, Somba) and Severnaya Dvina (Siya, Shenkursk).

At Petrozavodsk and in the Leningrad region, *P. arctica* has been found in marine silts or clays resting on varved clays. According to Lavrova (1961) *P. arctica* is a pioneer species that appeared when the water basin gradually became saline and when water temperature was low. When the transgression intensified and the climate became warmer, *Cardium ciliatum* and *Macoma calcarea* appeared. These species have been encountered in the dark grey, bituminous clays and silts. The species survived throughout the transgression and also during the early part of regression. It was accompanied by *Portlandia arctica* that survived as a relict in cold bottom waters (Lavrova 1961). The occurrence of *Portlandia-Macoma* assemblage with *Leda* sp., has also been found in the marine interglacial deposit of the River Luga on the southern coast of the Gulf of Finland (Lavrova 1961).

Mytilus edulis, which is a shallow-water species, has been found along with *Portlandia arctica* at Petrozavodsk. According to Lavrova (1961), the appearance of these species in the same habitat can be explained by surge action, which detaches *Mytilus* shells and algae from the upper sublittoral zone. Shells are subsequently carried offshore by currents. In interglacial deposits, *M. edulis* has been often found with *Zostera* remains.

Foraminifera were found between the depths of 6.45 - 8.15 m and consists of four assemblages (Abrukina & Krasilnikova 1972).

At depths of 8.15-7.75, only 35 specimens were recovered from 50 g sediment. Besides the dominant forms *Buccella* ex gr. *frigida* Cushman and

Protelphidium orbiculare Brady, the fauna also includes two other species *Protelphidium* sp. and *Globulina* sp.

At depths of 7.75-7.35 m the assemblage includes seven species of which the most abundant arctic species are *Buccella* ex gr. *frigida* Cushman, *Elphidium subclavatum* Gudina and *Ammonia flevensis*. In addition *Elphidium* ex. gr. *incertum* Williamson and *Protelphidium orbiculare*, *Protelphidium* sp. and *Globigerina* sp. are encountered.

At depths of 7.35-6.9 m foraminafera 50-200 per 50 g of sediment were found, which is half as much as in the second assemblage. The number of species is also reduced to five forms: *Ammonia flevensis*, *Protelphidium* sp., *P. orbiculare*, *Elphidium subclavatum* and *E.* ex gr. *subarcticum* Cushman, of which the two first-mentioned species dominate. At 7.10 m, the frequency of *Elphidium subclavatum* declines, while that of *Protelphidium orbiculare* increases.

Between 6.9-6.45 m, only one species *Elphidium* ex gr. *subarcticum* was encountered in the silt bed with sand layers except at 6.7 m where also *Cibicides* ex. gr. *rotundatus* occurred. The last mentioned species has been found in great abundance in the lower marine beds (Ponoi beds) at Chapoma, Ponoy, Svyatonosski bay and at Varzuga on the Kola Peninsula (Gudina & Yevzerov 1973) and in the Boreal transgression deposits in the river Onega and Mezen' basins (Abrukina & Krasilnikova 1972).

A quite similar fauna was found in core 5536 between 3.80-5.90m depth. The sequence represents the climatic optimum of an interglacial, on the basis of the pollen analysis (Abrukina & Krasilnikova 1972). The fauna includes species such as *Miliammina* ex gr. *arenacea*, *Buccella* ex gr. *frigida*, *Ammonia flevensis*, *Protelphidium orbiculare*, *Protelphidium* sp., *Elphidium subclavatum*, *E.* ex gr. *subarcticum* and *E.* ex gr. groenlandica.

The foraminiferal fauna in both profiles is quite poor in numbers (35-350/50 g dry matter) and species diversity (12) compared to typical Boreal transgression sections on the Kola Peninsula and in the Onega-Mezen' area. The fauna consists exclusively of arctic species, which nowadays colonize cold bottom waters (Abrukina & Krasilnikova 1972). According to these authors, migration of species occurred, when saline waters from the White Sea entered the area. A great proportion the normal marine fauna, which require high or varying salinity could not reproduce and develop in these unfavourable circumstances (Abrukina & Krasilnikova 1972).

The faunal assemblages in both profiles are completely different from the marine sequence at Petrozavodsk site 1. The boreal-subarctic species found at the latter are absent from both profiles at site 2. The fauna includes only one common species, *Protelphidium orbiculare*.

Klyucheva village (3)

A terrestrial interglacial deposit was found in the southern edge of Petrozavodosk near Klyucheva village (Fig. 2) (Ekman 1972). An interglacial deposit beneath a till here is composed of two sand beds (0.9 m and 2.0 m thick respectively) interbedded with a 1.5 m thick peat layer. The top of the upper sand bed is at 122.7 m above sea level. The lower sand layer is folded, hence the deposit may not be *in situ*. However, the pollen flora from the sand layers and peat is very similar. The dominance of *Pinus* and *Picea* pollen and the presence of *Carpinus* in these sediments most probably reflect the late phases of the Mikulino interglacial. *Osmunda cinnamomea* is present throughout the interglacial sequence, but is most abundant in the lower sand and peat beds. The abundance of the diatom flora in the sand and peat beds is restricted. The flora includes freshwater diatoms such as the genera *Eunotia* , *Stauroneis*, *Diploneis*, *Pinnularia* and *Cymbella*, which are very often corroded and fragmented. The greater proportion of the diatom species favour cold water.

Derevyannoe (4)

This site is situated about 25 km south of Petrozavodsk, on the western side of the Lake Onega (Ekman 1968). The interglacial sediments occur at depths of 9-31.5 m (at 16 m to 39 m above sea level), rest on Moscovian till and are overlain by two Valdai-age till beds. The interglacial sequence is composed of bituminous clayey-silt with vivianite and plant remains. At depths of 16 m-21 m there is an hiatus, 5 m thick in recovery. In the lower part of the section at 21.3-31.5 m, trees represent 60-92%. *Betula* values, which are generally 12-30%, show two peaks of 65% and 50% at depths of 30 m and 21.3 m respectively. The pollen values for *Picea*, *Pinus* and *Alnus* are quite similar, at 2-30%, 16-25% and 16-25% repectively, whilst temperate deciduous tree frequencies are 6-18%. The pollen curves of *Quercus* (3-7%), *Ulmus* (1-3%), *Carpinus* (2-8%) and *Corylus* (3-18%) are continuous. *Tilia* pollen and *Osmunda* spores are found sporadically. In the upper part of the sequence, at depths of 9 m-16 m *Betula* dominates the pollen flora (29-79%). *Pinus* pollen accounts for 5-27% and *Alnus* for 2-23%. *Picea* pollen values are 5-10%, but at depth of 10.5 m rise to 48%. The proportion of *Corylus* is below 10% and pollen of temperate deciduous trees were only found occasionally.

Previously Ekman (1987) assumed that the interglacial sequence represented the entire Mikulino interglacial (pollen zones M_2-M_8). However, the continuous occurrence of *Carpinus* pollen, in the lower part of the section, an abrupt decline of temperate tree species at 21.3 m depth and a subsequent increase of *Betula* pollen, together suggest that the interglacial unit most probably represents the late substages of the Mikulino.

The diatom flora in the basal part of the sequence, at depths of 30.5-31.5m includes 12 species which were only found sporadically. Besides freshwater species only two marine species *Coscinodiscus lacustris* v. *septentrionalis* and *C. radiatus* Ehrenberg were detected. Between 21.3-30.5 m depth the number of species ranges from 32-64. The diatom flora consists of both marine and freshwater species. The proportion of marine species is in the range 30-55% of the total taxa. The main marine flora includes species such as *Thalassiosira baltica* Grunow, *Th. gravida*, *Thalassionema nitzschioides*, *Coscinodiscus lacustris* v. *septentrionalis*, *C. radiatus* Ehrenberg, *C. obscurus*, *C. lacustris* Grunow, *Hyalodiscus scoticus*, *Chaetoceros* sp., *Actinoptychus undulatus*, *Rhabdonema arcuatum*, *Grammatophora* sp., *Diploneis didyma*, *D. fusca* (Gregory) Cleve, *D. smithii* and *Navicula humerosa* (Ekman 1968).

The freshwater flora consists of several genera. The main freshwater species of brackish water affinity present are *Cocconeis pediculus*, *Stephanodiscus* astrea and *Rhoicosphenia curvata*. Other characteristic freshwater species are *Diploneis domblittensis*, *Navicula falaisiensis* Grunow, *Epithemia turgida* and *Amphora ovalis* Kützing. Low numbers of *Melosira islandica* subsp *helvetica* were found in the lower part of the sequence. In the upper part of the sequence the proportion of freshwater species increases with new genera such as *Eunotia*, *Pinnularia* and *Stauroneis*.

At depths of 9-13.5 m the number of species ranges from 19-42. This characteristic freshwater flora consists of genera such as *Eunotia*, *Pinnularia*, *Diploneis*, *Stauroneis* and *Epithemia*. Also a small abundance of *Melosira* species is found. The marine flora include species such as *Thalassiosira baltica*, *Th. gravida*, *Coscinodiscus lacustris* v. *septentrionalis*, *Hyalodiscus scoticus*, *Rhabdonema arcuatum*, *Diploneis interrupta*, *D. smithii* and *Navicula järnefeltii* Hustedt. The proportion of marine species decreases from 30% (in the lower part) to 10% (the uppermost sample) in this upper part of the sequence.

The diatom flora in the lower part of the section reflects a lagoonal environment, which became progressively less saline. The isolation event is not recorded at the Derevyannoe site.

Vytegra (5)

The interglacial units found in the valley of the River Vytegra, on the southeastern coast of the Lake Onega were earlier regarded as glacial-lake and lake deposits (Barhatova 1941 in Biske 1959), but were later assumed to be analogous to those at the Mga (Cheremisinova 1962a). Stratigraphy of the Vytegra valley deposits includes the following units, from the base: Moscovian glaciofluvial and glaciolacustrine units and a till bed, an interglacial unit including marine Eemian Baltic (Mga) Sea beds, and lake beds, a Valdaian till bed and glaciolacustrine clay and glaciofluvial sand beds. The marine sequence consists of clay with vivianite, molluscs and plant remains, whereas the lake sediments are represented by clay and silt. Five phases (phases 1-3 at core site I and phases 4-5 core site II) can be distinguished in the Vytegra interglacial units (Cheremisinova 1962a):

1. According to this author, the grey plastic clay that rests on the Moscovian varved clay sequence, represents a lake deposit which was laid down during the initial phase of the interglacial. The diatom flora consists of planktonic freshwater diatom such as *Stephanodiscus astraea* and varieties, *Melosira islandica* subsp. *helvetica*, *M. granulata*, *M. distans* v. *alpigena*, *Cyclotella kützingii* v. *schumannii*. The diatom flora is very similar to the flora in the coarse silt layer above the varved clay at the Petrozavodsk site 1. According to Cheremisinova (1962a) the lake phase corresponds to the glaciomarine unit in the Mga sequence.

2. A lower lagoonal phase is reflected by dark green and black clays. The diatom flora includes saline water species such as *Chaetoceros* (spores), *Thalassiosira gravida* (spores), *Th. baltica* (Grunow) Ostenfeld et v. *fluviatilis* A. Cleve, *Coscinodiscus* sp., *C. antiquus* (Grunow) Cleve *Grammatophora* and *Rhabdonema* genera, *Coscinidiscus lacustris* and varieties. In addition, some planktonic freshwater species, such as *Melosira islandica* subsp. *helvetica* and *Stephanodiscus astrea* v. *minutula*, were found. Cheremisinova (1962a) equates the sequence with the lower lagoonal phase in the Mga profile.

3. Dark green clay with vivianite and molluscs represents a deep-water, marine phase. The diatom flora is dominated by saline planktonic species such as *Coscinodiscus perforatus* Ehrenberg, *C. antiquus* Grunow, *C. oculus iridis*, *C. asteromphalus* v. *centralis* (Ehrenberg) Grunow, *Actinophtychus undulatus*, *Chaetoceros* sp. and *Thalassiosira gravida*. Cheremisinova (1962a) concludes that some species, such as *Chaetoceros affinis*, *C. seiracanthus*, *Amphora robusta* Gregory and *Navicula latissima* Gregory, indicate a warm water current from the west. This phase represents the maximum transgression of the Eemian Baltic Sea, which at Vyterga reaches 50 m above sea level (Cheremisinova 1962a).

4. An upper lagoonal phase is indicated by dark grey compact clay, in which the diatom flora is more abundant including euryhaline species such as: *Coscinodiscus lacustris*, *Thalassiosira baltica* and v. *fluviatilis*, *Coscinodiscus lacustris* et varieties. The marine diatom flora include small numbers of species such as *Hyalodiscus scoticus*, *Thalassiosira kryophila* (Grunow) Joergensen, *Actinophtychus undulatus* and different *Coscinodiscus* species. The freshwater species include *Stephanodiscus astrea* v. *minutula*, *Cocconeis pediculus* and others. Overall this sequence represents regression and corresponds to the upper lagoonal phase at Mga and Rybatskoe (Cheremisinova 1962a).

5. An upper lake phase (60 m a.s.l.) is recorded by the clay and coarse silt beds. The dominant diatom species here are *Melosira islandica* subsp. *helvetica*, *M. granulata*, *M. distans* and *Stephanodiscus astrea* and varieties, *S. dubius* (Fricke) Hustedt and genera of *Eunotia* and *Pinnularia*. Similar species are also present in the upper lake phase at the Petrozavodsk site 1.

Vodla (6)

Interglacial deposits have been discovered in the middle course of the Vodla river, between Pudozh and Kubovskaya. Here interglacial deposits lie on a till bed and are overlain by upper till bed and late-glacial sediments (Biske 1959 and Biske & Devyatova 1965). The units consist of fresh-water and marine phases. The sediment in the fresh-water phase is represented by chocolate-coloured compact clay and silt, that passes upwards in some sections into fine-grained and unhomogeneous sand with clasts. The thickness of the fresh water sequence is 25 m. The pollen flora is dominated by *Betula* and *Alnus*. *Corylus* pollen account for 1.8-4.7%. *Artemisia* values are rather high. In the clay and silt layer frehswater diatoms indicate eutrophic-oligotrophic water body with low water level and temperature (Biske 1959). The fresh water sequence is covered by gray marine clay, which in turn is overlain by sand and fine sand layers or by the upper till bed. The dominant diatom species in the marine clay are as follows: *Hyalodiscus scoticus*, *Grammatophora oceanica*, *Coscinodiscus lacustris* v. *septentrionalis*, *Actinocyclus ehrenbergii* and v. *crassa* and *Thalassionema gravida* (spores). The proportion of marine diatoms is 72 % and that of brackish water diatoms 28 % (Biske 1959 and Biske & Devyatova 1965). According to Kuptsova (in Biske 1959) the diatom flora is very similar to the flora found in the deposits of Mga, Povenets, Petrozavodsk and Onega-White Sea watershed area.

Povenets (7)

The interglacial site is situated on the northern shore of Lake Onega. The marine interglacial unit resting on crystalline bedrock and covered by a till bed consists of sand and clay sequences (Zemlyakov 1936). Molluscs include species such as *Astarte crenata* v. *crebicostata* Andr. and Forbes, *Astarte crenata* v. *subaquilatera*, *Cardium edule* L.(?), *Panopea norvegica* Spengl., *Purpura lapillus* L., *Astarte borealis* Cheminitz, *A. elliptica* Brown, *Mya arenaria* L., *Saxicava arctica* L., *Macoma calcarea*, *M. baltica* and others. The dominant, five first-mentioned species do not thrive in the present White Sea and are not found in equal numbers in Holocene marine deposits of the White Sea either (according to Lavrova in Zemlyakov 1936). The dominant tree species in the pollen flora are *Betula*, *Alnus* and *Corylus*. The proportion of temperate deciduous trees is 7%. *Picea* pollen accounts for 12%. A change from a *Betula-Alnus-Corylus* assemblage to a *Picea-Pinus* assemblage has been detected in places in the Povenets deposit (Pokrovskaya & Sharkov 1947 in Biske 1959).

The diatom flora consist of marine species (72 %) and freshwater species (28 %). Dominant marine species are *Melosira sulcata* f. *radiata* and *Thalassionema nitzschioides*. The greater proportion of diatoms have a wide distribution, but there are also cold water species such as *Grammatophora arcuata*, *Synedra kamtzschatica* Grunow and others. According to Sheshukova (1939 in Biske 1959 and Biske & Devyatova 1965) the diatom flora with cold and fresh water affinity is very similar to the flora found in the deposit at the mouth of the Neglinka river at Petrozavodsk indicating an offshore or littoral zones of the sea.

Both marine and terrestrial interglacial sediments have been described from the Lake Onega region. In the Petrozavodsk area, marine interglacial sediments were found in several corings at elevations of 35-40 m above sea level, while terrestrial sediments are recorded at Klyucheva village at 122.7 m above sea level. Interglacial sequences are also documented in several corings in the middle course of the Vodla River. The interglacial units are overlain by one till bed at Klyucheva, Vytegra, Vodla and Povenets, while at Derevyannoe two till beds are found. Most of the sites discussed contain interglacial units that span only part of the vegetational succession or biostratigraphical data is limited and thus appropriate conclusions are difficult to reach. A more accurate picture of the Mikulino interglacial development in this area can be obtained from the biostratigraphical results from Petrozavodsk sites 1 and 2. The results from the site 1 show that marine water entered the area in the initial substage of the Mikulino interglacial, during the *Pinus-Betula*-NAP pollen zone/M_1. The marine phase proper began in the *Pinus-Betula*/M_2-M_3 zone and lasted into the *Picea-Alnus-Carpinus*/M_6 zone. In the beginning of the post-temperate substage, i.e. in the *Pinus-Picea*/M_7 zone, the connection of the Onega basin with the White Sea was closed. Correlation of the early marine phases at Petrozavodsk to glaciomarine and lagoonal phases at Vytegra cannot be accurately achieved because of lack of palynological evidence from the Vytegra sequence. However, the diatom flora in the Vytegra glaciomarine phase is very similar to that found in the coarse silt unit above the varved clay at Petrozavodsk site 1. Cheremisinova (1962 a) correlated the Vyterga lagoonal phase, that existed prior to the marine phase proper, with a similar phase recorded in the Mga deposit, in which the lagoonal phase corresponds to the upper part of the pollen zone d-e/M_3 (Znamenskaya 1959). At both Petrozavodsk and Vytegra the diatom flora of the marine phase also includes warm water species that indicate a connection of the Onega basin to the Eemian Baltic Sea. On the contrary, the marine fauna at both Petrozavodsk sites reflect rather cold conditions, while the greater part of fauna consists of arctic molluscs and foraminifera. However, at site 1 some foraminiferal species, which prefer warm water conditions were only found in low numbers. At Povenets the marine sequence probably only represents late substages of Mikulino. Here the mollusc species are more abundant than at Petrozavodsk site 2 and also include some boreal forms.

KARELIAN ISTHMUS

The description of the interglacial deposits in the Karelian Isthmus is based on the following authors: Brander (1937, 1943), Hyyppä (1937), Cheremisinova (1957), Malakhovski et al. (1959), Apukhtin and Ekman (1967), Vishnevskaya et al. (1968), Sokolova et al. (1970), Sokolova et al. (1972) and Abakumenko et al. (1977).

Marine deposits consisting of clay and silt or laminated silt have been found in both the centre and the periphery of the Karelian Isthmus. However, terrestrial deposits, mainly sand and peat, have only been reported from the central part of the isthmus (Fig. 8).

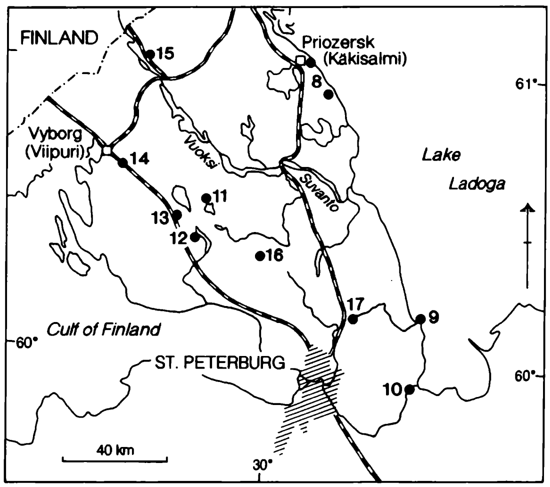


Fig. 8. Locality map of sites referred in the text in the Karelian Isthmus (area II in Fig. 1).

Priozersk (Käkisalmi) (8)

The thickest marine interglacial sequence is found in the depressions occupied by the lakes Gusinoe and Otradnoe, where marine interglacial sediments form a buried, abraded terrace, the top of which varies from 8 m to 22 m or less frequently to 28-29 m above sea level (Abakumenko et al. 1977). The marine sediments consist of silt and clay with coarse silt layers and sand inclusions. In the upper part of the sequence there is often sand apparently deposited during the regression. The deposits have been studied more throughly in the Priozersk area, where marine interglacial sediments were found in two core sites 33 and 52f, 24 km south-east and 4 km east of Priozersk and 1.5 km and 2 km from the western shore of Lake Ladoga, respectively. The interglacial sediments rest on a till bed. In core 33, interglacial sediments are overlain by a till, but in core 55 f the upper till is absent.

A typical interglacial succession of temperate trees is not seen in the pollen stratigraphy of the Priozersk cores (Abakumenko et al. 1977). In core 55 f, the zones assigned from the base are as follows: zone of maximum of temperate tree species, *Betula-Pinus* and *Betula* zone with two subzones. In core 33 the succession of zones is the following: *Betula-Pinus*, *Betula* with three subzones and *Betula* with maximum of temperate tree species. Hence, the maximum of *Alnus*, *Corylus* and temperate deciduous trees (*Carpinus*, *Quercus*, *Ulmus*) is found in the upper part of core 33 at depths of 16-30 m yet in the lower part of core 55 f at depths of 38.5-39.5 m. In core 33 (at depths of 65-90 m) *Picea* reaches maximum values in the beginning (40%) and at the end (34%) of the *Betula-Pinus* zone. *Carpinus* values account for 10%. The vegetational succession therefore appears to be more typical in the core 55 f than in core 33.

Diatoms have been analysed from core 33 from 16-88 m and from 55 f from 10-42.5 m. The bulk of the diatom species is concentrated in the upper part of both cores. The diatom flora contains 150 species of which the saline forms represents 30%. The sublittoral species in both cores include species such as *Rhabdonema arcuatum*, *Grammatophora oceanica* and *G. oceanica* v. *macilenta* (W. Smith) Grunow. The dominant species also include the neritic *Thalassionema nitzschioides* and *Thalassiosira gravida* (spores), which are more abundant in core 55 f, where mesohalobous *Hyalodiscus scoticus* and *Chaetoceros* spores have also been found. In both cores a small number of the neritic species *Actinoptychus undulatus* were found (Abakumenko et al. 1977). The frequence of freshwater species is greater than marine forms including species such as *Melosira islandica* subsp. *helvetica*, *Opephora martyi*, *Cocconeis disculus* v. *diminuta*, *C. pediculus*, *Achnanthes* oestrupii (A. Cl.) Hustedt, *Navicula jentzschii* Grunow, *Cymbella sinuata* and *Pinnularia* sp. In the upper part of the cores the marine diatom floral component decreases. A characteristic to these beds is the occurrence of euryhaline species such as *Coscinodiscus lacustris* v. *septentrionalis*, *Synedra tabulata*, *Diploneis smithii* and others. According to Abakumenko et al. (1977), the diatom flora represents a late phase in the history of the basin and includes a regressive phase.

Osinovets (9)

In the Lake Ladoga basin, near the Osinovets lighthouse, a 1 metre thick interglacial deposit is interbedded between two till beds. The uppermost part of the interglacial sequence ranges from -18 to -30 m asl. The clay and silt sequence contains a marine diatom flora and *Portlandia arctica* molluscs (Cheremisinova 1957, in Malakhovski et al. 1969).

Core 7/48 (10)

Core site 7/48 is situated in the southwestern corner of Lake Ladoga (Malakhovski et al. 1969). The top of the intergacial strata is here at 4 m above sea level. The sediments are overlain by Valdaian age glaciofluvial deposits and underlain by Moscovian glaciofluvial deposits. The sediment sequence starting from the base is composed of coarse silt clay with vivianite (6.5 m thick) and sand (14 m thick). In the clay bed *Portlandia arctica* molluscs are found. No diatoms are found in the sequence. The pollen assemblage represents the upper part of Moscovian lateglacial and Mikulino zones M_1-M_8. The sand layer spans pollen zone M8 (Cheremisinova 1957, in Malakhovski et al. 1969).

Krasnosel'skoe (Kyyrölä) (11)

The core site at this locality is situated on the northwestern side of Lake Vishnevskoe at 37.7 m above sea level, while the top of interglacial sediments is at 12.3 m above sea level. The interglacial sequence rests on Moscovian laminated silt, which in turn is underlain by Moscovian till. The interglacial sequence underlies lake sediments and a till of Valdaian age (Sokolova et al. 1972). The upper and lower contact of interglacial sequence is gradational. The sequence is 13.7 m thick and is composed of clay (at 39.1-32.75 m) and silt (at 32.75-25.4 m) with vivianite inclusions and *Zostera marina* moulds. The mollusc fauna found at 32.5-38.8 m, is dominated by *Portlandia arctica* Gray and *Macoma calcarea* Chemn. *Mytilus edulis* L. is sporadically found throughout with *Zostera* moulds. According to Sokolova et al. (1972), the dominant fauna represents that in a middle sublittoral zone and indicates a water depth of 70-80 m. The pollen diagram from Krasnosel'skoe (Fig. 9) comprises the pollen zones M_2-M_8 (Sokolova et al. 1972). According to Sokolova et al. (1972), the diatom flora represents an environmental change from an open marine, to a lagoonal and then a lake phase. The marine phase, at 33.0-38.0 m, spans the pollen zones M_2-M_6. Characteristic diatom species in these sediments are *Hyalodiscus scoticus* (Kützing) Grunow, *Thalassiosira gravida*, *Chaetoceros mitra*, *Ch. affinis*, *Ch. seiracanthus* and *Ch. subsecundus* (Grunow) Cleve, *Grammatophora* sp, *Coscinodiscus lacustris* v. *septentrionalis* and the silicoflagellates *Distephanus speculum* (Ehrenberg) Haeckel and *Dictyocha fibula* Ehrenberg. Occassional finds of species, which favour warmer water conditions than those listed above, include such species as *Actinoptychus areolatus* A. Schmidt, *Cocconeis quarnerensis*, *Coscinodiscus perforatus* Ehrenberg, *Diploneis subcinta* (A.Schmidt) Cleve, *Navicula abrupta* Gregory and *N. latissima* Gregory. The top of the marine phase is at a depth of 33 m and at 4.7 m above sea level. In the subsequent lagoonal phase, at 32.5-33.0 m (coinciding with pollen zone M_7), the brackish water species *Coscinodiscus lacustris* v. *septentrionalis* and the littoral species *Coscinodiscus curvatulus* Grunow et v. *minor* (Ehrenberg) Grunow dominate. The end of the lagoonal phase is at 32.5 m, which is at 5.2 m above sea level. During the following lake phase, at depths of 32.5-25.75 m, a freshwater diatom flora dominates. Marine saline species are only found sporadically. This diatom flora of the lake phase coincides with pollen zone M_8 and reflects shallow, cold water conditions in the basin (Sokolova et al. 1972).

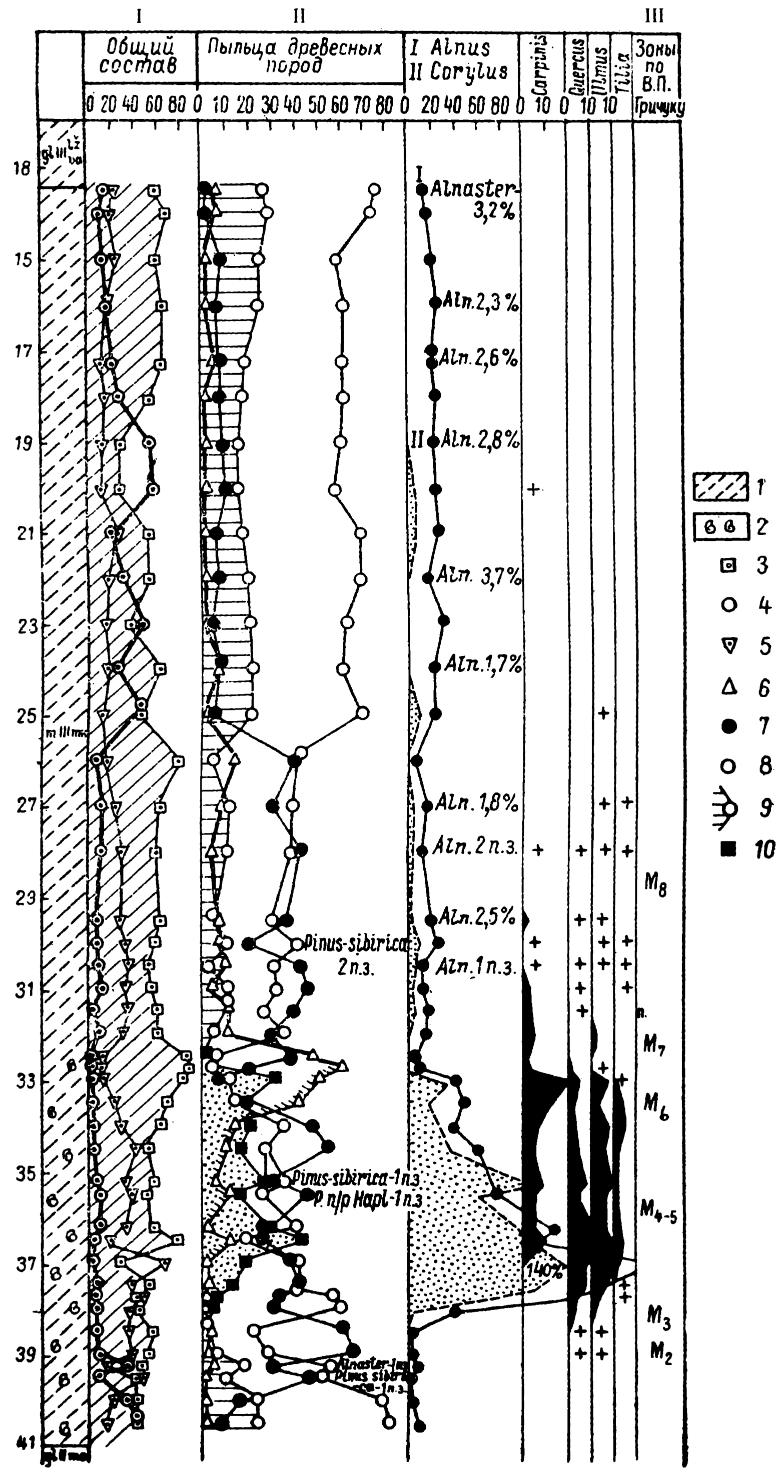


Fig. 9. Pollen diagram from Krasnosel'skoe (Sokolova et al. 1972 fig. 1). Legend: I Total pollen, II Tree pollen and III Zones according to Grichuk. 1. clay and silt, 2. molluscs, 3. trees, 4. herbs and shrubs, 5. spores, 6. *Picea*, 7. *Pinus*, 8. *Betula*, 9. *Betula* sect. *fruticosae* and *B. nana*, 10. *Alnus* 11. temperate deciduous trees.

Ovsyanoe (12)

In Pervomaiskoe (Kivennapa) region, interglacial marine beds lie at 38.6-40.4 m above sea level. An interglacial marine deposit found close to Lake Nakhimovskoe in the village of Ovsyanoe consists of clayey sand with gravel and pebbles (Apukhtin & Ekman 1967). The marine unit is sandwiched between two tills. The diatom flora from the unit consists of species such as *Melosira sulcata* v. *biseriata* Grunow, *Hyalodiscus scoticus*, *Coscinodiscus* sp., *Actionocyclus ehrenbergii*, *Rhabdonema arcuatum*, *Diploneis didyma* (fragments), *Pinnularia* sp. (fragments), *Epithemia turgida* and *Campylodiscus echeneis* Ehrenberg (fragments). This deposit was originally correlated with the Mologa-Sheksna Interglacial (Apukhtin & Ekman 1967). However, the deposits of the latter were more recently shown to be of Mikulino in age (Velichko & Faustova 1986).

Savikko (13)

The Savikko site is situated near the Kirillovskoe (Perkjärvi) railway station. The interglacial clay unit at about 40-43 m above sea level is overlain by one till bed (Hyyppä 1937) at this site. The pollen assemblage from this unit are dominated by *Betula* and *Alnus* (the average for *Betula* is 70-75% and for *Alnus* 10-20%); the proportion of *Pinus*, *Picea* and *Corylus* being very low. The accompanying diatom flora is very poor and the species found are usually fragmented. The most important of which is *Grammatophora oceanica*, which is occassionally found.

Häyry (14)

The Häyry site is situated 6 km northeast of Vyborg (Viipuri). Here a clay bed, about 60 cm thick, was found in a gravel pit (Hyyppä 1937). The top of the clay is at about 17 m above sea level and is overlain by gravel, 11-12 m thick. The diatom flora from the clay consists of marine and freshwater species. In the freshwater flora, species typical of both small and large lakes are present. The marine species found include *Grammatophora oceanica*, *Coscinodiscus* sp., *Campylodiscus clypeus* Ehrenberg, *C. echeneis* Ehrenberg and *Nitzschia scalaris* (Ehrenberg) W. Smith. According to Hyyppä (1937) the pollen and diatom flora at both Häyry and at Savikko indicate that the clay beds were deposited under similar conditions.

Rouhiala (15)

The site is located in Lesogorsk district (Jääski), Karelian Isthmus. A number of lumps of clay were recovered from esker sand at Rouhiala at 50-65 m (Brander, 1937, 1943). The pollen flora from the clay lumps includes two assemblages: one *Betula-Alnus-Corylus* assemblage with a small amount of *Pinus* and the other *Betula-Alnus-Corylus* assemblage with somewhat more *Pinus* pollen than in the previous group and *Picea*. In both assemblages a small amount of *Carpinus* pollen was found (Brander 1937, 1943). The diatom flora in the lumps consists mainly of marine species. The abundance of brackish water, freshwater and indifferent species is insignificant. The species in common between the Rouhiala site (listed on pages 14-17 in Brander 1937) and the Petrozavodsk site 1 consist of 45 species. Brander (1937 and 1943) concluded that the Rouhiala clasts represent of the same environment as the Mga interglacial deposit and assumed that they had probably been transported from the southern part of the present Lake Saimaa, in Finland. Hyyppä (1937) interpreted the clay lumps as representing an interstadial event.

Pervomaiskoe (Kivennapa) (16)

This core site is located 10 km northeast of the village Pervomaiskoe. The interglacial sediment here consists of sand (21.7 m thick) and peat (3 m thick), the top of which occurs at 134 m asl (Sokolova et al.1970). The interglacial bed lies on Moscovian till and is overlain by glacial lacustrine sediments and till of Valdaian age. According to pollen analyses the sand sequence represents Mikulino pollen zone M_2 and the peat pollen zones M_4 and M_7-M_8 (Sokolova et al. 1970). The diatom flora from the sand is very poor. The freshwater assemblage includes species such as *Eunotia faba*, *Melosira italica*, *Epithemia turgida*, *E. zebra* v. *porcellus* and *Eunotia* and *Pinnularia* species. Species indicating cold-water conditions are *Melosira italica* v. *subarctica* and *M. italica* v. *valida*, *Tetracyclus lacustris* Ralfs and *T. lacustris* v. *strumosus* (Ehrenberg) Hustedt.

Two different diatom assemblages are present in the peat. In the lower part, the dominant species is *Cyclotella stelligera* Cleve et Grunow. The flora also includes species such as *Tabellaria fenestrata*, *Stauroneis pygmaea* Krieger, *Gomphonema acuminatum* v. *coronatum* (Ehrenberg) W. Smith, *Eunotia* and *Pinnularia* species and *Melosira* species, which are also found in sand layer. In the upper part of peat the dominant species are *Tabellaria fenestrata*, *T. flocculosa*, *Fragilaria constricta* Ehrenberg and f. *stricta* A. Cl., *F. inflata* (Heiden) Hustedt and v. *istvanffyi* (Pant.) Hustedt, *Eunotia faba*, *E. polyglyphis* Grunow, *E. robusta* v. *tetraodon*, *E. tenella*, *Frustulia rhomboides*, *Anomoeoneis serians* v. *brachysira* (Brébisson) Hustedt, *Stauroneis anceps* Ehrenberg, *S. phoenicentron* Ehrenberg and *Pinnularia gibba* Ehrenberg (Sokolova et al. 1970).

Toksovo (17)

Another interglacial, terrestrial sediment bed was found on the Toksovo plateau (Malakhovski et al. 1969). This unit rests on Moscovian till and is covered by a Valdaian till bed. The top of interglacial unit is at 58 m above sea level, and is 21.5 m thick. It is composed from the base of coarse silt and fine sand. Whilst the pollen diagram covers zones M_1-M_3 and M_6 (Malakhovski et al. 1969), the diatom flora consists only of freshwater species.

Regional summary

In the Karelian Isthmus, *in situ* interglacial marine and terrestrial strata are covered and underlain by one till bed. The only exception appears to be core 7/48, in which till beds have not been found. The elevations of marine units occur in a range from -30 m (Osinovets) to 40-43 m above sea level (Savikko) and terrestrial units from 58-134 m above sea level. The majority of the interglacial deposits known from this area only represent parts of the interglacial vegetational succession. The most complete sequence is the Krasnosel'skoe (Kyyrölä) deposit, which spans pollen zones M_2-M_8. The diatom flora at Krasnosel'skoe reflects an open marine and a lagoonal phase corresponding the pollen zones M_2-M_6 and M_7, respectively. The isolation from the sea at this site occurred at the M_7/M_8 pollen zone boundary, which coincides with an abrupt decrease of *Picea* pollen.

The following description is based on the evidence of Apukhtin & Ekman (1967), Malakhovski et al. (1969), Lak (1977), Biske & Lak (1956), Biske & Devyatova (1965), Devyatova (1982) and Ekman (1987).

Both marine and terrestrial interglacial deposits have been found in several localities on the Ladoga-Onega Isthmus (Fig. 10). On the eastern coast of Lake Ladoga, in the lower course of the River Vidlitsa and in the Pitkäranta area, clay, coarse silt or coarse silty sand containing Mikulino interglacial diatom flora have been recorded (Lak 1977). The diatom flora includes species such as *Melosira sulcata*, *Hyalodiscus scoticus*, *Coscinodiscus radiatus*, *Actinoptychus undulatus*, *Rhabdonema arcuatum*, *R. minutum*, *Grammatophora oceanica* and others. The sediments rest on varved clay or on till. According to Lak (1977), the question of the age of these deposits has remained open because of lack of the necessary pollen evidence. Redeposition of an interglacial diatom assemblage is not ruled out for these sediments.

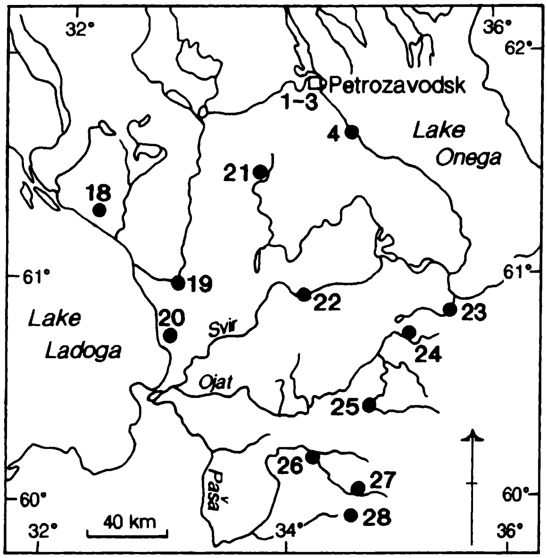


Fig. 10. Locality map of sites referred in the tex in the Ladoga - Onega isthmus (area III in Fig. 1).

Vidlitsa (18)

An interglacial deposit found in Vidlitsa occurs at 82.3 m above sea level (Biske & Devyatova 1965, Devyatova 1982). The deposit lying on a Moscovian late-glacial varved clays consists, from the base, of greenish grey clay occasionally showing a varved structure, greenish-grey clay with molluscs and plant detritus, grey clay with thin sand layers and grey clay with abundant plant remains. The upper part of the section comprises of slightly greenish-grey clay with thin sand layers and coarse silt with sand layers of Valdaian age. An upper till bed has been detected in places above the interglacial clay bed in the lower course of the River Vidlitsa (Biske & Devyatova 1965). The top of marine interglacial bed is about 56 m above sea level. The molluscs in the marine clay include *Tellina*, *Astarte* and others (Devyatova 1982). The diatom flora is dominated by marine species (72 %) including *Melosira sulcata*, *Hyalodiscus scoticus*, *Coscinodiscus radiatus*, *Thalassiosira excentrica*, *Actinoptychus undulatus*, *Rhabdonema arcuatum* and *Grammatophora oceanica* (Biske & Lak 1956 and Biske & Devyatova 1965). The pollen stratigraphy includes zones KA_1-KA_9/M_1-M_8 (Fig. 11). The marine phase occurs during pollen zones M4a-M6 and the lake phase in zones the M_7-M_8 (cf. notations in Fig. 28 p.88, in Devyatova 1982).

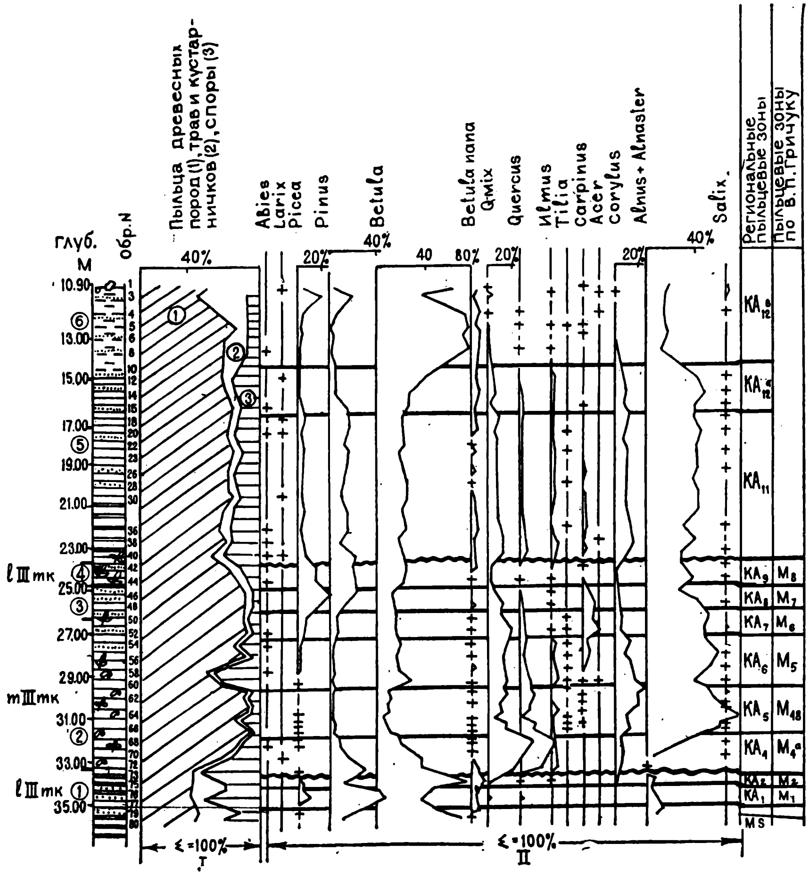


Fig. 11. Pollen diagram from Vidlitsa (a part of the pollen diagram in Devyatova (1982, fig. 28)). Legend: I Total pollen: 1. trees, 2. herbs and shrubs, 3. spores. Pollen zones (KA_1-KA_9/M_1-M_8) according to Devyatova and Grichuk: MS=Moscovian, KA_1-KA_9/M_1-M_8= Mikhulinian zones. Notations on the extreme left: lIIImk= lacustrine, Mikulino phase, mIIImk=marine Mikulino phase.

Olonets (Aunus) (19)

On the eastern coast of Lake Ladoga, at Olonets a silt and clay deposit containing interglacial flora underlying till was studied by Devyatova (1972). The pollen flora covers pollen zones VII-IX/M_4-M_5, which she correlated with the analogous zones at the Petrozavodsk site 2. Pollen of temperate deciduous trees (maximum 60%) are, however, much more abundant at Olonets than at Petrozavodsk. A mollusc fauna, including species such as *Portlandia intermedia* M. Sars, *P. lenticulata* Moller, and *Propeamussium* sp., was found in the Olonets clay (Ekman 1987).

Vasilevski Bor (20)

This site is situated south of Olonets at 25 m above sea level (Devyatova 1982). The interglacial deposit here consists of marine clay with molluscs and plant remains. The clay bed rests on Moscovian late-glacial clay, interbedded with sand and overlain by Valdain age sand. The interglacial sediment spans pollen zones KA_1-KA_8/M_1-M_7 (Fig. 12), with the marine phase spanning the zones M_{4a}-M_7. However, the sequence, which includes the zones M_1-M_2, might include either a marine or a lake phase (cf. Fig. 29 p. 90, in Devyatova 1982 and Fig. 12 herein). The top of interglacial layer occurs at 5.4 m below sea level.

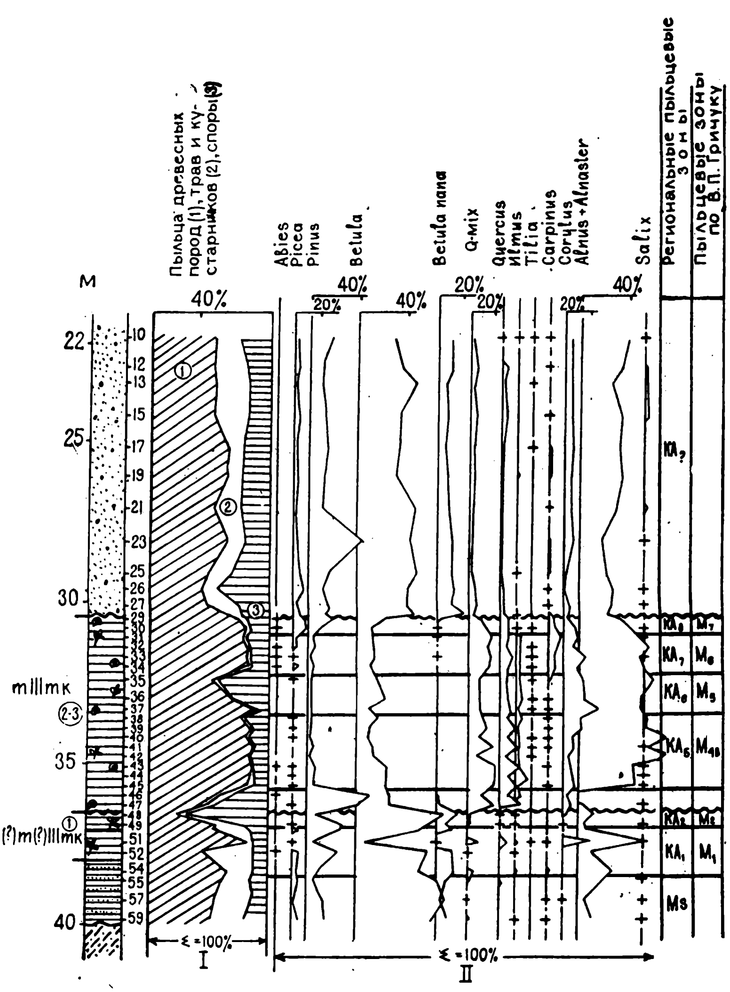


Fig. 12. Polle diagram from Vasilevski Bor (modified after Devyatova 1982 fig. 29). See explanations in Fig. 9.

Verkhnie Vazhiny (21)

The Verkhnie Vazhiny site is 115 m asl Malakhovski et al. 1969). Here the interglacial deposit underlies two till units and rest on one. The interglacial unit is 16 m thick here and consists, from the base, of sand, coarse silt clay and sand. The top of interglacial unit is at 90 m above sea level. In the upper part of the sequence, cones and wood remains were found in the sand bed. The interglacial sediments are of pollen zones M_1-M_5 (Malakhovski et al. 1969 and Ekman 1987). Only a small number of diatoms were found in these sediments and they consist exclusively of freshwater species such as *Melosira arenaria*, *M. scabrosa*, *M. italica* subsp. *helvetica*, *Cyclotella kützingii* and *Pinnularia* sp. (Apukhtin & Ekman 1967).

Podporozhye (22)

The Podporozhye core site is situated in the River Svyr basin (Malakhovski et al. 1969). The interglacial deposit, 26 m thick, is composed from the base of clay, finely laminated coarse silt and clayey sand. The deposit rests on Moscovian till and is buried by four till beds and lake sediments of Valdaian age. The Moscovian till is underlain by Middle-Pleistocene glacial and interglacial sediments. The top of interglacial unit is at 60 m above sea level. The pollen stratigraphy includes zones M_2-M_8 and freshwater diatoms were found only irregularly in the upper part of the deposit (Malakhovski et al. 1969).

Oshta (23)

This site is located southwest of Lake Onega in a fault zone, at the contact of the Precambrian Fennoscandian shield and Palaeozoic sedimentary rocks of the Russian Plain. The deposit, at depths of 37-93.2 m, rests on Palaeozoic bedrock and is covered by two till units (Apukhtin & Ekman 1967, Malakhovski et al. 1969). The clay unit, 56.2 m thick, lies at 0 m to -56 m asl. The diatom flora includes 104 species, of which 61 species were found at 84 m depth (Cheremisinova in Apukhtin & Ekman 1967). The dominant diatom assemblage includes species such as *Hyalodiscus scoticus*, *Actinoptychus undulatus* and *Actionocyclus ehrenbergii*. At other depths, the number of species ranges from 11-38. Only sporadic marine species, *Melosira sulcata* and v. *biseriata* and reworked Tertiary species were found at 60.2 m. Moreover, diatom numbers increase again at depths of 47-53 m. According to Cheremisinova (in Apukhtin & Ekman 1967), the diatom flora indicates an increase in salinity, at depths of 80-86.4 m, while at 84 m, the flora is characteristic of an estuary. Higher in the sequence, at 78.8 m the species indicate a littoral zone. According to Cheremisinova (in Apukhtin & Ekman 1967) the Oshta clay can be correlated with the beds deposited during the Mga (Mikulino) transgression. However, rather different opinion has been expressed by Vigdorchik (in Apukhtin & Ekman 1967 and Malakhovski et al. 1969). He considers that only the lowermost brownish-grey clay layer, one metre thick, the top of which is at 56.5 m below sea level, represents an interglacial phase. The pollen stratigraphy indicates that the sediments represent zone M_8, i.e. the lower part and and the subsequent zones V_1-V_3 of Valdaian age (Malakhovski et al. 1967). Apukhtin and Ekman (1967) consider that Vigdorchik's opinion is dubious and the whole section requires reinvestigation to resolve the age of the deposit. The Oshta deposit has not been studied since 1967.

Tuksha (24)

This site is situated southwest of Lake Onega, on the watershed area of the Rivers Tuksha and Oshta and in the same tectonic zone as Oshta. The interglacial clay-silt deposit is overlain by two till beds of different age (Apukhtin & Ekman 1967). The deposit lies at elevations from 12 m to 40 m above sea level. The diatom flora consists mostly of freshwater species, with only sporadic fragments of marine species being found (Apukhtin & Ekman 1967).

Oyat, Pasha and Kapsha rivers' area (25 - 27)

In the valleys of the Oyat', Pasha and Kapsha rivers and their tributaries, in the Leningrad and Vologda Regions, terrestrial Mikulino deposits lie on the Moscovian glaciofluvial and glacial sediments and are buried beneath the Early Valdai lake sediments (Kurgolovo, upper Volga) and rarely the Late Valdai till. The thickness of Mikulino sequences are from 4.5 m to 15.8 m and they range from 75 m - 140 m above sea level. The deposits consist of lake and lake-alluvial and lake-mire sediments (Pleshivtseva et al. 1998). According to Pleshivtseva a high abundance of *Quercus* pollen is characteristic of pollen flora of terrestrial deposits in the Leningrad and Vologda regions. During the climatic optimum *Quercus* values reach to 60%. After the climatic optimum, the forest changes to spruce-pine forests, where besides *Picea abies*, *P. abies* subsp. *obovata* and *Pinus sibirica* are also found. The two last-mentioned species are also included to the flora at the beginning of the interglacial.

The deposit in the Oyat' River valley, near Shondovichi (25) represents a half-closed or dammed lake. The horizontally-laminated, coarse silty clay and sandy-coarse silty clay, 6.1 m thick, contains abundant plant debris and vivianite. The interglacial sequence represents the pollen zones M_1-M_7 (Fig. 13). The diatom flora in the early substages of the interglacial (M_1-M_2 zones) comprises of planktonic species, which favour cold water. The dominant genera are *Melosira*, *Cyclotella* and *Stephanodiscus*. Benthonic species are only rarely recorded. The species that favour warmer waters, such as *Navicula oblonga* Kützing and *Cymbella ehrenbergii*, appear in zones M_4-M_6. The species number decreases during the pollen zones M_6-M_7. The dominant benthonic species present during these zones include *Eunotia praerupta* and *Diploneis elliptica* v. *ladogensis* Cleve. A second increase in diatom species occurs in pollen zone M_7, where the planktonic species *Melosira granulata* and *M. distans* v. *alpigena* dominate (Pleshivtseva et al. 1998).

The deposit found on the right bank of the River Kapsha (26), north of Redovichi, represents an infill of a shallow lake. The deposit is composed of laminated coarse silt clay and sandy clay with vivianite and layers of plant debris. As a result of lowering of water level and paludification, peat lenses and beds progressively increase from the bottom upwards, while a rise of water level is reflected by fine sandy clay overlying the peat (Pleshivtseva et al. 1998). The thickness of the interglacial unit is 4.5 m and it represents pollen zones M_1-M_8. The recovered diatom flora here contains benthonic and an overgrowth of freshwater species. The dominant genera are *Pinnularia*, *Eunotia*, *Cymbella* and *Navicula*. Cold-water species, such as *Melosira scabrosa*, *Tetracyclus lacustris* and *Pinnularia* species, dominate at the beginning (M_1-M_2) and at the end (M_7) of the sequence while species which favour warmer conditions are found in zones M_3-M_4 (Pleshivtseva et al. 1998).

The deposit discovered near Pashozero (27) represents a closed lake. Here the section comprises a basal gyttja, 5.3 thick that gives way to a fine-grained sand, 10.5 m thick. The base of the sand is sharp. The deposit spans pollen zones M_1-M_8 (Pleshivtseva et al. 1998)

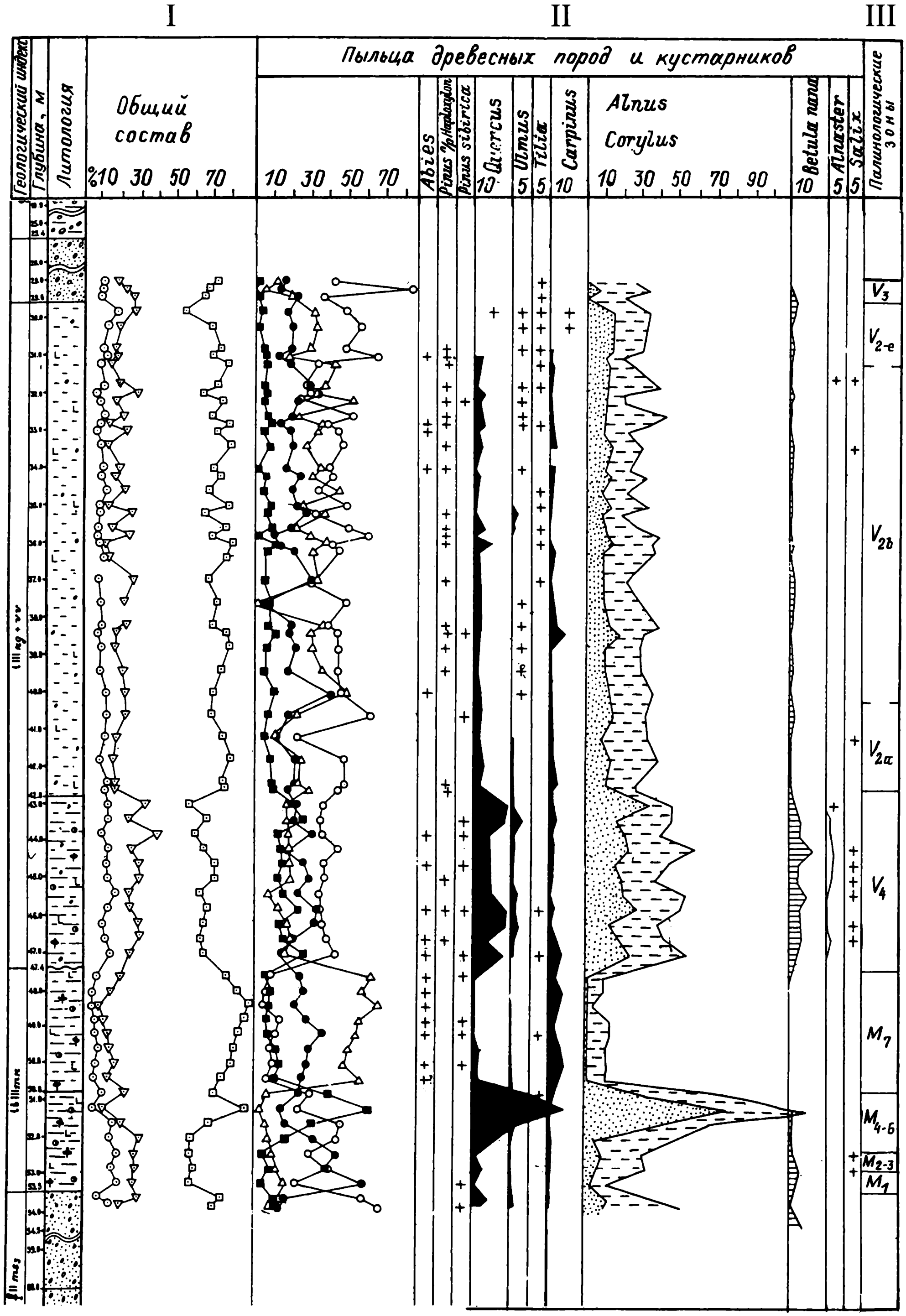


Fig. 13. Pollen diagram from Shondovichi section 350 (Pleshitseva et al. 1998 fig. 39). Legend: I Total pollen, II trees, shrubs and dwarf shrubs, III zones. Notations at extreme left (genesis of the sediments and chronostratigraphy): fIIms$_3$= fluvial Moscow Stage, lbIIImk= lacustrine Mikulino stage, lIIIkg+vv= lacustrine Early Valdaian Substages (Kurgolovski and Upper Volzki). Pollen symbols as in Fig. 9.

Shugozero (28)

An interglacial terrestrial deposit situated at a higher elevation (169 m a.s.l.) has been found in the same area as the lake deposits described above (Malakhovski et al. 1969). The deposit on the right bank of the River Kuysar, near the village Shugozero, rests on Moscovian till and is overlain by a Valdaian till. The interglacial sequence, 1.75 m thick, is composed from the base of sand, clay with thin peat layers and sand. Both the upper and lower boundary of the clay is gradational. The pollen flora comprises zones M_3-M_4 and M_6. The diatom flora consists of freshwater species. The dominant species present include *Anomoeoneis sphaerophora* (Kützing) Pfitz, *Stauroneis acuta* W. Smith, *S. schulzii* Jeuse, *Navicula oblonga* Kützing v. *subcapitata* Pantocsek and *Cymbella ehrenbergii* (Cheremisinova, in Malakhovski et al. 1969).

Regional summary

In the Ladoga-Onega isthmus, the interglacial marine units are overlain by one (Vidlitsa) or two (Oshta) tills. The terrestrial deposits are buried by two (Verkhnie Vazhiny) or four (Podporozhye) till beds. In the Oyat', Pasha and Kapsha river area, interglacial sequences underlie Early Valdai lake sediments and sometimes by Late Valdai till. The marine sediments vary from 56.5 m below sea level (Oshta) to 56 m above sea level (Vidlitsa). The terrestrial deposits range from 60 m (Podporozhye) to 165 m (Shugozero) above sea level. The most complete interglacial sequences, including pollen zones M_1-M_8 and M_1-M_7 are found at Vidlitsa and Vasilevski Bor, respectively. At Vidlitsa, the marine phase is found during pollen zones M_{4a}-M_6 and the lake phase M_7-M_8. At lower elevations at Vasilevski Bor, the marine phase is longer and definitely spans pollen zones M_4-M_7, but it had probably already begun in the M_1 zone.

AREA BETWEEN THE ONEGA BASIN AND THE WHITE SEA

This synthesis is based on the work of Biske (1959), Biske & Devyatova (1965) and Ekman (1987). A systematic study of the interglacial deposits on the watershed area between Lake Onega and the White Sea has been presented by Goretski (1949). The sites described here are shown in Fig. 14.

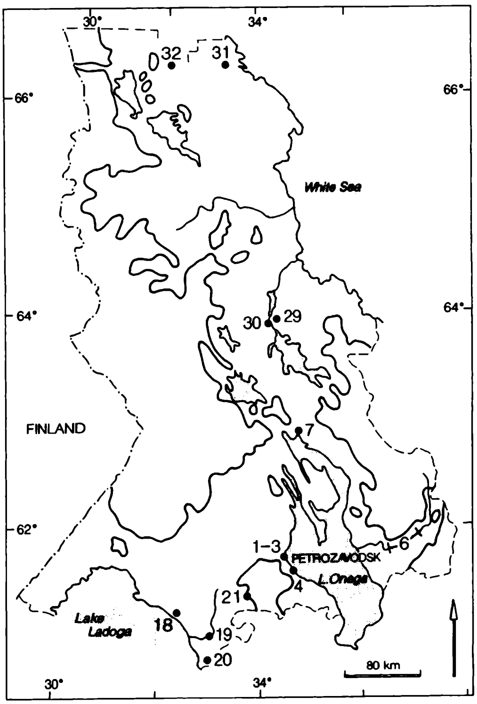


Fig. 14. Extent of the boreal transgression in Russian Karelia (bold line) (Ekman 1989). Numbers (1-7, 18-21 and 29-32) refer to the sites dscribed in the text. Broken line indicates the boundary of the Republic of Karelia.

Shavan (29)

The interglacial deposits of this locality comprise of grey clay with sparse gravel and clasts, and coarse silt with clay bands (Goretski 1949, in Biske 1959). The deposits lie on the Cambrian bedrock. The fauna is dominated by sublittoral species. Species that favour warmer conditions, such as *Littorina* sp. *Anomia squamula* L., *Cyprina islandica* L. and *Balanus hameri* Ascanius were also found. The diatom flora is dominated by marine species (85 %) such as *Coscinodiscus rhotii* v. *subsalsus* (Damrf.) Hustedt, *Hyalodiscus scoticus*, *Melosira sulcata* and v. *biseriata*, *M. sulcata* f. *coronata*, *M. sulcata* v. *siberica* Grunow, *Synedra affinis* (Kützing) and others. According to Goretski (1949, in Biske 1959), the marine fauna indicates a shallow basin and moderately cold conditions. Only one warm-water indicator *Melosira sol* (Ehrenberg) Kützing was found.

Onda (30)

The deposits at this site rest on till or directly on the Cambrian bedrock in several cores from the lower course of Onda River (Sokolova 1951, in Biske 1959; Biske & Devyatova 1965). The top of the interglacial beds ranges from 58 m to 76 m a.s.l., whilst their thickness ranges from 2 m to 13.7 m. The overlying upper till bed is 3 m to 9 m thick. The lower part of the interglacial sequence is composed of coarse sand with gravel and clasts. In the upper part, sediments change to fine sand and silt. The gravel and clasts content increases in the uppermost part of the sequence. Molluscs were found in the lower part of the interglacial sediments. At 10.34 m the fauna includes species such as *Littorina obtusata* L., *Purpura lapillus* L., *Mytilus edulis* L., *Modiola modiolus* L., *Astarte borealis* Chemnitz, *A. montaqui* Dillwyn, *A. compressa*, *Saxicava arctica* L. and at 11.1 m *Mytilus edulis*, *A. elliptica* Brown, *Macoma calcarea* and *Saxicava arctica*. According to Lavrova (in Biske 1959), the occurrence of *Purpura lapillus*, which is characteristic of interglacial marine faunas in the deposits in Severnaya Dvina area and which nowadays is absent in the White Sea, demonstrates the boreal (i. e. Mikulino) transgression age of the deposits.

Chkalovo (31)

The Chkalovo site is situated north of the Chupa Bay, on the slopes of Levina hill (Biske 1959). The sequence, the top of which is at about 60 m above sea level, consists of sandy clay and blue plastic clay with shell gravel. The pollen flora of the lower part of the sequence is dominated by *Pinus* and *Picea*, while in the upper part, where *Picea* pollen sharply decreases, *Pinus* and *Betula* dominate.

According to Lak (in Biske 1959) the marine flora comprises 75 % of the total diatom assemblage and includes species such as *Hyalodiscus scoticus*, *Coscinodiscus lacustris* v. *septentrionalis*, *Rhabdonema arcuatum*, *Rh. minutum*, *Grammatophora oceanica*, *Synedra kamtshatica* and others. Littoral species dominate, indicating a shallow water body. The proportion of cold-water species of the total diatom sum is 30%, including species such as *Melosira italica* v. *valida*, *Rhabdonema thorellii* Cleve, *Rh. arcuatum*, *Grammatophora angulosa* v. *islandica* (Ehrenberg) Grunow, *G. arctica*, *Achnanthes septata* and *Nitzschia filiformis* (W. Smith) Hustedt. In addition, one silicoflagellate *Distephanus speculum* and one flagellate *Ebria tripartita* were encountered. Lak (in Biske 1959) considers that the cold-water flora indicates a relatively low water temperature in the basin. Only one mollusc species, *Mytilus edulis*, the shells of which were compressed and eroded, was found (Lavrova in Biske 1959).

Tikshozero (32)

This site is situated 2-3 km north-east of the north-eastern bay of Lake Tikshozero (Biske 1959). An interglacial unit, at 110-130 m above sea level, was found in three sections at this site. Here the interglacial units consist of coarse silt and fine sand. The thickness of the overlying till bed ranges from 35 cm to 3 m. The diatom flora (analysed by Cheremisinova) in the coarse silt sequence includes marine species such as *Coscinodiscus lacustris* v. *septentrionalis*, *Diploneis interrupta*, *D. smithii* and v. *rhombica* Mereschkowsky, *D. stroemii* Hustedt, *D. subovalis* and also very frequent freshwater species with brackish-water affinities such as *Opephora martyi* and *O. martyi* v. *amphioxys*. *Pinus* dominates the pollen assemblages reaching a maximum of 81 % of the total tree pollen sum. The proportion of *Betula* and *Picea* pollen is low (Biske 1959).

Regional summary

In the area between Lake Onega and the White Sea, the interglacial marine deposits represent only fragments of the complete interglacial cycle. The deposits range in height from 58 m (Onda) to 130 m (Tikshozero) above sea level. Only the Chkalovo deposit can be reliably dated by pollen stratigraphy, according to which the deposit represents the late part of an interglacial. The mollusc fauna in the Shavan and Onda sequences besides including arctic species also yields boreal forms. The existence of interglacial deposits in the region is also recorded in the Masel'ga threshold area, where reworked interglacial marine diatoms are very often found in the Late Valdai glaciolacustrine sediments (Saarnisto et al. 1995).

The extent of the Mikulino Boreal transgression in Karelia based on this data is shown in Fig. 14.

KOLA PENINSULA

The description is based on references of Lavrova (1960), Armand et al. (1966), Armand and Lebedeva (1966), Apukhtin and Ekman (1967), Gudina and Yevzerov (1973) and Yevzerov et al. (1976). The location of the sites is indicated in Fig. 1 (area V, the Kola Peninsula).

Marine sediments underlying till were first found in this area on the right bank of the River Varzuga near the Kletnoi and Koitugov rapids in 1899-1900 (Rippas and Knipovich in Lavrova 1960). Since then, stratigraphical correlation problems related to tills of the last two glaciations in the Kola Peninsula have been under discussion and the age of the Kola Peninsula interglacial deposits has been a matter of dispute throughout the 20th century (Gudina & Yevzerov 1973 and references therein). The wide range of elevation heights and the lack of accurate stratigraphy of these deposits in publications therefore compounds the problem of whether or not the deposits can be considered *in situ*.

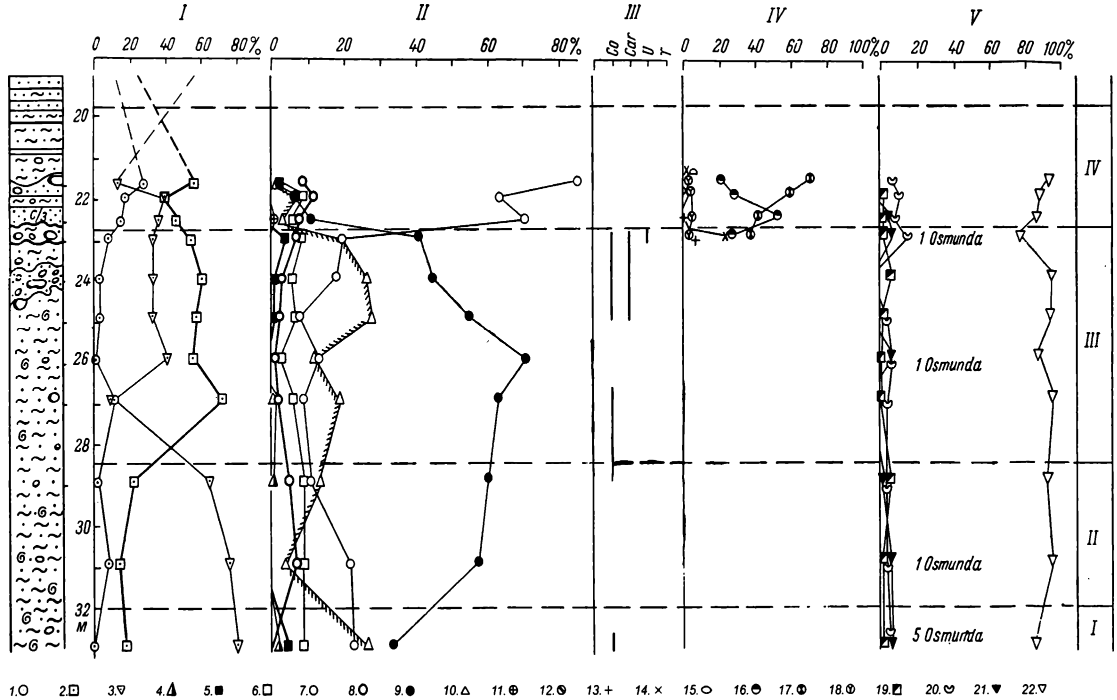


Fig. 15. Pollen diagram from Varzuga (Armand & Lebedeva 1966 fig. 2). Legend: I Total pollen, II tree pollen, III temperate deciduous trees, IV herbs and V spores. Pollen zones according to Armand and Lebedeva. Pollen symbols: 1. herbs and shrubs, 2. trees, 3. spores, 4. *Abies*, 5. temperate deciduous trees, 6. *Alnus*, 7. *Betula*, 8. *B. nana*, 9. *Pinus*, 10. *Picea*, 11. *Salix*, 12. reworked pollen, 13. *Artemisia*, 14. Chenopodiaceae, 15. Cyperaceae, 16. Gramineae, 17. herbs, 18. Ericaceae, 19. *Lycopodium*, 20. Polypodiaceae, 21. *Sphagnum*, 22. Bryales.

Varzuga (33)

The sediments at Kletnoi Rapid comprise (from the base upwards): 1. lower silt and clay (Ponoi Bed), 2. sand (Strel'na Bed) with an erosional lower contact overlain by a silt layer with boulders (observed only in section 1b), 3. Valdai till, and 4. late-glacial marine bed (Lavrova 1960, Gudina & Yevzerov 1973). The top of the marine Ponoi Bed is at 12 m above sea level. The mollusc fauna (studied by Lavrova) in this Ponoi Bed includes mainly arcto-boreal forms and also species such as *Cardium fasciatum* Mont., *Panopea norvegica* Spengl. and *Anomia ephippium* L., which do not live in the White Sea today (Gudina & Yevzerov 1973). According to Lavrova (1960), the fauna indicates a continuous regression of the sea. The complete species list is given by Gudina and Yevzerov (1973) and Yevzerov et al. (1976).

The number of foraminifera and the species diversity is lower here than in the deposits in the Ponoi and Svyatonosski bay. The foraminifera, mainly Elphidiidae and Cassidulinidae, are found only in the lower part of the silt and clay layer at 30-32.5 m (Gudina & Yevzerov 1973). The dominant species are *Cribroelphidium goesi* and *Cassidulina subacuta*. Other sublittoral species include *Elphidium subclavatum*, *Islandiella islandica*, *Astronion gallowayi*, *Buccella frigida*, *Nonionella labradorica* and *Protelphidium orbiculare*.

In the Ponoy Bed (at depths 33-23 m), Armand and Lebedeva (1966) identified three pollen zones representing forest-tundra (I), open birch-pine forest (II) and spruce-pine forest (III) (Fig. 15). Yevzerov et al. (1976) divided the flora into two zones representing sparse pine-birch-spruce forest (lower) and pine dominated coniferous forest (upper) both indicating the interglacial climatic optimum. The pollen flora of the whole section is quite similar, differences between zones being only in the dominance of tree pollen and occurrence of *Carpinus* pollen in the upper zone (III). *Osmunda* spores occur in all the zones, particularly in the lower zone (I). As a whole, the pollen flora indicates a somewhat similar vegetation to the present-day boreal forest in the area (vegetation map in Atlas Murmanskoi oblasti 1971).

The diatom flora in the Varzuga lower silt and clay beds (Ponoy Bed) is very rich and includes 150 species of which 80% are marine or brackish water forms (Cheremisinova 1962 in Gudina & Yevzerov 1973). The dominant species in the diatom flora are *Melosira sulcata* and varieties, *Thalassiosira gravida*, *Podosira delicatissima* Tscher., *Thalassionema nitzschioides*, *Rhabdonema arcuatum*, *Navicula distans* W. Smith, *Trachyneis aspera* v. *intermedia* Grunow, *Cocconeis scutellum* and *Chaetoceros* sp. (spores). According to Cheremisinova (1962b), the diatom flora indicates a sublittoral zone at water depths of 40-50 m. The diatom flora also includes species which favour warm water such as *Navicula palpebralis* Brébisson, *N. forcipata* Greville, *N. forcipata* v. *nummularia*, *N. lyra* Ehrenberg, *N. lyra* v. *elliptica* A. Schmidt., *N. lyra* v. *subelliptica* Cleve and *N. lyra* v. *ehrenbergii*.

Chapoma (34)

On the left bank of the Chapoma River (Fig. 17), 3.5 kilometres from the river mouth, the Ponoy and Strel'na Beds have been recorded in two sections (Gudina & Yevzerov 1973). The sections occur in the river terraces at 23 m and 31 m above sea level. The first section (section 5a in Gudina & Yevzerov 1973) exposed in the latter terrace, the Ponoi Bed rests on a till bed and is overlain by the Strel'na Bed and post-glacial deposits. In the second section (section 5b in Gudina & Yevzerov 1973) the lower till is absent. The Ponoy Bed, the top of which is at 12 m above sea level, is composed of coarse silt and silt, and includes molluscs. The mollusc fauna (23 species) is very similar to that in the Ponoy Bed in Varzuga (according to Gudina & Yevzerov (1973) and Yevzerov et al. (1976)). Radiocarbon dates from the Ponoy Bed molluscs give an age of 34500 ± 450 BP (Ta-270) (Yevzerov et al. 1976). Later, determinations by the uranium-thorium method gives much older ages of 85500 ± 3200 (LU-464A) and 86000 ± 3900 (LU-464B) for molluscs shells (Arslanov et al. 1981).

Foraminifera are much more abundant at Chapoma (50 species) than in the Ponoi Bed in Varzuga (Gudina & Yevzerov 1973). The fauna consists of Elphidiidae, Nonionodea, Islandiellidae, Cassidulinidae, and Cibicididae. The dominant species here is *Cibisides rotundatus*. The Chapoma Ponoi Bed has a rich warm water fauna, of which only three species have been found in the Varzuga deposit (Fig. 7 in Gudina & Yevzerov 1973). Some warmer water species such as *Bulimina aculeata*, *Bolivina pseudoplicata* and *Hyalina baltica* have their extreme eastern limit in the Mikulino at Chapoma. The limited number of cold-water forms present include *Buccella frigida*, *Protelphidium orbiculare*, *Cribroelphidium goesi*, *Stainforthia loeblichi* and *Nonionellina labradorica*.

Pollen analyses by Malyasova and Devyatova give two different interpretations of the contemporaneous vegetation cover in the Ponoy Bed in Chapoma. Malyasova concluded that a sparse spruce and pine forest prevailed during the interglacial (Gudina & Yevzerov 1973). However, Devyatova suggested that *Betula* pollen was dominant with minor amount of *Alnus*, *Pinus* and *Picea*. The NAP flora indicated that mesophytic herbs were dominant (Fig. 17 in Yevzerov et al. 1976).

The diatom flora in the Ponoy Bed in Chapoma includes 109 species, of which saline forms (51%) dominate the assemblage. The proportion of brackish and freshwater species is 15% and 32 %, respectively (Cheremisinova 1962b in Gudina & Yevzerov 1973). The maximum occurrence of diatoms is concentrated in the upper part of the coarse silt and in the lower part of silt sequence. The dominant marine flora includes species such as *Melosira sulcata*, *Coscinodiscus antiquus* Grunow, *C. curvatulus* v. *minor* (Ehrenberg) Grunow, *C. asteromphalus* v. *centralis* (Ehrenberg) Grunow, *C. granulosus* and others. Some epiphytic and bottom forms such as *Synedra crystallina* (Agardh) Kützing, *Diploneis bombus* Ehrenberg, *Navicula lyra* Ehrenberg, *N. lyra* v. *subelliptica* Cleve, *N. monilifera* v. *heterosticha* Cleve and others also occur. These together with the freshwater species indicate that sedimentation occurred near in a shore habitat influenced by river water (Cheremisinova 1962b).

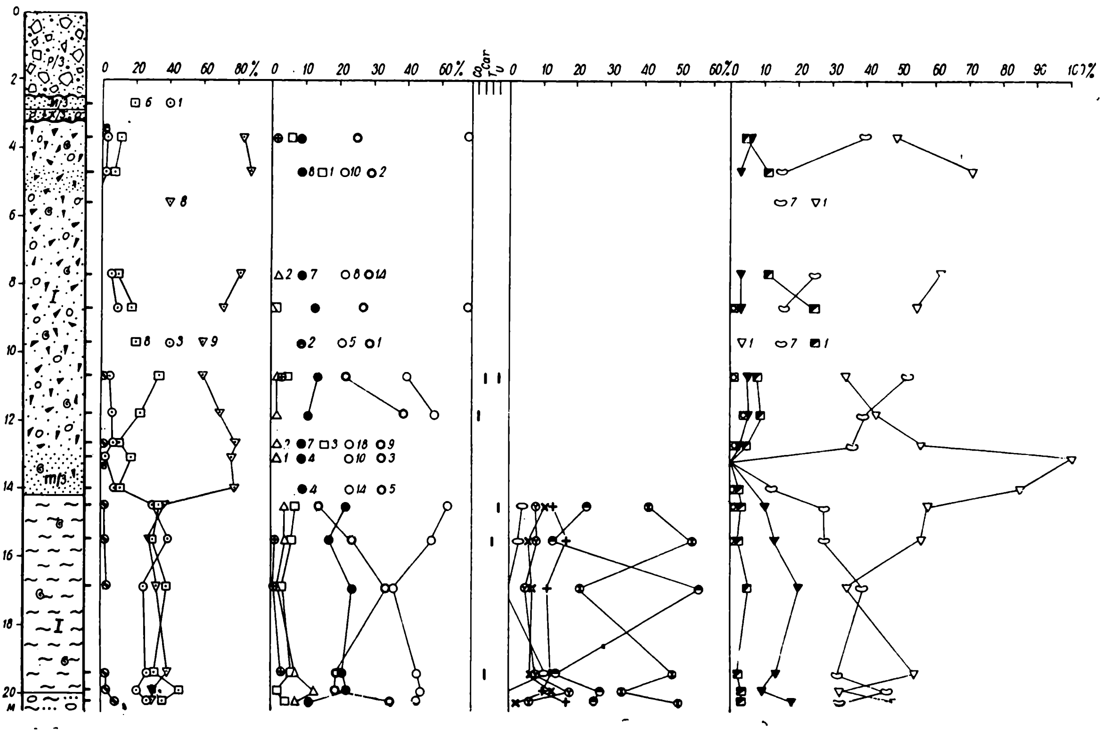


Fig. 16. Pollen diagram from Ponoy section 13a (analysed by Lebedeva in Gudina & Evzerov 1973 fig. 10). Legend: I Ponoy bed: lower clay and upper shelly sand beds. Pollen symbols as in Fig. 15.

River Ponoy (35)

On the lower course of the River Ponoy, there is a dispute over the number of marine interglacial phases and their stratigraphic position. Lavrova (1960) observed only one marine phase, while Nikonov (1966 in Gudina & Yevzerov 1973) distinguished two; one representing the Mikulino and the other, the Middle Valdai 'interglacial'. Whether of not an upper till bed overlies these sediments is also a matter for disagreement (see references in Gudina & Yevzerov 1973). The most complete section 13a (see Fig. 16) found in the area occurs on the left bank of the river, opposite the Ponoy village, at 27.5 m above sea level (Lavrova 1960, Gudina & Yevzerov 1973 and Yevzerov et al. 1976). The Ponoy Bed here consists (from the base) of red clay with sporadic molluscs (5.8 m), shelly sand (11 m), coarse sand including boulders with an erosional lower surface and finally fine-grained sand. At the base of the Ponoy Bed there is a layer of stones and boulders in a sandy-clay matrix and on the top a gravelly sand layer with stones and boulders.

Molluscs, which have only been studied from the shelly sand layer indicate a warmer water temperature than nowadays in the White Sea region and a water depth no more than 10 m, based on the occurrence of *Cardium edule* in the sand bed (Gudina & Yevzerov 1973). The dominant species include *Cyprina islandica* l., *Astarte borealis* Cheminitz v. *arctica* Gray and *Mactra elliptica* Brown (Lavrova 1960). The complete species list is given in Table 1 of Gudina & Yevzerov (1973) and in Table 2 of Yevzerov et al. (1976). A radiocarbon date, obtained from the shells of *Chlamys islandicus* Müll. and *Neptunea* sp., from the sand bed at 19.5-25 m above sea level gave an age of 33650 ± 400 BP (TA-271).

A small amount of foraminifera were found in the lower part of the clay, but more are present in the upper part. The species here include *Cassandra* *teretis*, *Cassidulina subacuta*, *Planocassidulina norcrossi*, *Astrononion gallowayi*, *Cibisides rotundatus* and others (Fig. 8 in Gudina & Yevzerov 1973). The faunal assemblage changes in the sand bed, in which the abundance of the dominant species, *Cibicides rotundatus* and *Trifarina angulosa*, increases to 60-70%. In addition there are significant amounts of Miliolidae. A large number of warm water foraminiferal species, indicating an influence of warm Atlantic waters, are found in the Ponoy Bed and particularly in the sand sequence. According to Gudina and Yevzerov (1973), during sedimentation of the clay sequence, the lower part of which was apparently deposited in the initial phase of transgression, the water level was higher than in the sand bed. This is supported by the finds of Miliolidae and *Cibisides rotundatus*, which prefer shallower habitats.

Pollen analysis of the Ponoy section (Fig. 16) yields somewhat different results from the clay and sand sequences. In the clay the abundance of trees, herbs and spores is approximately equal and the proportion of *Betula*, *B. nana* and *Pinus* is 36-52%, 19-34% and 17-24%, respectively. However, in the sand the proportion of herbs and grasses decrease, *Pinus* values are somewhat lower, but the proportion of *B. nana* is comparable to that in the clay layer (Fig. 16). According to Gudina and Yevzerov (1973) the flora in the whole section indicates tundra vegetation very similar to that present in the area today.

The diatoms found are concentrated in the clay unit. Only a few species were found sporadically in the sand layer. The numbers of marine planktonic species are highest in the clay, although the sublittoral species are more common. The planktonic diatom flora includes species such as *Coscinodiscus asteromphalus* Ehrenberg, *C. oculus iridis* , *Thalassionema nitzschioides*, *Thalassiosira gravida* and *Chaetoceros* sp. (restingspores). This marine flora also include species *Porosira glacialis* (Grunow) Joergensen, *Coscinodiscus marginatus* Ehrenberg, *Bacterosira fragilis* Gran, *Isthmia nervosa* Kützing, *Nitzschia frigida* Grunow, *Melosira sulcata* and *Hyalodiscus scoticus*. The presence of southern boreal forms in the clay indicate the influence of warm Atlantic waters (Gudina & Yevzerov 1973).

Malaya Kachkovka (36)

On the eastern shore of the Kola Peninsula the highest interglacial deposit (135-140 m above sea level) has been found in the lower course of a tributary of the Kachkovka River (Lavrova 1960, Gudina & Yevzerov 1973). This deposit comprises, from the base, clay (0.5 m), fine-grained sand with molluscs in layers or sporadic (4.4 m), coarse- and medium-grained sand with abundant molluscs (1.2 m), a band of stones with gravel and sand (1.2 m), including abundant molluscs and fine-grained sand, with intermittent stony gravel (0.5 m) in places. The marine sequence lies on and is covered by coarse silts, which include gravel and clasts. According to Lavrova (1960) the coarse silt sequences represent till beds, but Gudina and Yevzerov (1973) state that there is no proof of the sediments' glacial origin. More recently, the lower coarse silt sequence has also been correlated with the Early Valdai glaciation (Yevzerov et al. 1976).

The mollusc fauna in the marine sequence represents the upper sublittoral zone (Lavrova 1960). The dominant species are *Cyprina islandica*, *Mactra elliptica* Brown., *Astarte borealis* Chemn. v. *arctica* Gray. and *Hyatella arctica* L. Other species found in the upper coarse-grained sediments include, in addition to the species mentioned above, such as *Anomia squamula* L., *Modiola modiolus* L., *Cardium fasciatum* Montagu, *Mya truncata* L., *Saxicava arctica* L., *Acmaea rubella* L., *Acmaea virginea* Müller, *Margarites cinereus* Couthoy, *Natica clausa* Broderip and Sowerby, *Lunatia groenlandica*, *Lacuna divaricata* Fabricius, *Buccinum undatum* L. and others (Lavrova 1960, see also Table 1 in Gudina & Yevzerov 1973 and Table 2 in Yevzerov et al. 1976). According to Gudina and Yevzerov (1973), the faunal assemblage in the Kachkovka deposits is one of the warmest found in the interglacial deposits of the Kola Peninsula. Moreover, Yevzerov et al. (1976) consider that the finds of *Cardium edule* shells in the fine- grained sand demonstrate a low-water level of no more than 10 m. Radiocarbon dates from the mollusc shells give ages of 35540 ± 510 BP (LU-136A) and 43700 BP (LU-136B) (Yevzerov et al. 1976). Later 230Th/234U dates from *Astarte borealis* shells have yielded much older ages of 102000 ± 4000 (LU-452A) and 114000 ± 4000 (LU-452B) (Arslanov et al. 1981).

The dominant foraminiferan in the clay is *Cassandra teretis*. Other species found in lower numbers include *Cibisides rotundatus*, *Fissurina marginata*, *Elphidium boreale* and others. The foraminifera become more frequent in the sand layers, where the main proportion of the fauna comprises of *Cibicides rotundatus*. The miliolidae family, which is rather widely represented includes species such as *Quinqueloculina arctica*, *Q. borea*, *Q. ovaliformis*, *Pyrgo williamsoni* and *Pateoris hauerinoides*. Other species are found only sporadically (p. 61 in Yevzerov. et al. 1976). In the upper part of the section, the foraminiferan frequences decrease. The dominant species here is *Cibisides rotundatus*. According to Yevzerov et al. (1976) the foraminiferal fauna for the most part reflects environments in a narrow sandbank zone (based on the almost total lack of Elphidideae). Gudina and Yevzerov (1973) have pointed out certain characteristics of the faunal assemblage. This, combined with the high elevation of the Malaya Kachkovka marine sequence led these authors to suggest that it might represent an older interglacial than the other deposits described in the Kola Peninsula, which they assigned to the Middle Valdai Substage.

The pollen diagram from the Kachkovka deposits has been divided into three zones: *Betula*-Gramineae-Bryales, *Betula-Pinus* and *Betula-Pinus-Picea*-Polypodiaceae zones (analysis by Lebedeva in Fig. 17 section 14 in Yevzerov et al. 1976). In the first zone, which comprises the lower clay bed, the proportions of trees, herbs and spores are almost equal. In the upper zones the proportion of spores increases to 60-70%. The herb pollen NAP flora in the *Betula-Pinus*-zone includes Gramineae, *Artemisia* and a range of herbs. Bryales spores dominate the lower part of the zone, but Polypodiaceae spores are most abundant in the upper part as well as in the upper zone (*Betula-Pinus-Picea*-Polypodiaceae). Here Ericaceae pollen also increases. According to Yevzerov et al. (1976), the second zone reflects an open forest with pine stands, and the upper third zone, a true forest vegetation. Tundra vegetation reflected in all the pollen zones probably indicates a similar tundra as formed in the area today, but in the third phase the zone was narrower (Yevzerov et al.1976).

Svyatonosski bay (37)

On the coast of the Barents Sea an interglacial deposit, found and studied by Nikonov and Vostrukhina and later also by Yevzerov, is situated in the farthest corner of the Svyatonosski bay (Gudina & Yevzerov 1973, Yevzerov et al. 1976). The section is exposed in a terrace (at 37 m a.s.l.), which is covered for a long distance by talus which previously impeded the thorough examination of the deposits. According to Yevzerov, the deposits consist of two marine interglacial sequences separated by an erosion surface. The upper marine unit (Strel'na Bed) is covered by till of the last glaciation. Nikonov and Vostrukhina (1964, in Gudina & Yevzerov 1973) do not record an erosion surface and relate both the sequences to the Boreal transgression. The top of the lower marine unit is at 25 m above sea level. This (Ponoy bed) rests on bedrock and is composed from the base of a sandstone boulder layer (3 m), silt with abundant of molluscs (5 m) and clay with rare molluscs (10 m). Stones and small boulders are found both in the silt and in the clay bed.

The mollusc species (listed in Table 1, in Gudina & Yevzerov (1973); in Table 2 in Yevzerov et al. 1976) in the silt bed represent a middle and upper sublittoral faunal assemblage. In the clay bed, the proportion of cold-water molluscs increase, which according to Nikonov and Vostrukina (1964 in Yevzerov et al.1976) indicates a deeper water basin. Radiocarbon dates obtained from the shells in the silt bed gave ages of 41900 ± 1290 (LY-137A) and 46540 ± 1770 (LY-137B). However, more recent uranium/thorium date of *Cyprina islandica* shells from the bottom of the section confirmed an age of 97000 ± 4000 to the Ponoi Bed (Arslanov et al. 1981).

The foraminiferal fauna in the silt and clay beds is dominated by Cassidulinidae and Islandiellidae with many Trifarina. The dominant species is

Cibisides rotundatus (Fig. 11, in Gudina & Yevzerov 1973). Several species are confined to the Svyatonosski bay deposit and are absent completely towards the east and southeast or else occur only sporadically. These species include *Lagena semilineata*, *Amphicoryna scalaris* f. *compacta*, *Guttulina lactea*, *Fissurina latistoma* and *Hyalinea baltica*. The foraminiferal assemblage as a whole is very similar to that of the present southwestern part of the Barents Sea (Gudina & Yevzerov 1973).

The diatom flora in the silt and clay sequences contains 59 species of which 51 are autochthonous. Saline and brackish water species predominate (27 species). The planktonic taxa *Thalassiosira excentrica* (Ehrenberg) Cleve, *Thalassiosira gravida*, *Thalassionema nitzschioides*, *Stephanopyxis turris* (Greville) Ralfs have been found throughout the silt-clay sequence. While the oceanic planktonic species *Coscinodiscus asteromphalus*, *C. marginatus* Ehrenberg and *C. oculus iridis* are restricted to the clay sequence at 13-20.5 m. The later flora also include sublittoral benthonic forms such as *Cocconeis scutellum*, *Trachyneis aspera* v. *intermedia* Grunow and *Grammatophora* species, whilst the littoral forms *Melosira sulcata* and *Hyalodiscus scoticus* are also frequently found (Gudina & Yevzerov 1973).

Nikonov and Vostrukhina (1964 in Gudina & Yevzerov 1973) and Yevzerov et al. (1976) have proposed two different interpretations of the vegetation history of the Svyatonosski deposits. According to Nikonov and Vostrukhina, during the sedimentation of the lower sandstone boulder layer and lower part of silt bed sparse birch stands, ericaceous tundra and *Artemisia* stands occupied the area. This was followed subsequently by replacement of the birch stands and by true birch forests with pine, alder and spruce. Yevzerov et al. 1976 distinguished two zones in the pollen diagram (Fig. 17, section 15 in Yevzerov et al. 1976): zone I (sandstone boulder and silt bed) reflecting a tundra and forest tundra vegetation, and zone II (clay layer) representing for the most part a forest tundra. The present vegetation of the Svyatonosski bay area consists of shrub tundra (cf. Atlas Murmanskoi oblasti 1971).

Upper course of the River Ponoy

In the central part of the Kola Peninsula, the upper coarse of the River Ponoy, the deposits included within the Boreal transgression consist of plastic clay, silt, coarse silt and occasionally sand. The strata lie on eluvial deposits and are overlain by Holocene sediments (Lavrova 1960, Armand et al.1966). In the mouth of the Kisenka river a till resting on the Mikulino Boreal transgression sediments has been identified. The deposits are frequently disturbed as a result of frost activity at the end of interglacial or by deformation by ice sheet overriding (Armand et al. 1966 and references therein). These Boreal transgression sediments occur below 175 m a.s.l. (Lavrova 1960). Armand et al. (1966) list elevations such as 173 m (brook Schuschi), 165 m (Saharnaya river), 157 m (the mouth of the Kisenka river) and 152 m (the lower course of the El' river) for the upper limits of the Boreal transgression sediments.

The diatom flora of strata correlated with the Boreal transgression consists mainly of freshwater diatoms. The marine species are found only occasionally and they also include Tertiary forms. The marine taxa listed by Armand et al. (1966, p. 47-48) include *Melosira sulcata*, *Hyalodiscus scoticus*, *Diploneis bombus* Ehrenberg, *Podosira stelligera* (Bailey) Mann., *Campylodiscus echeneis* Ehrenberg, *Nitzschia navicularis* (Brébisson) Grunow and *Thalassiosira nitzschioides*.

The pollen flora in the Saharnaya deposits indicate tundra and forest tundra with dominance of *Betula* reaching 80 %. The pollen flora also include redeposited and corroded Cretaceous and Tertiary species (Armand et al.1966). The pollen assemblage of the Churozero deposits represents forest (*Betula* 80 %, *Pinus* 10%, *Picea* 5 % and *Corylus* up to 95%). According to Biske (in Lavrova 1960) the Churozero deposit was formed during the Tapes transgression, but Lavrova (1960)considers that the Tapes transgression was restricted to much lower elevations. The great abundance of *Corylus* is very questionable, while in the other interglacial sequences, as well as in Holocene deposits in the Kola Peninsula, *Corylus* percentages are very low and sporadic (according to the data in Yelina et al. 1995).

Khibiny-Lovozero area (39)

Further west, in the Khibiny-Lovozero tundra area, an interglacial deposit has been reported from the highest elevation, 205 m above sea level (Grave et al. 1965 in Gudina & Yevzerov 1973). The interglacial sequence overlain by two Valdaian till beds, with an interbedded interstadial unit, is composed from the base of coarse silt and silt and fine- and medium-grained sand. The total thickness of the sequence is 48 m. The diatom flora from thee sediments includes 16 species of which 4 freshwater, 3 slightly saline, 2 brackish and 7 marine species. The marine species are concentrated in the lower part of the deposit (28 m thick), in which pollen analyses indicates a pine-birch forest. In the upper part the pollen spectra reflect birch tundra. According to Grave et al. (1965, in Gudina & Yevzerov 1973) the deposition of the interglacial sequence occurred in a freshwater bay of the Boreal Sea. Gudina and Yevzerov (1973), referring to late- and post-glacial uplift history in the area by Nikonov (1967), have pointed out that the top of the Lovozero interglacial deposits must be placed at a lower elevation, at 130-140 m above sea level and consequently the main part of the deposit represents a terrestrial accumulation in which the marine diatoms were redeposited. The present authors consider that the vegetational succession implies deposition during a late phase of an interglacial, when the sea-level was already lowering. Hence the position of the sea level during the deposition of these beds is problematic and cannot be reliably identified from the present evidence.

Umbozero (40)

Another terrestrial interglacial deposit interbedded between two tills has been detected on the south-eastern shore of the lake Umbozero (Nikonov 1966, in Gudina and Yevzerov 1973). The interglacial sequence is 10 m thick and consists of silt and fine sand. The top of the sequence is at 160 m above sea level. The pollen assemblage from these sediments indicate a succession from a spruce-birch forest, with pine, to pine-spruce forest. According to Gudina and Yevzerov (1973) the pollen assemblage in the silt and fine sand bed is analogous to that in the Varzuga silt and clay bed and hence the whole section represents the Ponoi Bed and not the Strel'na Bed, as suggested by Nikonov (1966, in Gudina & Yevzerov 1973).

Regional summary

Lavrova (1960) and Armand and Lebedeva (1966) have reported two marine interglacial sequences, which represent a single interglacial including the Boreal and the White Sea transgressions, and have correlated them with the deposits in the Severnaya Dvina area. Nikonov (1966, in Gudina & Yevzerov 1973) separated two interglacials: the first belonging to the Boreal and the second to the much younger White Sea transgression of Middle Valdaian age. Some scientists have separated two marine beds (the Ponoy and Strel'na Beds) and connected both to an independent Middle Valdai interglacial based on radiocarbon dates (Gudina & Yevzerov 1973, Yevzerov et al. 1976). However, more recent 230Th/U234 dates obtained from mollusc shells have indicated, that the Boreal transgression sediments (Ponoy Beds) are equivalent to the Mikulino/Eemian interglacial and the upper marine beds (Strel'na Beds) to an independent Middle Valdai transgrssion (Arslanov et al. 1981, Arslanov 1993 and Faustova 1984). The mean D/L ratio from *Arctica islandica* shells obtained from the lower marine beds at Ponoy, Chapoma and Malaya Kachkovka is 0.039 ± 0.005, which according to Miller and Mangerud (1985) indicates that the deposits represent a single interglacial, the Mikulino.

On the Kola Peninsula marine beds are covered by one till at Varzuga and at Svyatonosski bay. The overlying units at Chapoma units are of post-glacial age. The origin of the beds overlying the marine

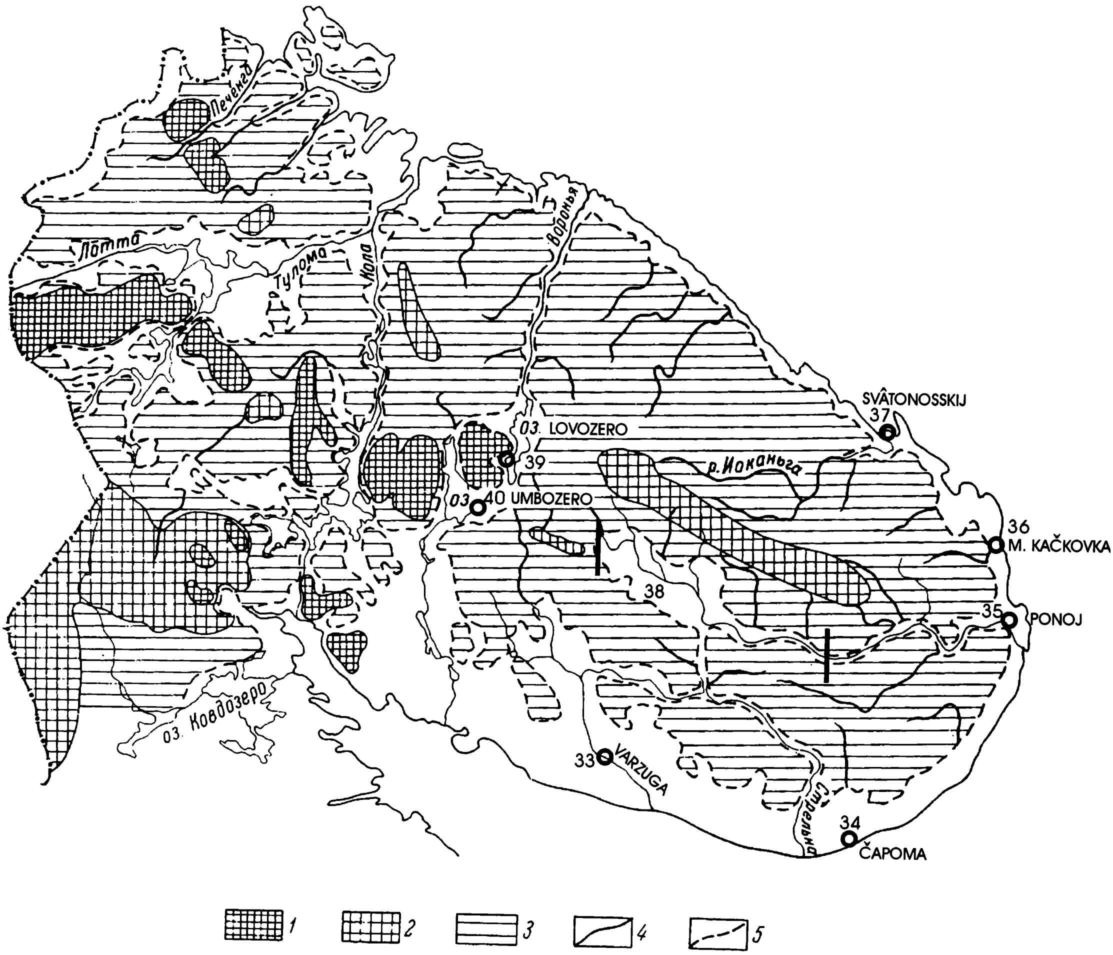


Fig. 17. Palaeotopographical scheme during the maximum extent of the Ponoy transgression (Evzerov et al. 1976 fig. 19). Legend: 1. mountain cliffs, 2. highlands, 3. denudation plain, 4. rivers, 5. boundary of the maximum extent of the Ponoi transgression. Numbers (33-40) refer to the sites described in the text.

layers at Ponoy and Malaya Kachkovka is ambiguous. In the central part of the Peninsula, in the upper course of the Ponoy river the deposits mostly underlie Holocene sediments and an overlying till has only been found in one section. At Umbozero and in the Khibiny-Lovozero area the interglacial units underlie one or two till beds. The initial phase of the Boreal transgression is recorded at Ponoy and at Svyatonosski bay and the regressive phase in the upper part of the Ponoy deposit and at Varzuga. The determination of the succession of the forest development in the Kola Peninsula is not possible because of the lack of complete interglacial sequences and also because of the different interpretations of the same deposits. The forest succession in the Kola Peninsula in the modern boreal forest zone has been undoubtedly different from the northern and eastern tundra zone. Thus for example, the regressive phase of the Boreal transgression at Ponoy occurs in the tundra zone whilst that at Varzuga occurs in the coniferous forest zone. The present boreal forest / tundra boundary crosses the interior of the Kola Peninsula in the WNW – ESE direction.

The absolute height of the interglacial deposits correlated with the Boreal transgression ranges from 12 m (Varzuga and Chapoma) to 205 m (in Khibiny-Lovozero tundra area). An apparent discrepancy in the elevations of the deposits situated on the eastern part of the Peninsula (at Malaya Kachkovka 135-

140 m and at Ponoy 27.5 m a.s.l.) is difficult to resolve because the accurate stratigraphical positions of interglacial units are unclear. The Holocene shorelines descend towards the east so that the 0-isobase of the Tapes transgression approximately follows the present shoreline in the east reflecting decreasing ice load eastwards (Ramsay 1898, Snyder et al. 1996). Assuming that the isostatic rebound after the penultimate glaciation (Moscovian) on the Kola Peninsula broadly resembled that of the last glaciation, although the Moscovian Glaciation was more extensive, the Mikulino marine deposits reported to occur at over 135-140 m a.s.l . in the eastern part of the Kola Peninsula may not represent *in situ* deposition. On the contrary, in the western part of the Kola Peninsula higher elevations, over 100 m a.s.l., seem plausible. During the maximum transgression the Lovozero, Umbozero and Imandra lake basins were connected to the Barents Sea and to the White Sea (Fig. 17). The northern water route from the Lake Imandra depression passed through the Kola river valley and that from the Umbozero-Lovozero basins via the Voronya river. The connection to the south passed via the Niva and Umba River valleys and possibly also via the Pana and Varzuga rivers (Yevzerov et al. 1976).

RIVER ONEGA AREA

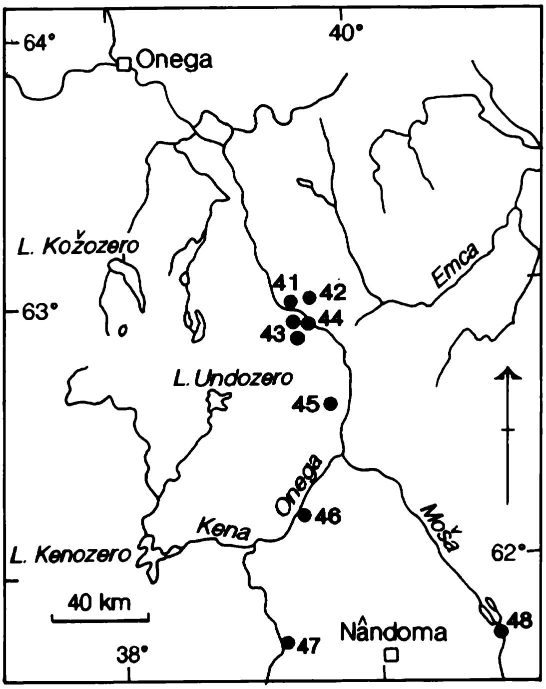


Fig. 18. Locality map of sites referred in the text (VI Onega river area.in Fig. 1)

The description is based on the references of Devyatova (1961), Biske & Devyatova (1965), Apukhtin & Ekman (1967) and Abrukina & Krasilnikova (1972).

In the Onega river basin, interglacial deposits are found on the banks of the Onega river and its tributaries (Fig. 18). The sequences do not span the whole interglacial period, but only parts of it. Here the thickness of interglacial sequences ranges from 70 cm (in the Somba river area) to 33 m (in Kakovka). The interglacial sequences (clay and sandy clay), are found at greatest depths, in the Onega river basin, in the mouth of River Tyoksa and near Pustynka. Here the top of interglacial sequences is at 18-28 m and 23 m, respectively. Very often the deposits are situated below the water level. Both sublittoral and littoral phases can generally be distinguished in the Onega river basin (Devyatova 1961). In the Onega Peninsula, interglacial deposits mostly represent a regressive phase of the Boreal transgression sea (Biske & Devyatova 1965).

River Tyoksa (41)

The top of interglacal sequences in the Tyoksa river basin is at 18-28 m above sea level (Devyatova 1961). On the right bank of the Onega River, near the mouth of the river Teksa, the interglacial clay sequence (section 17) rests on colluvial debris. No till was found on the top of the deposit. The molluscs present represent a deeper part of the sea, including *Astarte crenata* Gray, *A. elliptica* Brown, *A. montagui* Dillw.v. *striata* Leach, *Cardium ciliatum* Fabricius and *Leda pernula* Müller. The fauna also includes taxa that are widely-distributed or have drifted from nearer shore habitats. They include *Corbula gibba* Olivi, *Cardium edule* L.and *Macoma baltica* (Appendix 1, in Devyatova 1961). The upper part of the river Tyoksa basin (section 37-G) interglacial sequence comprises 5 m thick sandy clay with mollusc fragments and plant remains. This interglacial sequence overlies Moscovian till and is, in turn, overlain by two Valdai tills.

Verhnaya Tyolza (42)

In the river Verhnaya Tyolza basin the top of the interglacial marine deposits occurs at 55-85 m above sea level. The deposits underlie Valdai till and consist mostly of sand, that rest on bedrock, till or colluvial sediments. A clay bed has only been found in a couple of sections; in section 25 between sand layers and in section 38 at bottom. The molluscs fauna found in section 25 include species such as *Cardium edule*, *Littorina saxatilis* Olivi, *L. rudis* Maton, *Mytilus edulis*, *Macoma baltica*, *M. calcarea*, *Saxicava arctica*, *Astarte elliptica*, *A. montagui* v. *striata* Leach., *A. borealis* v. *arctica* Gray, *A. borealis* f. *typica* Cheminitz and *Puncturella noachina* L. In section 38 the dominant species are *Cardium edule*, *C. echinatum* and *Hydrobia ulvae*. Other rather common species include *Corbula gibba* Olivi, *Mactra subtruncata* Da Costa, *Bittium reticulata* Mont.and *Mactra elliptica* Brown. A similar fauna is also known from section 44 (Appendix 1, in Devyatova 1961). Devyatova (1961) interpretes the mollusc fauna as representing the upper sublittoral zone. Littoral species are only rarely found. Arctic species are absent but species indicating warmer water dominate.

The diatom and pollen assemblages have been investigated from two deposits in the river Verkhnaya Tyolza area. The top of the marine layer lies at 84 m above sea level in section 44. The pollen assemblages in the lower part of the deposit represents the interglacial climatic optimum, where the proportion of temperate deciduous trees and *Corylus* is 18% and 38%, respectively (fig. 6, in Devyatova 1961 and Fig. 19 herein). The foraminifera in the lower part of sand bed comprises 12 species, of which the dominant taxa are *Cibicides rotundatus* Shschedrina, *Elphidium subclavatum* Gudina and *Cassidulina teretis* Tappan. Higher in the sequence the number of species increase to 15, yet *E.*

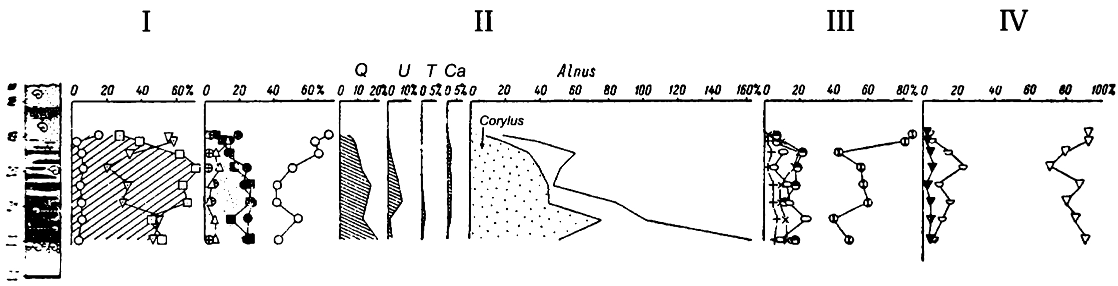


Fig. 19. Pollen diagram from Verhnaya Telza section 44 (Devyatova 1961 fig. 6). Legend: I Total pollen, II trees, III herbs and graminids, IV spores. See pollen symbols in Fig. 22.

subclavatum and *C. rotundatus* remain dominant (Abrukina and Krasilnikova 1972). Diatoms are only found in the lower part of the sand from 19 m downwards (71 m a.s.l.). The dominant species are *Melosira sulcata*, *Isthmia nervosa* and *Navicula distans*. Planktonic species are present in low numbers. The dominant epiphytic species represent *Rhabdonema*, *Grammatophora* and *Cocconeis* genera. In addition, the flora also contains species alien to the present White Sea, such as *Coscinodiscus hauckii* Grunow, *Diploneis bombus* (Ehrenberg) Cleve, *Navicula lyra* Ehrenberg and *N. humerosa* v. *constricta* Cleve. Some cold water species, *Grammatophora arcuata* and *Thalassiosira gravida* are also present (Appendix 2, in Devyatova 1961). Overall the diatom flora represents a littoral environment (Devyatova, 1961).

Further section (no. 23) in the river Verhnaja Tyolza area that yields a cold-water mollusc fauna was previously thought by Devyatova (1961) to represent a regressive phase of the Mikulino boreal sea. Later she revised her opinion (1982) and equated it to Siyan marine unit, which is correlated with the Strel'na Beds of the Kola Peninsula. Opinion differs over the age of this latter transgression. Devyatova (1982) ascribes it to the Early Valdai, but others (Gudina & Yevzerov 1973, Arslanov et al. 1981) to the Middle Valdai.

River Somba (43)

In the river Somba basin the top of interglacial deposits occurs at 62-74 m above the sea level (Devyatova 1961). Here deposits lying on colluvial sediment are covered by a Valdai till. In section 231 (4 km from the mouth of the river Somba), the mollusc fauna found in the sandy clay sequence at the base includes *Cardium ciliatum* Fabricius, *Astarte montagui* Dillwyn and *Saxicava arctica*, while the overlying sand includes many species, which are common in a neighbouring section. In section 239 (13 km from the mouth of the river Somba) the sand sequence predominatly contains boreo-subarctic species, which today inhabit the White Sea, but also lusitanic-boreal and boreal species were found including *Cardium edule* v. *rusticum* L., *Cyprina islandica* L., *Cardium fasciatum* Mont., *Hydrobia ulvae* Penn. and *Mytilus edulis*. The main component of this fauna represents littoral taxa (Appendix 1, in Devyatova 1961).

The diatom flora found in the Somba deposits is poor and the abundance decreases upwards with the change from sandy clay to sand. The dominant species are *Synedra ulna* and *Stephanodiscus hantzschii* Grunow. *Melosira sulcata* was also found occasionally (Appendix 1, in Devyatova 1961). According to Zhuzhe (in Devyatova 1961) the flora indicates a lagoonal phase.

Basina (44)

On the left bank of the Onega River, near the village of Basina the lithostratigraphy of the interglacial unit is of a different type. The deposit (section 270) comprises from the bottom upwards, sand, clay with a thin coarse silt layer in the middle passing into sand and then clay. The top of the upper clay sequence is at 37.7 m. The interglacial sequence rests on colluvial diamicton and is buried by glaciofluvial sand. The pollen flora is dominated by *Betula* and *Alnus* (Fig. 20). In the upper part, *Pinus* pollen values increase to 20 %. According to Devyatova (1961), the pollen indicates an early phase of an interglacial cycle.

The diatom flora in the lower clay unit consists of freshwater species and those with brackish-water affinity. The dominant species are *Cyclotella meneghiniana*, *Stephanodiscus hantzschii* Grunow and *Synedra ulna*. In the upper clay, besides the diatom species found in the lower clay the flora also include marine littoral types such as *Melosira sulcata*, *Actinocyclus ehrenbergii* v. *tenella* and *Biddulphia aurita* (Lyngbye) Brébisson (Appendix

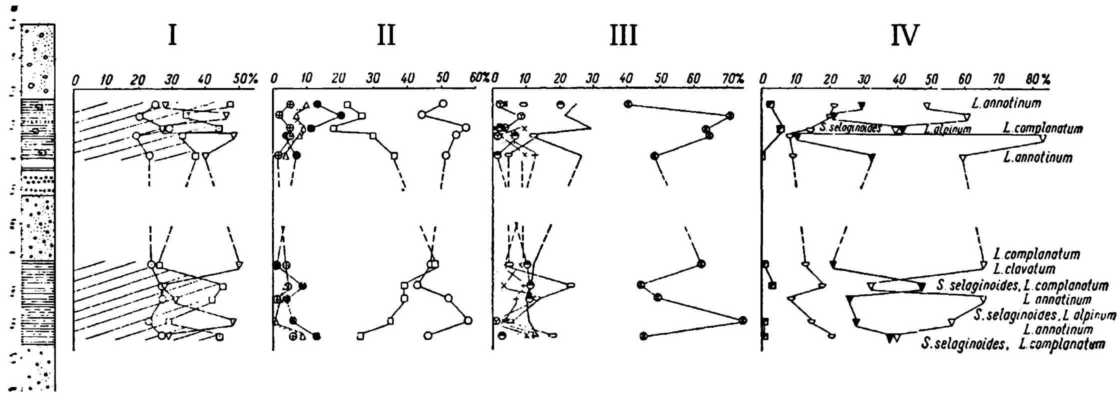


Fig. 20. Pollen diagram from Basina section 270 (Devyatova 1961 fig. 5). See explanations and symbols in Fig. 22.

2. in Devyatova 1961).

The mollusc assemblage in the upper clay include arctic, arcto-boreal and boreal species such as *Astarte montaqui* f. *typica* (dominant), *A. crenata*, *Leda pernula*, *Saxicava arctica*, *Cardium edule*, *C. echinatum* f. *typica* and *Cyprina islandica* (Appendix 1, in Devyatova 1961). The dominant taxon, *A. montaqui* f. *typica*, has not lived in the White Sea since the last glaciation. Devyatova (1961) interprets the upper clay as representing the marine transgressional phase. The molluscs also include embryonic forms, which Lavrova (in Devyatova 1961) cocluded to indicate a rapid sedimentation rate at the beginning of transgression.

River Iksa (45)

On the left bank of the Iksa River, an interglacial marine sequence (section 22) occurs from 47 m (bottom) to 56.5 m asl. The marine clay sequence lies on Moscovian till and is overlain by a Valdai till (Devyatova 1961). The mollusc fauna in this clay unit is poor and has not been determined, except for *Saxicava arctica*. The pollen flora however, indicates the end of a climatic optimum (*Betula* 78%, QM 11-16%) and subsequent birch and pine-spruce and spruce forest phase (Devyatova 1961). According to Devyatova (1961) the pollen diagram (Fig. 21) can be regarded as a continuation to the diagram of the section 44 in Verkhnaya Tyolza.

The characteristic diatom assemblage includes littoral species such as *Melosira sulcata*, *Podosira stelligera* (Bailey) Mann, *Grammatophora oceanica*, *Rhabdonema arcuatum* and *Dimerogramma* species. The dominant forms are *M. sulcata* and *Podosira* species. Planktonic species such as *Thalassiosira decipiens* Cleve, *Th. costata* Cleve, *Bacterosira fragilis* Gran and *Chaetoceros* species are present in lower numbers. Warmer water conditions are indicated besides *Podosira* and *Dimerogramma* species also by *Coscinodiscus hauckii* Grunow, *Diploneis bombus* Ehrenberg and *Navicula* species. However, arctic species such as *Bacterosira fragilis*, *Synedra kamtzschatica* Grunow and *Thalassiosira gravida* are met sporadically. Freshwater *Stephanodiscus*, *Cyclotella* and *Synedra* species are also included in the diatom assemblage (Appendix 2, in Devyatova 1961). Devyatova (1961) concludes that the diatom flora indicates a sublittoral marine phase with water depth of about 60 m.

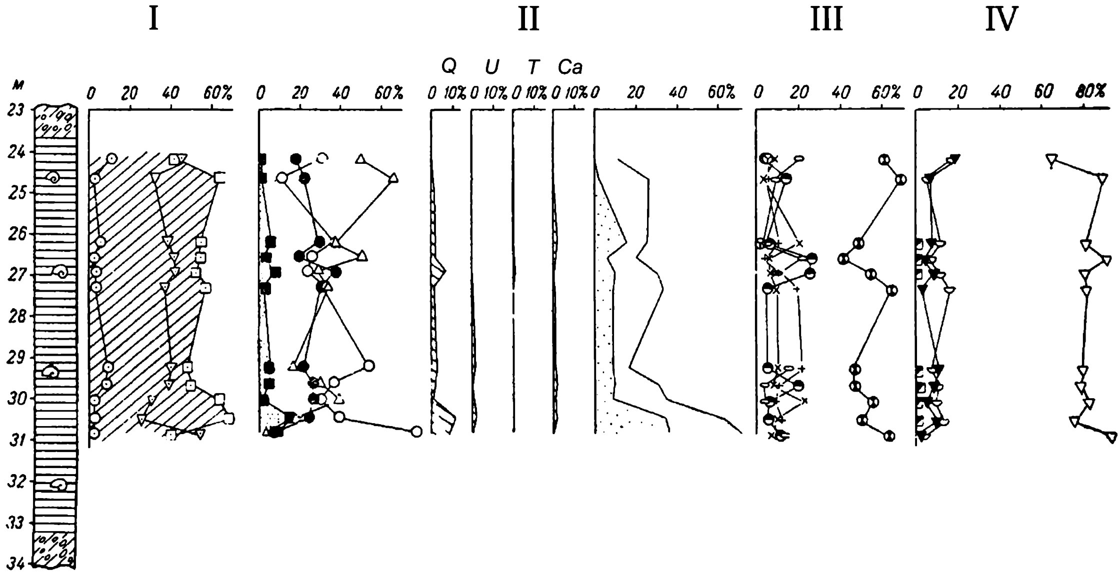


Fig. 21. Pollen diagram from Iksa section 22 Devyatova 1961 fig. 7). See explanations in Fig. 22.

Kakovka (46)

In the upper course of the Onega River, the typical marine interglacial deposits are replaced by strata in which a freshwater influence is more pronounced. The thickest deposit of this type is found in the Kakovka village section, where the interglacial sequence (sand interbedded with clay) is 33.65 m thick. The interglacial sequence is overlain by till 14.95 m thick. Diatoms have been analysed from only some samples at this site. At a depth of 46.55 m only two marine species *Melosira sulcata* and *Grammatophora* sp. were identified (Devyatova 1961)

Demenino (47)

The highest deposit in this area (the top 97 m above sea level) occurs in Demenino village (section 304-d). The clay bed here is four metres thick and underlies till. The pollen assemblage represents an early phase of the interglacial, in which *Betula* pollen accounts for 59-70%, *Alnus* 16-30%, *Pinus* 2-7% and *Picea* 0-3% (Fig. 22). The diatom flora in the clay consists both of freshwater species and those with brackish water affinities. The species found most abundantly are *Synedra ulna* and *Cyclotella meneghiniana* f. *unipunctata*. In the upper part of the clay occassional marine species such as *Grammatophora oceanica* and *Surirella ovata* v. *salma* were also found. According to Devyatova (1961), the high elevation of the deposit implies, that the sedimentation occurred during the maximum transgression, which according to the pollen evidence occurred before the climatic optimum. The diatom and pollen floras are similar to those found in the Basina section. Devyatova (1961) speculated that the difference in the height and the distance between these localities might indicate a rapid inflow of seawater into upper course of the Onega River. This inflow is supported by the finds of immature mollusc forms.

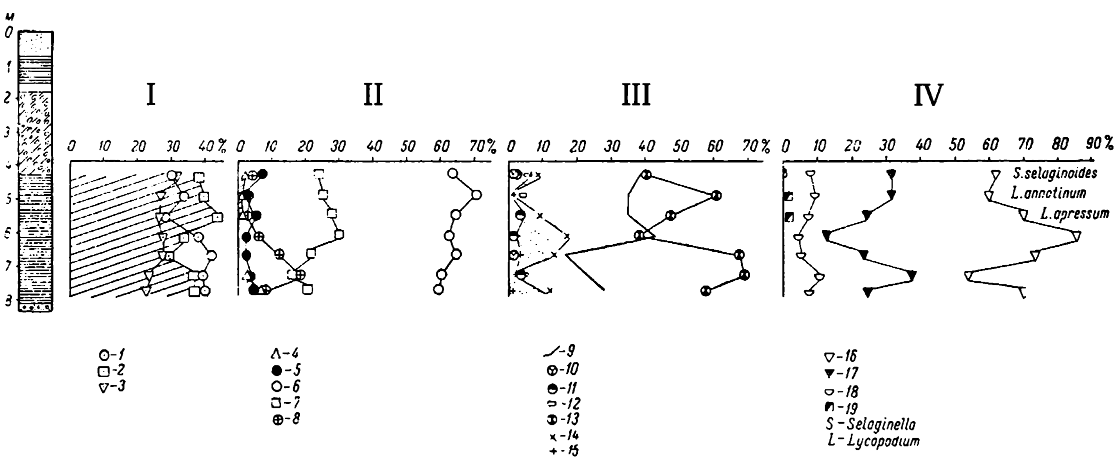


Fig. 22. Pollen diagram from Demenino section 304 (Devyatova 1961 fig. 4). Legend: I Total pollen, II trees and shrubs, III herbs and IV spores. 1. Herbs and graminids, 2. trees, 3. spores, 4. *Picea*, 5. *Pinus*, 6. *Betula*, 7. *Alnus*, 8. *Salix*, 9.*Betula* sect. *nanae*, 10. Ericaceae, 11. Gramineae, 12. Cyperaceae, 13. herbs, 14. Chenopodiaceae, 15. *Artemisia*, 16. Bryales, 17. *Sphagnum*, 18. Polypodiaceae, 19. Lycopodiaceae.

River Mosha (48)

Interglacial deposits have also been found in the upper course of the river Mosha. One (section 1-L) on the left bank of the river, near the mouth of the river Iksa, and the other (section 2-L) on the left bank of the river between the lakes Voyozero and Moshozero (Lukoyanov 1941, in Devyatova 1961). The interglacial sequence (clay laminae interbedded with sand) in section 1-L rests on colluvial diamicton and is buried by a silt-clay bed. The top of interglacial sequence is at about 84 m above sea level. A mollusc fauna in the sand layer includes *Nassa reticulata*, *Cardium edule*, *Saxicava arctica* and *Macoma* sp. In section 2-L, the deposit overlain by diamicton comprises sand, 10 m thick, the top of which is at about 90 m above sea level (see Fig. 2, in Devyatova 1961). The mollusc fauna from this profile includes *Astarte compressa*, *Saxicava arctica*, *Corbula gibba* and *Nassa reticulata*, of which the two last-mentioned species have not been found in the Boreal transgression deposits in the Kola Peninsula (Devyatova 1961).

Regional summary

In the Onega river basin the interglacial sequences are generally overlain by one till, but two till units have been seen in a section in the Tyoksa river basin. In a few sites (e.g. the Basina sections), the upper till is absent. The sequences are underlain by one till unit or they lie either directly on bedrock or on colluvial diamicton. The elevation of the deposits varies from 18 m (near the mouth of the river Tyoksa) to 97 m (in the Demenino depression). The whole interglacial cycle is not represented in any one section, but the vegetational succession can be assembled from different localities. Thus, the beginning of interglacial is recorded in the Demenino and Basina sections, the optimal phase in the Verkhnaya Tyolza and the late phase in part at the Iksa section (Figs. 19 - 22). According to Devyatova (1961) the Tyoksa mollusc fauna reflects a deeper area of the sea, while the faunal and diatom flora

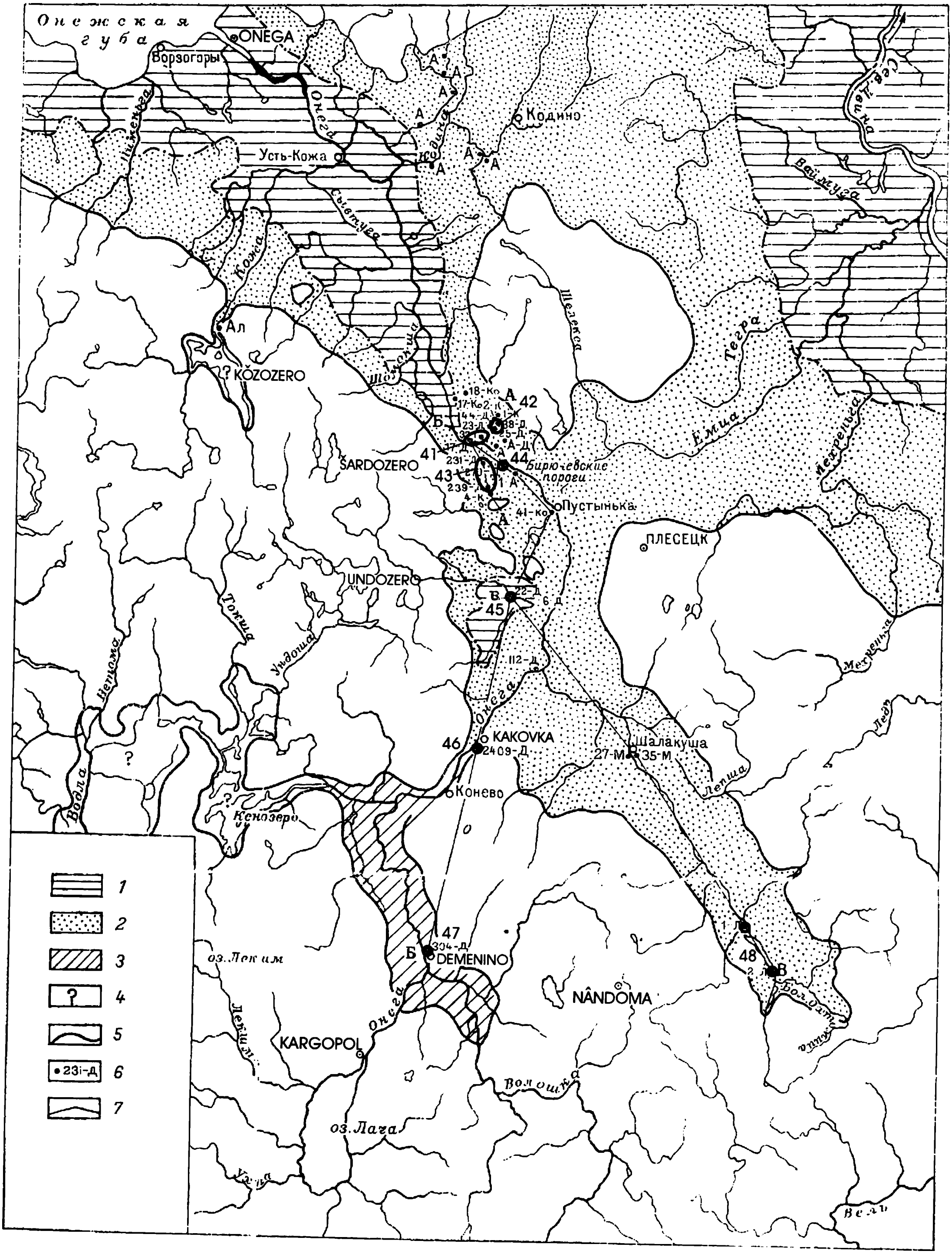


Fig 23. Extent of the Boreal transgression in the Onega river basin (Devyatova 1961, fig. 3). Legend: 1. Deep water basin, 2. shallow water basin, 3. fresh water-marine lagoonal area, 4. probable connection to the Vodla river basin, 5. boundary of the boreal transgression, 6. numbers of the sections described by Devyatova, 7. Schematic profiles, 8. Numbers (41-48) refer to the sites described in the current text.

from the remaining sections indicate the littoral (Somba), sublittoral (Iksa) or upper sublittoral zones (Verkhnaya Tyolza, Mosha) (see Fig. 23). The 'warm' boreal mollusc fauna is not as rich as in the interglacial sediments of the Severnaya Dvina river; the 'warmest' assemblage occurring in the Verkhnaya Tyolza beach deposits (Devyatova 1961). The mollusc evidence from Verkhnaya Telza and Mosha (at 57-90 m a.s.l.) accumulated in a shallow basin with water depths of 20 m. Hence the height reached by the Boreal transgression, 110-115 m a.s.l., which occurred before the climatic optimum in the Onega River basin seems accurate (Devyatova 1961). During the transgression, the Onega river basin was connected to the Severnaya Dvina basin via the Yemtsa and Kodina river valleys. A connection to the west to the Lake Onega basin probably ran through the Kenozero-Vodla system (Devyatova 1961, 1982).

SEVERNAYA DVINA-VAGA AREA

The description is based on the work of Devyatova (1961, 1982), Biske & Devyatova (1965), Loseva (1968, 1992), Pleshivtseva 1972, and Larsen et al. (1999).

In the Severnaya Dvina and Vaga river basins interglacial deposits are much more complete than in the Onega river basin. In the the lower course of Severnaya Dvina River (at Izma) the interglacial sequences consist of clay, while in the middle course of the Severnaya Dvina and in the Vaga river basin the sediments are mainly composed of sand and coarse silt (Krasnaya Gorka, Osinovskoe) and occasionally with clay at some sites (Pas'va and Shenkursk). Peat beds have been recorded in Pas'va-Koleshka sections.

Izma (49)

The most complete deposit in the north-eastern part of the Severnaya Dvina depression has been found near Lake Izma (Pleshivtseva 1972). Here the interglacial sequence consists of clay with plant detritus and marine molluscs. It is underlain by Moscovian late-glacial silt and till and buried by marine clay and till of Valdaian age. The top of interglacial marine clay is at 7.5 m below sea level. The interglacial sequence spans pollen zones IV-VIII/M_1-M_8. The vegetation succession shows some particular carateristics: *Picea* is present throughout the interglacial, even during the climatic optimum it is a dominant tree species. It is accompanied by *Betula* (Pleshivtseva 1972).

Siya (50)

The sections found at Siya occur on the right bank of Severnaya Dvina (Devyatova 1982). In section 1, opposite the village Siya, the interglacial unit lies on a Moscovian silt sequence, the origin of which is unclear (Devyatova 1982). The silt bed is overlain by an internally complex sequence of sand or lenses of laminated clay and marine clay with mollusc. The latter includes *Cardium ciliatum*, *Leda pernula*, *Saxicava arctica* and *Astarte* species. The top of the Mikulino unit is at about the 9.5 m above sea level. The complex sequence covers pollen zone KA_1/M_1 and the clay zones KA_2-KA_6/M_2-M_5.

In a neighbouring section (2) the Mikulino member (correlated to pollen zones M_1-M_2) is overlain by a marine bed consisting of sand and silt units. Both of the units have sharp lower boundaries. The mollusc fauna in the sand includes *Macoma baltica*, *M. calcarea*, *Balanus hameri* Ascanius and less frequently *Leda pernula*, *Mytilus edulis* and *Astarte* and *Pecten* species. In the silt the dominant species are *Macoma calcarea* and *M. baltica*. Devyatova (1982) considered that the marine bed represents a younger marine phase than the Boreal transgression but Lavrova and Legkova (1937, 1961, in Devyatova 1982) attributed both of the units to the Boreal transgression.

Chelmokhta (51)

The sections at Chelmokhta are situated a few kilometres up the Severnaya Dvina River from Siya (Larsen et al. 1999). At Chelmokhta, a Mikulino laminated silt unit rests on Moscovian till and is overlain by diamicton, which upwards changes to silt. The diamicton has a sharp lower boundary and includes sand lenses and shell fragments. The top of the Mikulino unit is at 8 m above the sea level (Fig. 2, in Larsen et al. 1999).

Krasnaya gorka (52)

This site is situated on the first terrace of the Severnaya Dvina River, at the mouth of the river Malaya Shen'ga (Devyatova 1982). The interglacial unit rests on Moscovian till. It consists, from the base, of sand, slightly sandy coarse silt, sandy coarse silt with stones and coarse silty sand, the top of which is 16 m above the sea level. In the basal sand bed, which is placed in the pollen zones KA_4-KA_2 / M_1-M_2 (Fig. 24), the mollusc fauna indicating cold water includes *Saxicava arctica* L, *Leda pernula* Müll., *Pecten* cf. *islandica*, *Mya truncata* L. and rarely *Mytilus edulis* L. and *Neptunea despecta* L. According to Devyatova (1982), the sequence represents an early phase of the Boreal transgression. The subsequent sandy coarse silt unit, which dates from the pollen zones KA_4-KA_5/ M_{4a}-M_{4b}, yields molluscs species such as *Cardium edule* L., *Mytilus edulis*, *Leda pernula*, *Astarte* spp. In the upper part of the sequence, which is assigned to pollen zones KA_6-KA_9/M_5-M_8 the sporadic

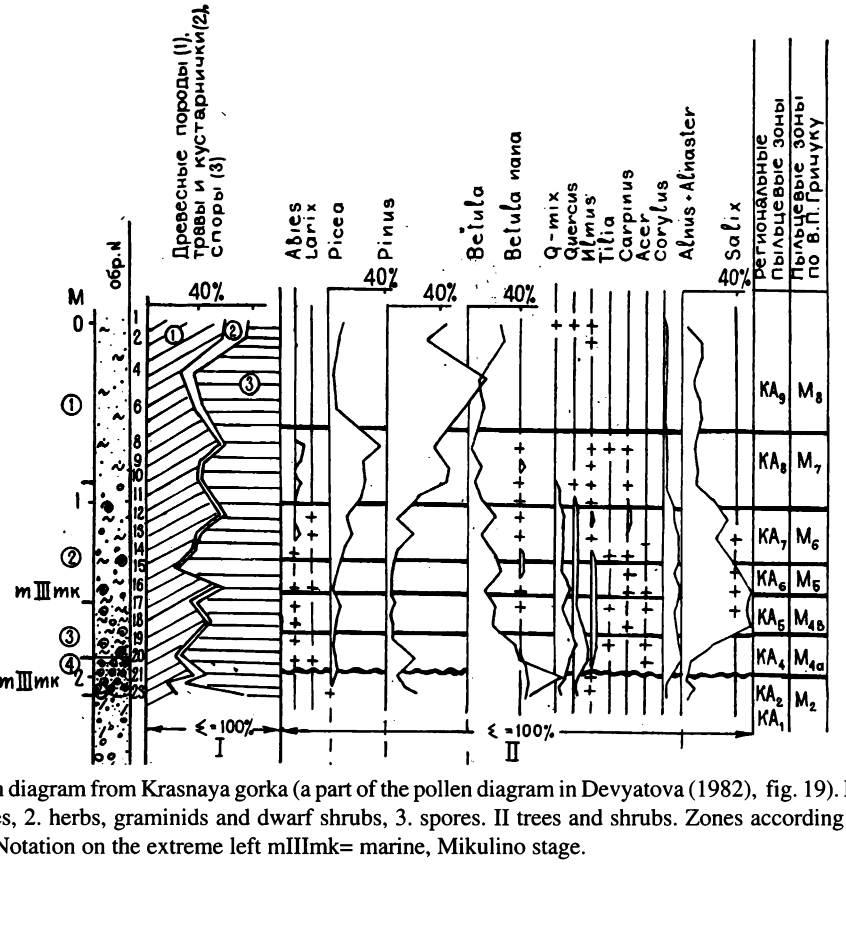


Fig. 24. Pollen diagram from Krasnaya gorka (a part of the pollen diagram in Devyatova (1982), fig. 19). Legend: I total pollen: 1. trees, 2. herbs, graminids and dwarf shrubs, 3. spores. II trees and shrubs. Zones according to Devyatova and Grichuk Notation on the extreme left mIIImk= marine, Mikulino stage.

molluscs are fragmented. However, controversial results from an analogous sequence to the bottom layer above the till bed have been presented by Lavrova (1937, in Devyatova 1982). A mollusc fauna, indicating warmer waters than that described by Devyatova, includes species such as *Cardium edule*, *C. fasciatum*, *C. echinatum*, *Astarte sulcata*, *Mactra elliptica*, *Corbula gibba* and others. Devyatova (1982) considered that this apparent controversy requires additional research.

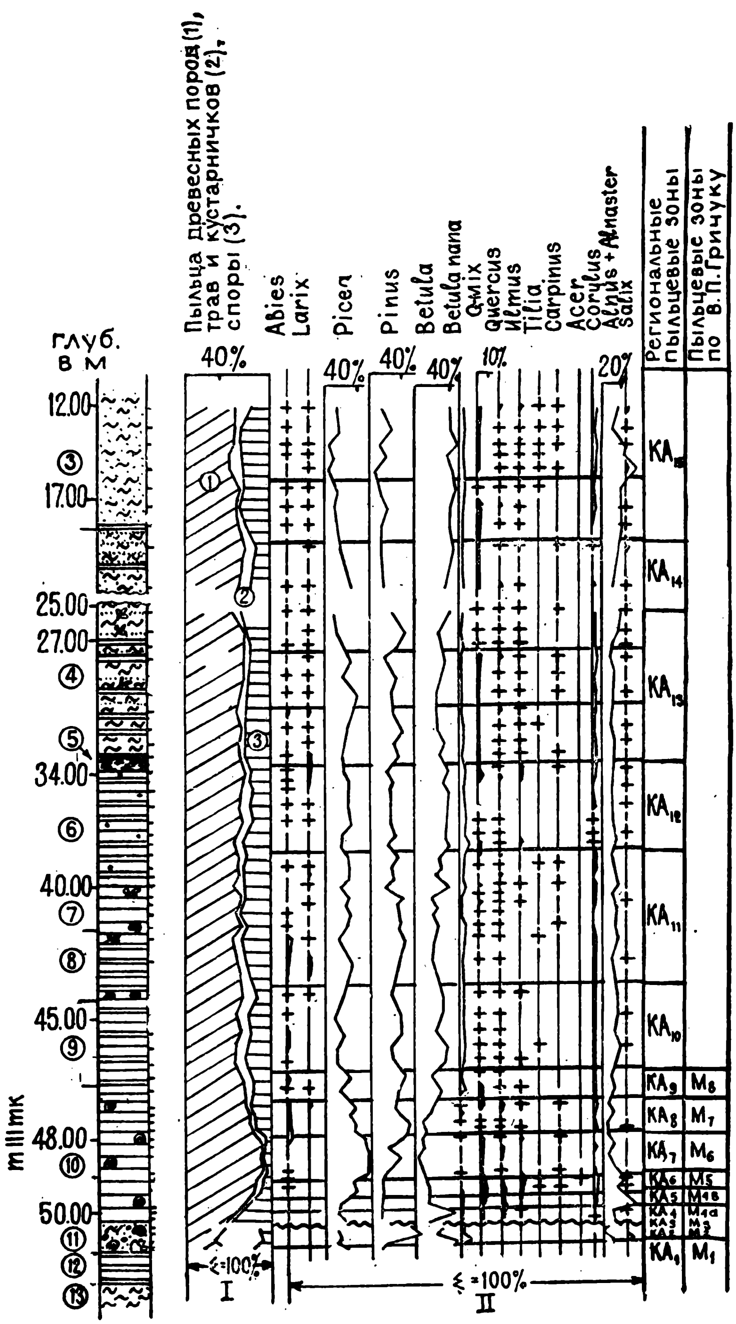


Fig. 25. Pollen diagram from Shenkursk (modified after Devyatova (1982), fig. 11). For explanations see caption to Fig. 24.

Shenkursk (53)

The section here is located on the right bank of the Vaga River (Devyatova 1982). The top of the section is at 47 m above sea level. Here neither Moscow nor Valdai till are found. Instead the interglacial unit consisting of sandy coarse silt and clay rests on Moscovian clay. At the contact of the lower clay layer and the interglacial unit shelly gravel is present. The interglacial unit is overlain by a range of Valdai-age units. An early phase of the Boreal transgression is also revealed in the Shenkursk deposit (Devyatova 1982). The basal sandy coarse silt layer with gravel and stones, which represents pollen zones KA_2-KA_3/M_2-M_3 (Fig. 25), has a similar cold water fauna to that at Krasnaya gorka. Species present here include *Cardium ciliatum* Fabr., *Leda pernula*, *Saxicava arctica* and *Macoma calcarea*. In the subsequent clay unit, which dates from pollen zones KA_4-KA_8/M_4-M_7, the fauna consists of species such as *Mytilus edulis*, *Mya truncata*, *Macoma baltica*, *M. calcarea* and *Astarte* spp. No mollusca have been recovered from the upper part of the clay, which represents the pollen zone KA_9/M_8. The top of the marine clay is at sea level (0 m a.s.l.).

Osinovskoe (54)

The Osinovskoe locality consists of several sections, of which the most complete, section 1, is situated on the left bank of the Vaga River, one kilometre south of the village Osinovskoe (Devyatova 1982). The marine interglacial sequence (10) consists of coarse silty sand, the top of which is at c. 39 m above sea level. The sequence spans the pollen zones KA_7-KA_9/M_6-M_8. The rich mollusc fauna here is either scattered or in layers. The dominant species are *Cyprina islandica*, *Macoma baltica* and *M. calcarea*. The fauna also include species such as *Lunaria pallida* Broderip et Sowerby, *Bela harpularia* Couth., *B. trevelyana* Turt., *Scalaria coarctata* Jeffr., *Trophon clathratus* L., *Astarte borealis* Chemn., *A. banksi* Leach., *A. compressa* L., *Mya truncata* L., *Panopea norvegica* Spengl., *Saxicava arctica*, *Zirphaea crispata* L., *Balanus balanus* L. and *B. crenatus* Bruguiere (Devyatova 1982).

The Mikulino-age unit is covered by a sandy coarse silt sequence (9), which occasionally includes gravel and weathered stones. The lower boundary of the sequence is sharp. The overlying subsequent sequences (4-8) consist of silt, sand and coarse silt. According to Devyatova (1982) sequences 4-9 were formed during preglacial conditions. The uppermost units lying on colluvial debris consist of till and glaciofluvial sediments.

The Osinovskoe section has been recently studied by Larsen et al. (1999). The Mikulino sand unit in this section is at 36 m above sea level. The unit is covered by marine silts and laminated sandy beds of which the latter are interpreted as a beach deposit. The beach deposits are overlain by a till bed and rhythmically laminated silty clay (Larsen et al. 1999).

Ust'-Padenga (55)

The Ust'-Padenga site is situated on the left bank (c. 26 m high) of the Padenga River, 3 kilometres from the river mouth (Devyatova 1982). The lithostratigraphy of the section has been compiled from two profiles, about 70-75 m apart. In the first profile, which comprises the upper parts of the section, the sandy coarse silt sequence 6 (correlated by Devyatova to the Osinovskoe sequence 9) overlies the Mikulino sand unit 7 (correlated to Osinovskoe sequence 10). The top of the Mikulino layer is at c. 39 m above sea level (Fig. 8, in Devyatova 1982). The second profile, located at a higher level, 47-61 m above the sea level, comprises of five units, of which the lower cross-bedded shell-rich sand bed (5) represents a marine phase. The mollusc fauna with thin shells includes species *Macoma baltica*, *M. calcarea* and *Littorina littorea*. According to Devyatova's interpretation (1982), the sedimentation during the marine phase occurred during the Early Valdai under more severe conditions than during the previous Mikulino phase (sequence 7 at Ust'-Padenga and sequence 10 at Osinovskoe).

Koleshka (56)

In the Pas'va-Koleshka area, interglacial units have been encountered in several profiles on the right bank of the river Vaga 1.5 kilometres from the village Koleshka and 0.5 kilometre from Pas'va (Devyatova 1982). An upper till has not been found in the profiles (Devyatova 1982, Larsen et al. 1999). Sequences from the Vaga River section at Koleshka have been studied by Vollosovich (1966), Loseva (1973, 1992), Devyatova (1982) and Larsen et al. (1999).

The most complete profile studied by Devyatova (1982) consists of the following main units; 1. Moscovian till and glaciofluvial sediments, 2. Mikulino bed consisting of sand, peat, clay and sand and 3. Valdaian sand and clay beds. The mollusc fauna in the Mikulino sand bed includes species such as *Cyprina islandica* (dominant), *Macoma baltica* and others. Another profile, in which the lithostratigraphy is almost the same as that above, includes a clay / coarse silt bed, which on the basis of its height is assumed to rest on Moscovian varved clay and till found in the profile described by Devyatova and Punning 1976, in Devyatova (1982). The marine mollusc fauna of the bed includes *Macoma baltica*, *M. calcarea*, *Mytilus edulis* and others. The pollen flora from this unit represents the *Betula* and the subsequent *Pinus* phase (Devyatova 1982).

The profiles 3 (Koleshka 2 in Devyatova 1982) and 4 studied by Vollosovich (1966 in Devyatova 1982) and Loseva (1973 and 1992) are situated on the eastern side of the river Vaga, 2-2.5 km down river from the mouth of the river Koleshka. The interglacial sequences are very similar in both of the profiles, including from the base the following: 1. silt with plant debris, 2. coarse silt and 3. fine sand with molluscs. In profile 3, a thin peat block occurs between the coarse silt and sand layer with molluscs. The top of shelly sand is at 48.8 m above the sea level in profile 3 and 50 m in profile 4. Diatoms were only found in the silt and coarse silt sequences. The diatom flora is very similar in both deposits (Loseva 1992). It consists mainly of marine and brackish water types, which indicate low water level. The most common species are *Nitzschia navicularis* (Brébisson) Grunow and *Paralia sulcata* (27 and 17.4% respectively). Other species, which together with those above comprise 83% of the taxa include *Detonula confervacea* (Cleve) Gran, *Cymatosira belgica* Grunow, *Delphineis surirella* (Ehrenberg) Andrews, *Coscinodiscus granulosus*, *Chaetoceros* genera, *Scoliopleura tumida* (Brébisson) Rabenhorst, *Hyalodiscus obsoletus* Sheshuk and *Caloneis westii* (W. Smith) Hendey. The 10 subsequent species: *Paralia arenaria* (Moore) Moiss, *Coscinodiscus perforatus* Ehrenberg, *Porosira glacialis* (Grunow) Joergensen, *Rhizosolenia hebetata* f. *hiemalis* Gran, *Chaetoceros mitra*, *Trachyneis aspera*, *Zygoceros rhombus* Ehrenberg, *Nitzschia ovalis* Arn., *Thalassionema nitzschioides* and *Diploneis interrupta* represent 10 % of the taxa. The remaining 250 identified diatom species represent less than 7 % of the whole assemblage.

According to Loseva (1992), most of the dominant species found from this site are widespread along the coasts of the present northern seas. The southern boreal diatom flora includes *Coscinodiscus asteromphalus* Ehrenberg, *C. nitidus* Gregory, *C. perforatus* Ehrenberg, *Rhaphoneis nitida* (Gregory) Grunow, *Cymatosira belgica*, *Grammatophora hamulifera*, *Diploneis incurvata* (Gregory) Cleve, *D. papula* (A. S.) Cleve, *Pleurosigma normannii* Ralfs, *Amphora acuta* v. *arcuata* Gregory, *A. marina* (W. Smith) V. H. and *Nitzschia bilobata* W. Smith.

According to Devyatova (1982), the silt layer in the Koleshka section 2 (profile 3, in Loseva 1992) corresponds to the basal silt bed in the section Koleshka 4 that represents the *Betula* and the subsequent *Pinus* phase.

In the river section investigated by Larsen et al. (1999) at Koleshka the top of interglacial unit is at c. 48 m above the sea level. The marine interglacial sediments here are overlain by trough and planar cross-bedded fluvial sand with several ice-wedge casts. According to Larsen et al. (1999) this fluvial sand was deposited under periglacial conditions during the Valdai glaciation.

At Pas'va, in profile 1 the top of the interglacial sequence is at c. 58 m above sea level. The sequence includes the following units, from the base, sand, peat, clay, peat with sand wedges and sand. The sequence represents pollen zones KA_3-KA_9/M_3-M_8, of which zone M_{4a} corresponds to the clay bed. The interglacial sequence is overlain by Valdaian units; various types of sand beds with laminated clay on the top (Devyatova 1982).

In profile 2, the interglacial sequence rests on late-glacial deposits (clay and sand) and till of Moscovian age. The lithostratigraphy of the sequence includes the following main units from the base (Devyatova 1982): 1. sand with coarse silt and plant detritus, 2. peat, 3. clay with plant debris (dominantly *Phragmites*), which in the lower part changes to coarse silt and 4. organic bed (peat and coarse silt with humus). The elevation of the top of the Mikulino sequence and the upper limit of the marine clay is 56 m and 55-55.5 m above sea level, respectively (c.f. Fig. 3 in Devyatova 1982). The interglacial sequence includes pollen zones KA_1-KA_8/M_1-M_7 (Fig. 26). The clay layer was deposited during zone M_{4a} (Devyatova 1982).

The diatom flora from the marine clay layer was studied by Zhuzhe and Poretskii (1937) and Loseva (1992). According to Zhuzhe and Poretskii (1937, in Devyatova 1982), the proportion of marine diatoms is 91% of the total diatom flora indicating a marine littoral zone. The diatom flora includes species, which do not live in the present White Sea, such as *Coscinodiscus hauckii* Grunow, *Actionocyclus nebulosus* M. Peragallo, *Tropidoneis elegans* W. Smith, *Navicula forcipata* v. *nummularia* Gregory, *N. humerosa* v. *constricta* Cleve and *N. palpebralis* v. *minor* Grunow. According to Loseva (1992), the diatom flora from the marine clay reveals three phases. The basal part of clay is probably related to lagoonal or bay conditions, including species such as: *Cocconeis placentula* (dominant), *Nitzschia acuminata* (W. Smith) Grunow, *N. navicularis* (Brébisson) Grunow, *N. punctata* (W.Smith) Grunow and *Synedra tabulata*. Further upwards, the abundance of *Nitzschia* species decreases, but the dominat species is *Achnanthes hauckiana*. The marine epiphytic *Catenula adhaerens* Mereschkowsky was also found here.

The subsequent transgressional phase is indicated by an increase in the abundance of brackish water and marine taxa. The species found include the mesohalobous *Nitzschia ovalis* Arnott ex Cleve and the polyhalobous pelagic species *Detonula confervacea* (Cleve) Gran, *Chaetoceros* genera and *Thalassionema nitzschioides*. Further upwards, the pelagic species numbers increase, accounting for over 50 % of the total. The dominant species is *Thalassionema nitzschioides* with mesohalobous *Cyclotella caspia* Grunow, polyhalobous *Detonula confervacea* and *Chaetoceros mitra* and benthonic *Achnanthes hauckiana* and *Nitzschia navicularis*.

In the upper part of the clay, the proportion of pelagic species decreases. *Nitzschia navicularis* is the dominant taxa with *Caloneis westii* (Smith) Hendey and *Paralia sulcata*. Other species frequently found are *Rhizosolenia hebetata* f. *hiemalis* Gran and *Coscinodiscus granulosus*. The taxa indicate a regressive sea phase (Loseva 1992).

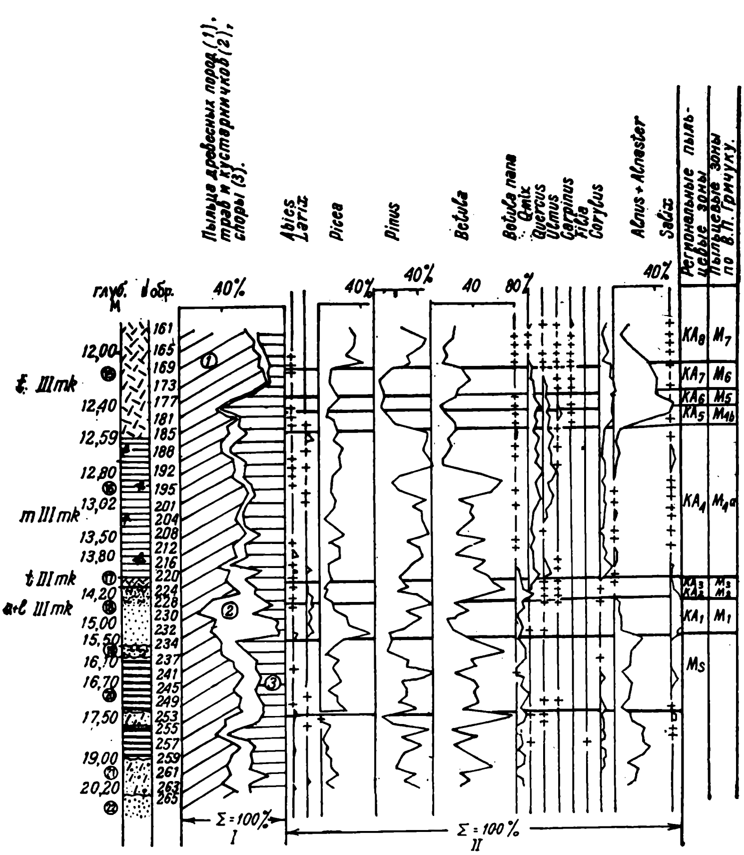


Fig. 26. Pollen diagram from Pas'va 2 (a part of the pollen diagram in Devyatova 1982, fig. 5). Legend: I Total pollen: 1. trees, 2. herbs, graminids and dwarf shrubs, 3. spores. Notations (genesis of sediments and chronostratigraphy) at extreme left: a+l IIImk= alluvial + lacustrine, Mikulino phase, tIIImk= terrestrial, Mikulino phase, mIIImk= marine, Mikulino phase.

White Sea coast

In the White Sea coastal area, between the Severnaya Dvina and Mezen' rivers, marine interglacial deposits are extensively recorded (Biske & Devyatova 1965). Here they are overlain by a last glaciation till or by late-glacial or Holocene sediments. The lithology of the deposits varies from clay and silt to sand with coarse silt and to silt beds or pure sand. The mollusc fauna found in the clay and sand beds includes *Mya truncata* L, *Mytilus edulis* L., *Macoma calcarea* Chemnitz, *Astarte borealis* Chemnitz, *Cyprina islandica* L. and *Cardium groenlandicum* Chemnitz. These species represent a sublittoral and upper sublittoral fauna of rather cold marine water aspect (Biske & Devyatova 1965).

In the watershed area between the Mezen' and Kuloi rivers, the interglacial deposits buried by last glaciation till reflect a deep phase of the Boreal transgression (according to Markina, in Biske & Devyatova 1965).

Moscovian late-glacial sediments and/or tills have been detected in the sequences at Izma, Chelmokhta, Krasnaya gorka, Pas'va and Koleshka. The marine deposits in the northeastern part of the Severnaya Dvina basin at Izma is at 7.5 m below sea level, while the deposits of the Severnaya Dvina and Vaga area vary from the sea level (Shenkursk) to 55.5 m (Pas'va) a.s.l. According to Devyatova (1982), the maximum height of the marine sediments in the Severnaya Dvina basin is 60 m above sea level. Terrestrial Mikulino sediments have been found at Pas'va-Koleshka, in which a marine clay bed is interbedded with a peat layer. In the lower course of the Severnaya Dvina, the interglacial sequences consist of deep-water clay, but in the middle course of the Severnaya Dvina and Vaga rivers they comprise sand and coarse silt (Fig. 27). The early phases of the Boreal transgression, corresponding to pollen zones M_1-M_2, are represented in the Severnaya Dvina and Vaga basins at Krasnaya gorka, Shenkursk and Koleshka. The peat beds in the Pas'va-Koleshka sections relate to pollen zones M_3 (the lower peat) and M_{4b} (the upper peat) and the clay unit to pollen zone M_{4a}. Thus the Pas'va site was already isolated from sea in pollen zone M_{4b}, but at Shenkursk and Osinovskoe the marine phase continued to the end of the Mikulino interglacial.

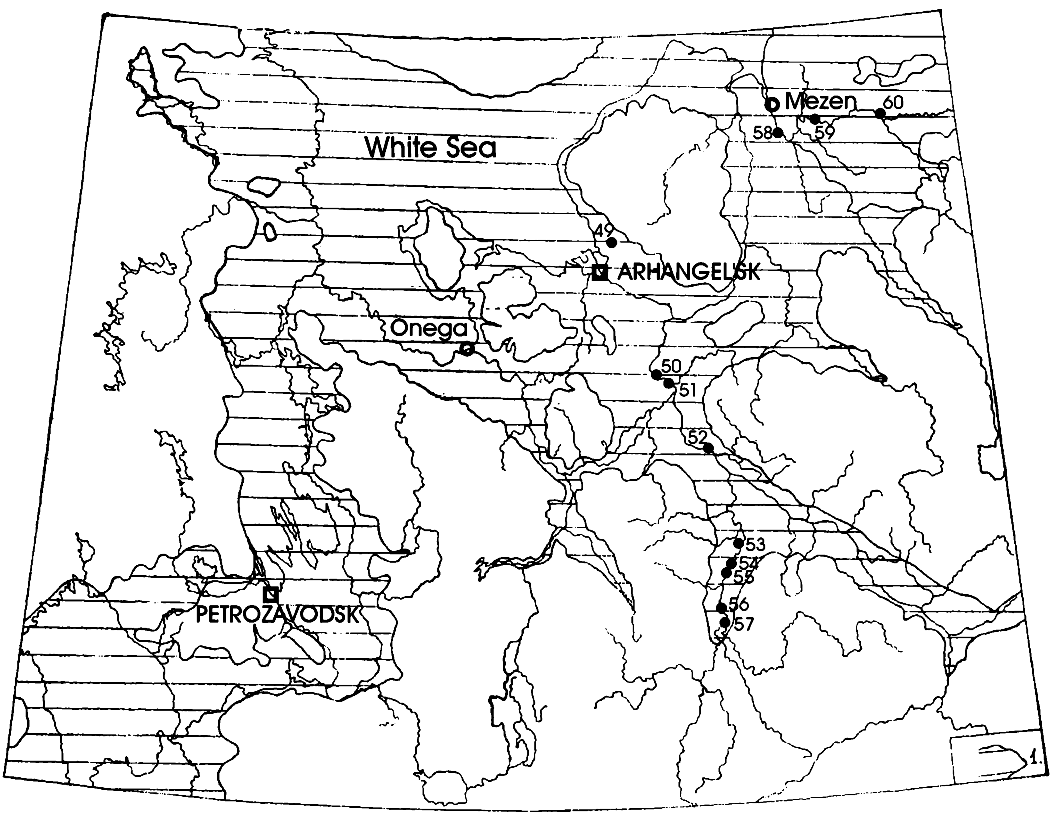


Fig. 27. Marine submergence during the Mikulino interglacial (Devyatova 1982 fig. 30). Numbers refer to the sites described in the text.

MEZEN'-PYOZA AREA

The description is based on the studies by Biske & Devyatova (1965), Loseva (1968, 1992), Devyatova (1982), Abrukina & Krasilnikova (1972), Molodkov & Raukas (1988), Miller & Mangerud (1985) and Svendsen et al. (1999).

The interglacial sediments exposed in the lower course of Mezen' and Pyoza rivers (Bych'e and Zaton) consist of clay and silty sand, and in the middle course of the Pyoza river at Pyoza 30a section they comprise of sand. The deposits on the banks of the Pyoza river are deep-water clay that changes upwards into sand, the top of which is eroded. The interglacial sequences are covered by glaciofluvial sands of the last glaciation (Biske & Devyatova 1965).

Zaton (58) and Bych'e (59)

The Zaton interglacial site is situated on the left bank (height 12-13 m) of the river Mezen'. The nearby Bych'e site is located on the right bank (height 14 m) of the river Pyoza (Devyatova 1982). These interglacial deposits in Bych'e range from 14 m to 20 m. The interglacial sequence at both sites is overlain by Valdai marine sands. Till beds have not been seen in the sections. The basal layer of the interglacial sequence at both sites consists of clay with abundant Mollusca: *Astarte borealis* Chemn., *A. borealis* v. *placenta* Mörch., *A. elliptica* Brown, *Cardium ciliatum* Fabr., *Cyprina islandica* L., *Saxicava arctica* L., *Mya truncata* L., *Pecten islandicus* Müll and *Neptunea despecta* L. (Devyatova & Loseva 1964 and Devyatova 1982). The basal layers were formed during early stages of the interglacial (corresponding to pollen zones KA_1-KA_4/M_1-M_4 (Figs. 28 and 29). The upper part of the sequence is composed of silty sand, where the dominant Mollusca include *Macoma baltica* L., *M. calcarea* Chemitz., *Mactra elliptica* Brown, *Mytilus edulis* L., *Littorina littorea* L., *Cardium edule* L. v. *rusticum* and *C. fasciatum* Mont. The silty sand bed were deposited during pollen zones KA_5-KA_8/M_{4b}-M_7.

Foraminifera from the lower part of the clay sequence at Zaton include 20 species (Abrukina and Krasilnikova 1972). The species found most abundantly is the arctic taxon *Cassidulina teretis* Tappan, 70-80% of the total taxa. The rest of the assemblage comprises species such as *Elphidium subclavatum* Gudina, *E. groenlandica* Cushman, *Cassidulina norcrossi* Cushman, *Angulogerina angulosa* Williamson and *Nonion labradoricum* Dawson. In the upper part of clay and the lower part of silty sand, the number of species decreases. The dominant types are *Cibicides rotundatus* Shschedrina 50%, *Elphidium subclavatum* 20% and *Cassidulina teretis* Tappan 15 %. Higher in the silty sand, the proportion of *Cibicides rotundatus* reaches 50-80%. The other more commonly found species are *Cassidulina teretis*, *E. subclavatum*, *E. subarcticum* Cushman and *E. excavatum* Terquem (Abrukina and Krasilnikova 1972).

Absolute dates have been obtained from these sites using ESR dating from mollusc shells. The Zaton marine beds cover the time span 82 000 ± 6000 to 120 000 ± 8000 years (Molodkov and Raukas 1988). The shells dated are from the upper silty sand bed, which corresponds to pollen zones M_5-M_7. According to Miller and Mangerud (1985), the mean D/L ratio from mollusc shells collected from the silty sand bed give 0.051 ± 0.006 which is slightly higher than expected, but relate to an Eemian age. The thermoluminescence dating of sands beneath a Weichselian till in the Arkhangel'sk district gave an age 93 ka (Hütt et al. 1985 in Miller & Mangerud 1985).

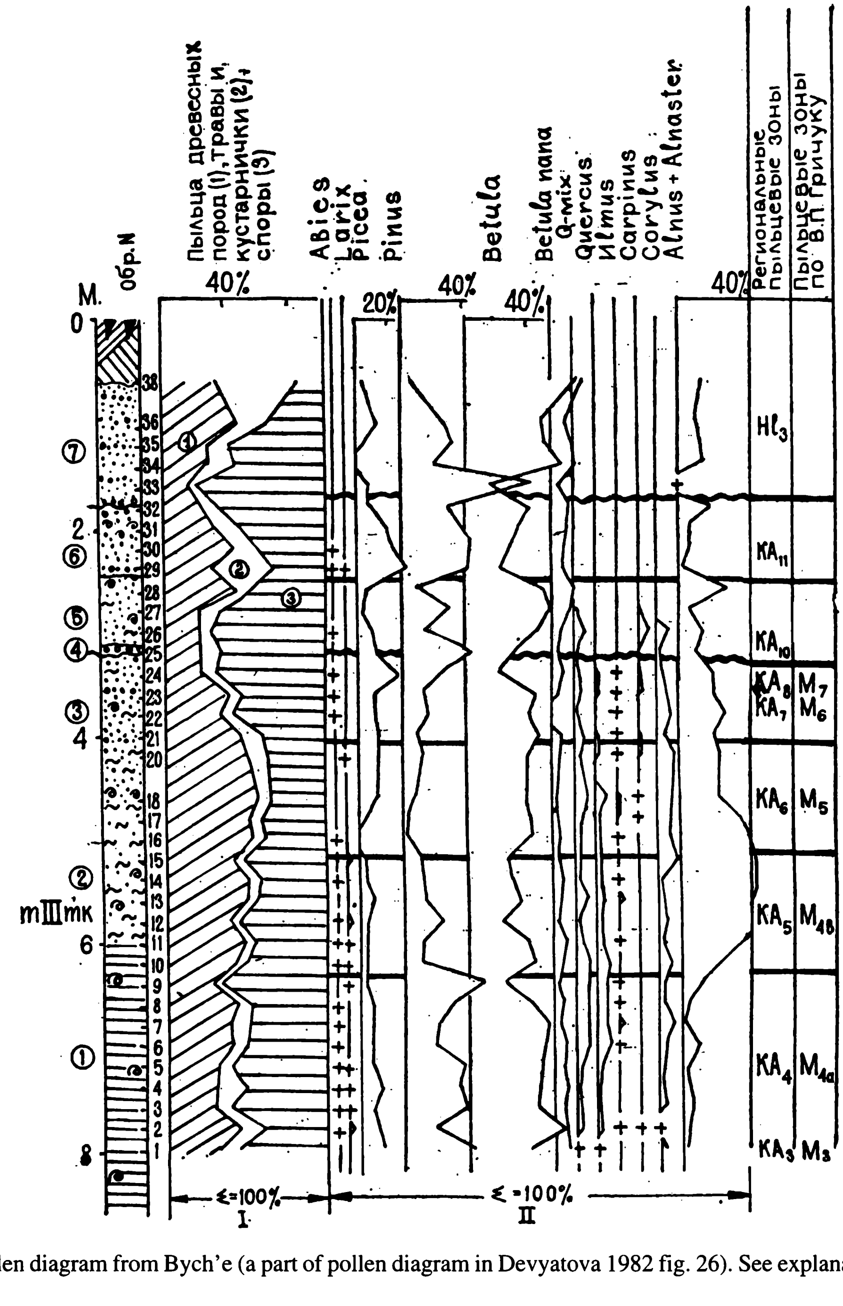


Fig. 28. Pollen diagram from Bych'e (a part of pollen diagram in Devyatova 1982 fig. 26). See explanations in Fig. 24.

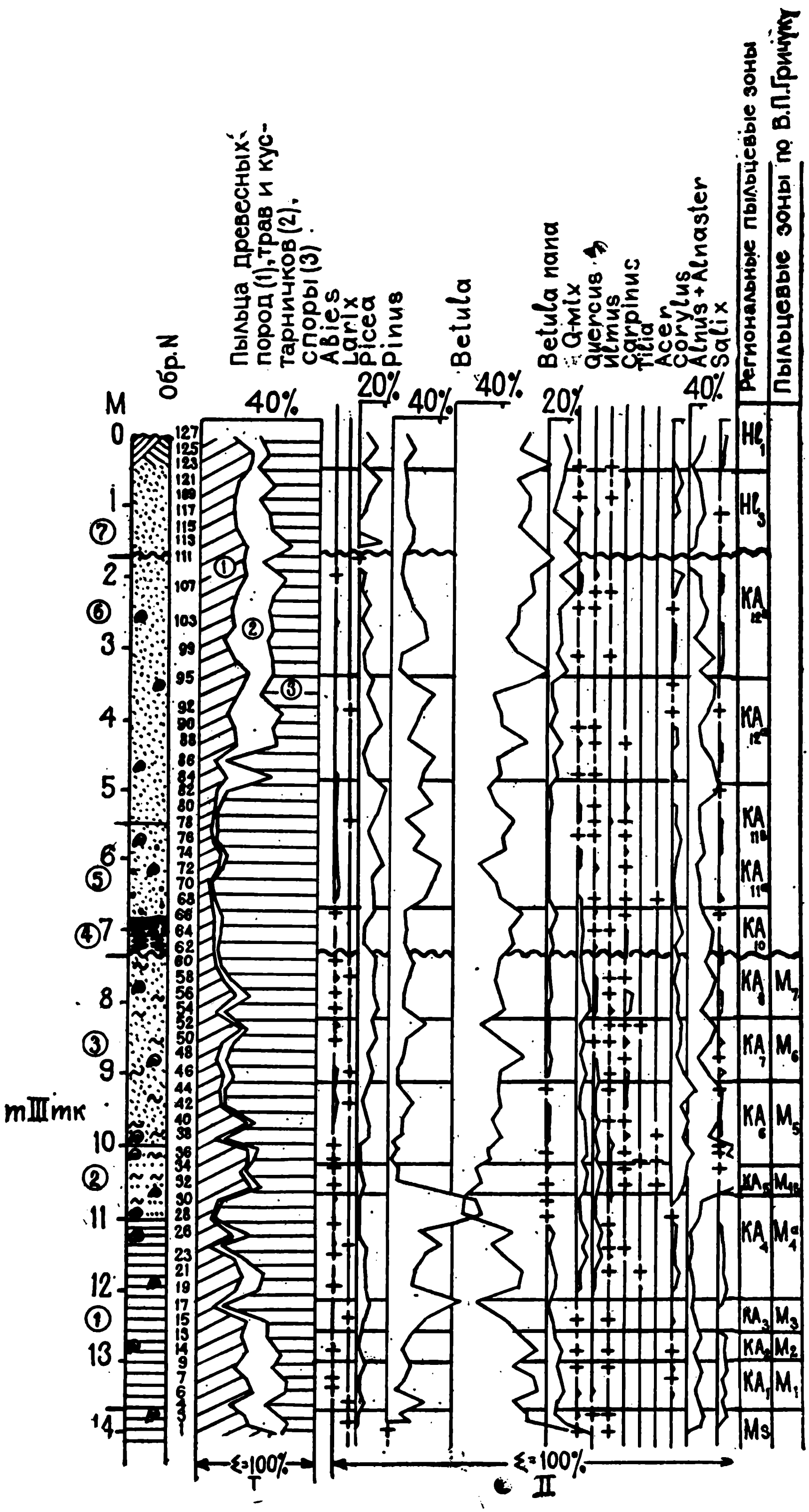


Fig. 29. Pollen diagram from Zaton (a part of pollen diagram in Devyatova 1982 fig. 27). See explanations in Fig.24.

Pyoza

The interglacial site Pyoza 30a occurs on the third terrace of the Pyoza river, 156 km east of the mouth of the river and 9 km down the river Orlovets (Loseva 1968, 1992). Here the interglacial marine sequence, 8 m thick, consists of fine sand and silt with molluscs. The sequence is covered by till (Loseva 1968). The top of marine sequence is at 43 m above sea level. *Betula* and *Alnus* dominate pollen flora, whilst *Picea*, *Pinus* and temperate deciduous tree pollen are found throughout the sequence (Biske & Devyatova 1965). According to Loseva (1968), the pollen assemblage reflects interglacial vegetation. The diatom flora consists of marine (82.8%) and freshwater species (17.2%) (Loseva 1968, 1992). The dominant species is *Paralia sulcata*. Other species found (in varying quantities) include *Podosira stelligera* (Bailey) Mann, *Cymatosira belgica* Grunow, *Rhaphoneis rhombica* (Grunow) Andrews, *Delphineis surirella* (Ehrenberg) Andrews, *Navicula distans* W. Smith, *Zygoceros rhombus* Ehrenberg, *Plagiogramma staurophorum* (Greg.) Heib., *Actinoptychus senarius* Ehrenberg, *Rhaphoneis amphiceros* Ehrenberg, *Rhabdonema arcuatum* and *Lyrella abrupta* (Gregory) Karayeva. The proportion of planktonic species is limited. The main part of the flora consists of species, which are widely distributed along the coasts of the present-day northern seas. According to Loseva (1992), the diatom flora indicates the littoral zone of a shallow water body.

In addition to the species above, the diatom assemblage contains species which favour warmer water than in the present White Sea such as *Glyphodesmis distans* (Gregory) Grunow, *Opephora schwartzii* (Grunow) Petit, *Diploneis chersonensis* (Grunow) Cl., *D. crabro* Ehrenberg, *Navicula lyra* v. *subelliptica* Cleve, *N. monilifera* v. *heterosticha* Cleve, *Nitzschia granulata* Grunow and *N. navicularis* (Brébisson) Grunow. Species which favour cold waters such as *Porosira glacialis* (Grunow) Joergensen, *Coscinosira polychorda* Grunow, *Thalassiosira gravida*, *Coscinodiscus curvatulus* Grunow, *Grammatophora arctica* and *Nitzschia polaris* Grunow are also recorded.

Loseva (1992) noted that the diatom flora in the Pas'va and Koleshka deposits is similar. In both sites, species such as *Porosira glacialis*, *Detonula confervacea*, *Thalassionema nitzschioides* and *Caloneis westii* were found while they are absent in the Pyoza deposits. On the other hand, the species such as *Podosira stelligera* and *Rhabdoneis rhombica* are found 'often' in Pëza but are not present in Pas'va and Koleshka deposits. The species that are common in all three deposits include *Hyalodiscus obsoletus*, *Zygoceros rhombus*, *Cymatosira belgica* and *Delphineis surirella*.

The number of diatom species in common with Petrozavodsk site 1 and the Pas'va, Koleshka and Pyoza sections is 50 (of which 28 are marine), 68 (43) and 37 (26) species, respectively.

Regional summary

A till covering the interglacial units has been found in the Pyoza 30a section. In the lower course of Mezen' and Pyoza river interglacial units are composed of clay and sand. In the middle course of Pyoza river, the interglacial unit is composed of fine sand and silt. The elevation of the interglacial units at Mezen' and Pyoza ranges from 20 m to 43 m a.s.l. The early phases of the Boreal transgression, covering the pollen zones M_1-M_2, are present in the Mezen-Pyoza area at Bych'e. In the lower course of Mezen' and Pyoza rivers the marine phase continued throughout the entire Mikulino interglacial (Fig. 30).

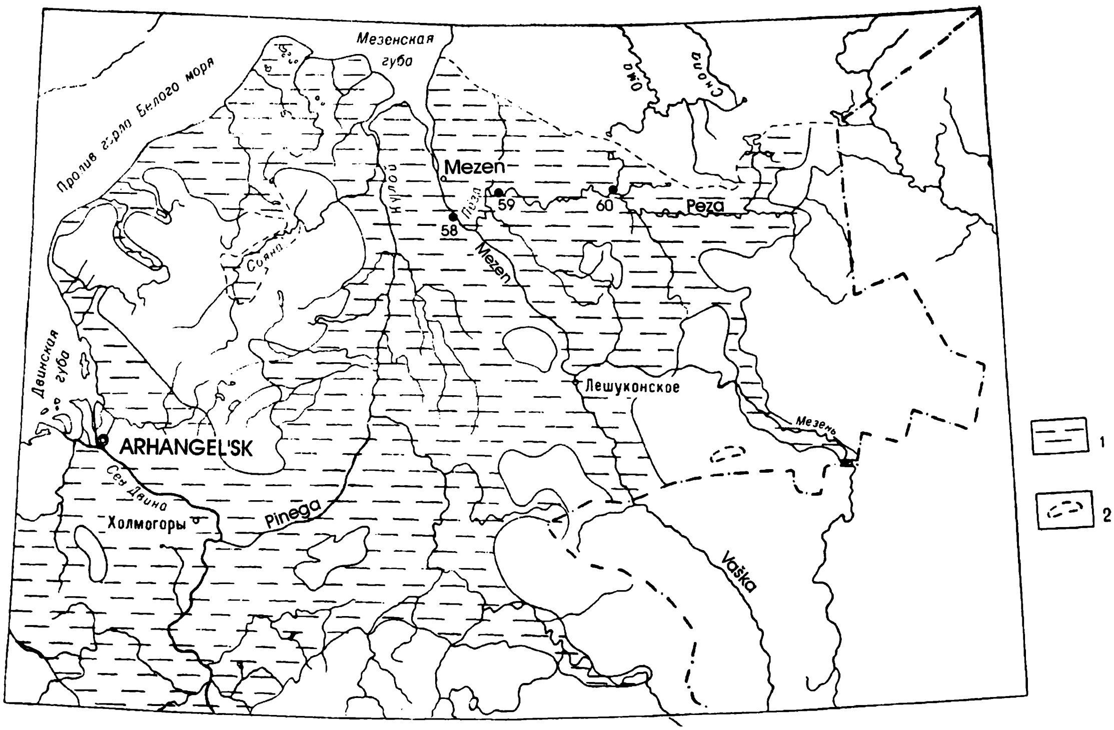


Fig. 30. Schematic map showing the extent of the Boreal transgression in the Severnaya Dvina, Kuloi and Mezen basins (Legkova 1967 fig. 31. Legend: 1. Extent of the boreal transgression sediments, 2. boundary of the boreal transgression proposed by Legkova. Numbers (58-60) refer to the sites described in the text.

DISCUSSION

Vegetational history

Paleobotanical evidence from the European part of northern Russia reflects the successive changes in forest composition during the Mikulino/Eemian interglacial stage. In the southwestern part of the area, birch-pine forests, in the southeast coniferous and in the north, birch forests dominated during the pre-temperate substages (M_1-M_3) of the interglacial. In the Onega River area, where the succession can be compiled from several sections, birch and alder have a major role in the early phases of the interglacial. On the Kola Peninsula, where complete sections are lacking, the initial vegetation cover was tundra and forest-tundra associations.

In the following substages, thermophilous associations became prevalent in response to the improving climatic conditions. The most characteristic feature is the succession of temperate deciduous trees over large areas. According to Grichuk (1984), the characteristics of the vegetation revealed in the diagrams are typical of the entire Eastern European Plain from latitude 47° N to 62° N. However, regional (even local) differences in the succession of oak (*Quercus*) - elm (*Ulmus*) - hazelnut (*Corylus*) – lime (*Tilia*) and hornbeam (*Carpinus*) can be distinguished in the study area. The proportion of *Tilia* pollen is very low and discontinuous, and therefore a *Tilia* peak can hardly be distinguished. A similar dilemma concerns the

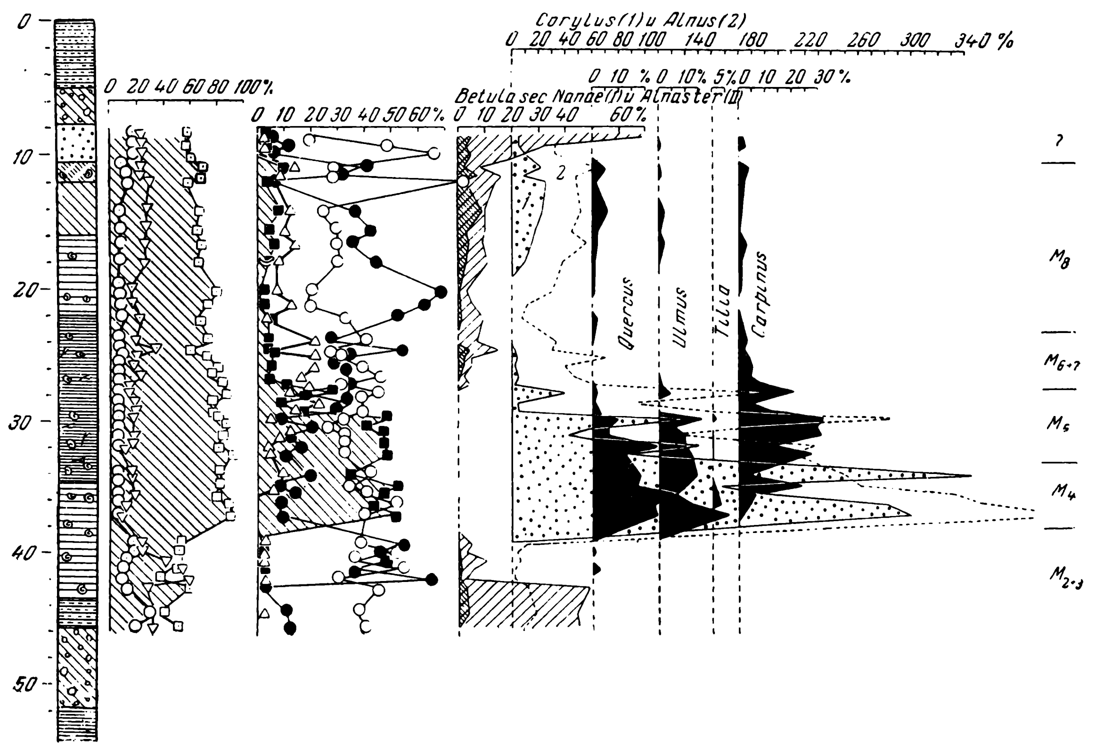


Fig. 31. Pollen diagram from Rybatskoe according to Lavrova & Grichuk 1960 (Grichuk 1961, fig. 11).

abundance of all the temperate tree pollen in the pollen diagrams from the Severnaya Dvina, Vaga, Mezen' and Pyoza area. On the Kola Peninsula and the Onega river area, the succession cannot be determined because of the lack of complete sequences.

On the Karelian Isthmus, on the Ladoga-Onega isthmus and in the Leningrad region, the maximum occurrence of *Quercus* and *Ulmus* coincides with the *Corylus* peak (e.g at Krasnosel'skoe, Sinyavino, Rybatskoye, Verkhnie Vazhiny, Fig. 31) or is just before the *Corylus* peak (e.g. at Mga, Vidlitsa, Vasilevski Bor). The maximum occurrence of *Carpinus* occurs simultaneously with the upper *Picea* maximum (at Krasnosel'skoe, Sinyavino) or predates it (at Mga, Rybatskoe, Vidlitsa, Vasilevski Bor). At the Petrozavodsk site 1, *Quercus* and *Ulmus* pollen are only found sporadically and the maximum occurrence of *Carpinus* pollen is concentrated in the lower part of the upper *Picea* maximum. The maximum proportion of temperate deciduous trees during the climatic optimum is 40% on the Karelian Isthmus, 34-70% in the Leningrad region, 20-45% in southern Karelia, 18% in the Onega river area, 10-28% in the Severnaya Dvina - Vaga area and 18% in the Mezen' - Pyoza area.

In the post-temperate substages of the Mikulino, the deciduous forests were progressively replaced by spruce and pine forests; in some places first by spruce and in others simultaneously by both species. The pollen zones M_7-M_8 represent the coniferous forest optimum.

In the northeastern area (at Pas'va, Shenkursk, Krasnaya Gorka, Izma) *Picea* is an important component in the forest vegetation throughout the whole interglacial (a continuous *Picea* curve is seen in all diagrams). On the other hand, a two-fold partition of the *Picea* curve is present in many pollen diagrams from the regions in southwest (at Mga, Sinyavino, Rybatskoe, Vasilevski Bor, Vidlitsa, Petrozavodsk). However, the lower *Picea* maximum (zone M_1), characteristically found in terrestrial sequences from the sites farther to the south (Grichuk 1961), is rarely clearly apparent in the sites, in which sedimentation occurred in large glaciolacustrine basins. The upper empirical limit of spruce varies: from the upper part of the M_4 zone (at Mga, Rybatskoe) to the upper part of the M_6 zone (at Vasilevski Bor). At the Petrozavodsk site 1, the continuous *Picea* curve begins in the *Alnus-Corylus* zone. By contrast, *Betula* played a major role in the forest composition almost throughout the Mikulino interglacial in the Mezen' and Pyoza river area (at Zaton and Bych'e).

The end of the interglacial is marked by a decline of coniferous forests in favour of birch. With respect to the dwarf-shrubs and herbs, the increase of *Betula nana*, Ericaceae, Cyperaceae and Gramineae is assigned to this phase. However, in several deposits minerogenic sediments above the interglacial units include reworked interglacial flora, which hamper the precise identification of the Mikulino/Valdai boundary.

Boreal transgression

Prior to the inflow of marine waters, large glaciolacustrine basins existed along the periphery of the Fennoscandian shield (Lavrova 1948, in Biske 1959; Cheremisinova 1961). According to Lavrova (1948), isolated basins were formed in the Gulf of Finland, the Ladoga and Onega basins, but Cheremisinova (1961) assumed that the basins were connected by sounds. The proxy data indicate that an inflow of marine waters in the peripheral zone of the Fennoscandian shield occurred in the pre-temperate substage of the Mikulino interglacial. In the Leningrad region, at Sinyavino the glaciomarine phase is already represented at the transition from the Moscovian late-glacial to the Mikulino interglacial (Cheremisinova 1960). The analogous phase at Mga is defined near to the c/d pollen zone boundary (after Jessen & Milthers, M_2/M_3 in Grichuk's zonation) (Znamenskaya 1959, Cheremisinova 1960). At Petrozavodsk, in the Lake Onega basin, the first marine pulse is found in the pollen zone M_1. Glaciomarine sediments are also detected in the lower course of the Severnaya Dvina and in the White Sea coast area, between Severnaya Dvina and Mezen'. In the Vaga river basin, the sediments below the interglacial units are of glaciolacustrine origin (Devyatova 1982).

At Mga and at Sinyavino, in the Leningrad region, the glaciomarine basin developed first into a lagoonal environment, prior to the fully marine phase. The transgession here coincides at both sites within pollen zone M_4 and the regression with the pollen zone M_6 (Cheremisinova 1960). In the Karelian Isthmus, at Krasnosel'skoe, the marine phase covers pollen zones M_2-M_7. The isolation here occurred at the M_7/M_8 pollen zone boundary (Sokolova et al. 1972). At the sites lying at lower elevations (Vasilevski Bor), in the Ladoga-Onega isthmus the marine phase was probably already initiated during pollen zones M_1-M_2 and continued until the pollen zone M_7. At higher elevation sites e.g. Vidlitsa, the isolation already had occurred at the M_6/M_7 zone boundary (Devyatova 1982).

The marine phase proper began in the Lake Onega basin in pollen zones M_2-M_3 (*Pinus-Betula*) and continued until the upper part of the M_6 (*Picea-Alnus-Carpinus*) zone, when the regression began. Isolation of the Onega basin occurred at the beginning of the *Picea-Pinus*/M_7 zone, when the connection to the White Sea basin was closed. These new results demostrate that the marine phase is longer than suggested earlier by Devyatova (1972) and contradicts the concept of a shorter duration of an open passage between the Eemian Baltic and the White Sea basins proposed by Funder et al. (1998).

On the northern and eastern coasts of the Kola Peninsula, the marine phase began in the tundra zone, that represents the earliest substage of the interglacial. The regressional phase on the southern coast corresponds to the coniferous forest zone and on the eastern coast to the tundra zone (Gudina & Yevzerov 1973). The inflow of marine waters into the Onega river basin as far as Demenino, occurred in the early part of the interglacial, in the *Betula-Alnus* pollen zone (Devyatova 1961).

In the Severnaya Dvina depression in the Arkhangel'sk region, the marine phase spans the entire Mikulino interglacial pollen zones M_1-M_8. The inflow of marine waters reached the Koleshka site in the Vaga river basin in the early pre-temperate substage (M_1-M_8) and the Pas'va site at the beginning of climatic optimum (M_{4a}). At Pas'va, the regression already began during pollen zone M_{4b}, but at Shenkursk and Osinovskoe, the marine phase was prolonged to the end of the interglacial (Devyatova 1982). In contrast, the marine conditions remained throughout the Mikulino interglacial in the lower course Mezen' and Pyoza rivers.

Extent of the Boreal transgression

The Mikulino/Eemian Boreal transgression covered the vast shoreline areas of the Barents and White Sea and penetrated several hundred kilometres into the interior of the European Russian Plain. In the Vaga river valley, the sea extended as far as Pas'va. However, in the Mezen' and Pyoza river area, the sea failed to penetrate as far inland as in the Severnaya Dvina and Vaga basins. The connection between the Onega River and the Severnaya Dvina basin was formed through the valleys of the Yemtsa and Kodina rivers. In the Onega river basin the sea extended to the south near Lake Lacha and to the Mosha River, near Lake Moshozero. A connection to the west to the Lake Onega basin probably run via the Kenozero-Vodla water routes. To the west of the Onega River the shoreline was bordered by the high land southwest of the Onega bay. The Barents Sea was connected through a sound across the Masel'ga threshold between the Lakes Segozero and Vygozero to the Onega-Ladoga basins and to the Baltic Sea. On the Kola Peninsula during the maximum trasgression the the Imandra and Umbozero-Lovozero basins were connected to the Barents Sea and to the White Sea through sounds formed via depressions i.e. the main part of the Kola Peninsula was an island.

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DIATOM TAXA IDENTIFIED FROM THE PETROZAVODSK SITE 1

Polyhalobous taxa

A. septata A. Cleve
Actinoptychus senarius (Ehrenberg) Ehrenberg (= *A. undulatus* (Bailey) Ralfs)
C. quarnerensis (Grunow) A. Schmidt
Coscinodiscus apiculatus Ehrenberg
C. granulosus Grunow
C. kützingii A. Schmidt et v. *glacialis* Grunow
C. obscurus A. Schmidt
C. oculus iridis Ehrenberg
C. plicatus Grunow
Thalassiosira leptopa (Grunow) Hasle et Fryxell (= *Coscinodiscus lineatus* Ehrenberg)
Coscinodiscus sp.
Chaetoceros affinis Lauder
Ch. amanita Cleve
Ch. coronatus Gran
Ch. mitra (Bailey) Cleve
Ch. seiracanthus Gran
Diploneis constricta (Grunow) Cleve
Grammatophora arctica Cleve
G. arcuata Ehrenberg
G. hamulifera Kützing
G. marina (Lyngbye) Kützing
Licmophora juergensii Agardh
Navicula glacialis (Cleve) Grunow
Opephora marina (Gregory) Petit
Plagiogramma staurophorum (Gregory) Heiberg
Rhizosolenia serigera v. *arctica* I. Kiss
Rhoicosphenia marina (W. Smith) M. Schmidt
Thalassionema nitzschioides Grunow
Thalassiosira gravida Cleve
Trachyneis aspera (Ehrenberg) Cleve
Tr. aspera v. *contermina* A. Schmidt

Meso- and Mesopolyhalobous taxa

Achnanthes brevipes v. *intermedia* (Kützing) Cleve
A. taeniata Grunow
A. octonarius v. *crassus* (W. Smith) Hustedt (=*Actinocyclus ehrenbergii* Ralfs et v. *crassus* (W. Smith) Hustedt
A. octonarius v. *tenellus* (Brébisson) Hendey (= *A. ehrenbergii* v. *tenella* (Brébisson) Hustedt)
Cocconeis scutellum Ehrenberg
C. scutellum v. *ineoquaterpunctata* Missuna
C. scutellum v. *parva* Grunow
C. scutellum v. *stauroneiformis* Grunow
C. jonesianus v. *comutatus* (Grunow) Hustedt (= *C. comutatus* Grunow)
Coscinodiscus lacustris v. *septentrionalis* Grunow
C. subsalsus Juhlin-Dannfelt
Ch. holsaticus Schütt
D. didyma (Ehrenberg) Cleve
D. interrupta (Kützing) Cleve
D. smithii (Brébisson) Cleve
G. oceanica v. *oceanica* (Ehrenberg) Grunow
G. oceanica et v. *subtilissima* (Bailey) Hustedt

Hyalodiscus scoticus (Kützing) Grunow
Petroneis marina (Ralfs) Mann (=*N. punctulata* W. Smith*)*
Paralia sulcata (Ehrenberg) Cleve (= Melosira sulcata (Ehrenberg) Kützing)
Rhabdonema arcuatum v. *arcuatum* (Lyngbye) Kützing
Rh. arcuatum v. *robustum* (Grunow) Hustedt
Rh. arcuatum v. *ventricosa* Cleve
Rh. minutum Kützing
Rhoicosphenia curvata (Kützing) Grunow
Tabularia tabulata (Agardh) Williams & Round (=*Synedra tabulata* (Agardh) Kützing) et *Synedra obtusa* Pant
Tabularia tabulata (Agardh) Williams & Round (=*Synedra tabulata* (Agardh) Kützing) et varieties

Oligohalobous taxa

Achnanthes
A. borealis A. Cleve
A. conspicua A. Mayer
A. conspicua v. *brevistriata* Hustedt
A. exiqua Grunow
A. exiqua v. *exiqua Grunow*
A. exiqua v. *capitata* Hustedt
A. exiqua v. *heterovalva* Krasske
A. hankensis Skvortzov
A. hastata Skvortzov
A. koshovii Jasnitsky
A. kryophila J. B. Petersen
A. oestrupii (A. Cleve) Hustedt
A. striata Skvortzov
A. suchlandtii Hustedt
Karayevia laterostrata (Hustedt) Round & Bukhtiyarova (= *Achnanthes laterostrata* Hustedt)
Planothidium calcar (Cleve) Round & Bukhtiyarova (= *Acnanthes calcar* Cleve)
Planothidium ellipticum (Cleve) Round & Bukhtiyarova (= *Achnanthes lanceolata* var. *elliptica* Cleve)
Planothidium haukianum Round & Bukhtiyarova (= *A. hauckiana* Grunow)
Planothidium lanceolatum (Brébisson) Round & Bukhtiyarova (= Achnanthes lanceolata (Brébisson*)* Grunow
Planothidium rostatum (Oestrup) Round & Bukhtiyarova (= *Achnanthes lanceolata* v. *rostrata* (Oestrup) Hustedt
Rossithidium linearis (Smith) Round & Bukhtiyarova (=*Achnanthes linearis* (W.Smith) Grunow
Amphora libyca Ehrenberg (= *Amphora ovalis* v. *libyca* (Ehrenberg) Cleve)
A. mongolica Östrup
A. mongolica v. *gracilis* Skvortzov
Asterionella gracillima (Hanztsch) Heiberg
A. formosa Hassal
Aulacoseira ambiqua (Grunow) Simonsén (= *Melosira ambiqua* (Grunow) Müller)
A. granulata (Ehrenberg) Simonsén (= *Melosira granulata* v. *granulata* (Ehrenberg) Ralfs)
A. granulata v. *angustissima* (O. Müller) Simonsén (= *Melosira granulata* v. *angustissima* (Müller) Hustedt
A. distans v. alpigena (Grunow) Simonsén (= *Melosira distans* v. *alpigena* Grunow)
A. distans et v. *alpigena* (Grunow) Simonsen (= *Melosira distans* (Ehrenberg) Kützing et v. *alpigena* Grunow)
A. islandica (includes morfotype *helvetica*) O.Müller (= *Melosira islandica* subsp. *helvetica* O. Müller)
A. italica (Kützing) Simonsen (= *Melosira italica* (Ehrenberg) Kützing)
A. italica (Kützing) Simonsén (= *Melosira italica* v. *italica* (Ehrenberg) Kützing)
A. subarctica (O. Müller) Simonsén (= *Melosira italica* subsp. *subarctica* O. Müller)
A. tenuissima (Grunow) Simonsén (= *Melosira italica* v. *tenuissima* (Grunow) O. Müller
A. valida (Grunow) Simonsén (= *Melosira italica* v. *valida* (Grunow) Hustedt)
Ellerbeckia arenaria (Moore) Crawford (= *Melosira arenaria* Moore)
Melosira scabrosa Oestrup
Caloneis bacillum (Grunow) Mereschkowsky
C. ventricosa (Ehrenberg) Meister (= *C. silicula* v. *silicula* (Ehrenberg) Cleve)
C. ventricosa v. *truncatula* (Grunow) Meister (= *C. silicula* v. *truncatula* Grunow)

Cocconeis disculus (Schumann) Cleve
C. disculus v. *diminuta* (Pantocsek) Scheshukova
C. placentula Ehrenberg
C. placentula v. *euglypta* (Ehrenberg) Cleve
C. placentula v. *intermedia* (Herib. et Perag.) Cleve
C. pediculus Ehrenberg
Cyclotella comta (Ehrenberg) Kützing
C. kützingiana Thwaites
C. kützingiana v. *schumannii* Grunow
C. meneghiniana Kützing
C. meneghiniana v. *hankensis* Skvortzov
Cymatopleura librile (Ehrenberg) Pantocsek (= *Cymatopleura solea* v. *subconstricta* O. Müller)
Cymbella aequalis W. Smith
C. affinis Kützing
C. amphicephala Naegli.
C. aspera (Ehrenberg) Peragalli
C. borealis Cleve
C. cymbiformis Agardh
C. ehrenbergii (Kützing) Van Heuck
C. hustedtii Krasske
C. lanceolata (Ehrenberg) Van Heuck
C. naviculiformis Auerswald
C. parva (W. Smith) Cleve
C. tumidula Grunow
C. turgidula Grunow
C. minuta v. *minuta* Hilse ex Rabenhorst (= *C. ventricosa* Kützing)
Encyonema hebridicum Grunow ex Cleve (=*Cymbella hebridica* (Gregory) Grunow
E. prostratum (Berkeley) Kützing (=*Cymbella prostrata* (Berkeley) Cleve)
E. turgidum (Gregory) Grunow & Schmidt (= *Cymbella turgida* (Gregory) Cleve)
Reimeria sinuata (Gregory) Koliolek & Stoermer (= *Cymbella sinuata* Gregory)
Diatoma elongatum (Lyngbye) Agardh
D. vulgare v. *vulgare* Bory
D. vulgare v. *ehrenbergii* (Kützing) Grunow
D. vulgare v. *linearis* Grunow
Denticula tenuis v. *tenuis* Kützing
D. tenuis v. *crassula* (Naegli) Hustedt
Didymosphenia geminata (Lyngbye) M. Schmidt
Diploneis domblittensis (Grunow) Cleve
D. domblittensis v. *subconstricta* A. Cleve
D. elliptica (Kützing) Cleve
D. finnica (Ehrenberg) Cleve
D. ovalis (Hilse) Cleve
D. parma Cleve
D. subovalis Cleve
Epithemia adnata (Kützing) Brébisson (= *Epithemia zebra* (Ehrenberg) Kützing
E. adnata v. *porcellus* (Kützing) Ross (= *Epithemia zebra* v. *porcellus* (Kützing) Grunow)
E. adnata v. *saxonica* (Kützing) Patrick & Reimer (= *Epithemia zebra* v. *saxonica* (Kützing) Grunow
E. argus (Ehrenberg) Kützing
E. argus Kützing var. *argus*
E. argus v. *angustata* Fricke
E. argus v. *alpestris* (Grunow) Hustedt
E. hyndmannii W. Smith
E. hyndmannii v. *curta* Skvortzov et Mayer
E. sorex v. *sorex* Kützing
E. sorex v. *gracilis* Hustedt
E. turgida v. *turgida* (Ehrenberg) Kützing

E. turgida et v. *granulata* (Ehrenberg) Grunow
Epithemia sp. sp.
Eunotia arcus v. *arcus* Ehrenberg
E. arcus v. *bidens* Grunow
E. baicalensis Skvortzov
E. diodon Ehrenberg
E. faba (Ehrenberg) Grunow
E. flexuosa Kützing (= *E. formica* Ehrenberg)
Eunotia pectinalis v. *minor* (Kützing) Rabenhorst
E. incisa Gregory (= *E.veneris* (De Toni) O. Müller)
E. monodon Ehrenberg
E. pectinalis v. *pectinalis* (Kützing) Rabenhorst
E. praerupta v. *praerupta* Ehrenberg
E. praerupta v. *muscicola* Boye
E. septentrionalis Oestrup
E. serra Ehrenberg (= *E. robusta* Ralfs)
E. robusta v. *tetraodon* (Ehrenberg) Ralfs
E. sudetica v. *bidens* Hustedt
E. tenella (Grunow) Hustedt
Fragilaria heidenii Oestrup (= *F. inflata* (Heiden) Hustedt)
F. spinosa Skvortzov
F. virescens v. *oblongella* Grunow
F. virescens v. *subsalina* Grunow
Fragilariforma virescens (Ralfs) Williams & Round (= *Fragilaria virescens* Ralfs)
F. virescens et varieties (Ralfs) Williams & Round (= *F. virescens* Ralfs v. *virescens* et varieties)
F. bicapitata (A. Mayer) Williams & Round (= *Fragilaria bicapitata* A. Mayer)
Staurosira construens (Ehrenberg) Grunow v. *construens* et varieties
Staurosira construens (Ehrenberg) Williams & Round (= Fragilaria construens (Ehrenberg) Grunow)
Staurosirella leptosauron (Ehrenberg) Williams & Round (=*F. leptosauron* (Ehrenberg) Hustedt)
Staurosirella pinnata (Ehrenberg) Williams & Round (= *Fragilaria pinnata* Ehrenberg)
Gomphonema acuminatum v. *acuminatum* Ehrenberg
G. acuminatum v. *brebissonii* (Kützing) Cleve
G. angustatum v. *angustatum* (Kützing) Rabenhorst
G. angustatum v. *productum* Grunow
G. clevei Fricke
G. lagerheimei A. Cleve (= *G. lanceolatum* v. *lanceolatum* Ehrenberg)
G. lanceolatum v. *capitatum* Skvortzov
G. longiceps v. *longiceps* Ehrenberg
G. auritum A. Braun ex Kützing (= *G. longiceps* v. *subclavatum* Grunow)
G. longiceps v. *subclavatum* f. *gracile* Hustedt
Gyrosigma acuminatum (Kützing) Rabenhorst
Martyana martyi (Heribaud) Round (= *Opephora martyi* Heribaud)
Mastogloia smithii v. *smithii* Thwaites
M. smithii v. *amphicephala* Grunow
M. smithii v. *lacustris* Grunow
Meridion circulare v. *circulare* (Greville) Agardh
M. circulare v. *constrictum* (Ralfs) Van Heurck
Navicula galikii (Pant) Cleve (= *Navicula amphibola* v. *amphibola* Cleve)
N. amphibola v. *orientalis* (I. Kiss) Zabelina
N. exiqua (Gregory) O. Müller
N. salinarum v. *intermedia* (Grunow) Cleve (= *N. cryptocephala* v. *intermedia* Grunow)
N. placentula (Ehrenberg) Grunow
N. pusilla v. *lanceolata* Grunow
N. radiosa Kützing
N. scutelloides W. Smith
N. semen Ehrenberg
Cavinula lacustris (Gregory) Stickle & Mann (= *Navicula lacustris* Gregory)

Nitzschia fonticola Grunow
N. gracilis v. *capitata* Wisl et Poretzky
N. vermicularis (Kützing) Grunow
Pinnularia viridis (Nitzsch) Ehrenberg
Rhoicosphenia curvata (Kützing) Grunow
Rhopalodia gibba (Ehrenberg) O. Müller
R. gibba v. *ventricosa* (Ehrenberg) Grunow
Stephanodiscus rotula (Kützing) Hendey et varieties. (= *S. astrea* (Ehrenberg) Grunow v. *astrea* et varieties)
Cyclostephanos dubius (Fricke) Round (= *Stephanodiscus dubius* (Fricke) Hustedt
Surirella delicatissima Lewis
Surirella robusta Ehrenberg
Synedra amphicephala Kützing
S. tenera W. Smith
S. ulna (Nitzsch) Ehrenberg
S. ulna (Nitzsch) Ehrenberg et varieties.
S. vaucheria Kützing
Tabellaria fenestrata (Lygnbye) Kützing
T. fenestrata v. *fenestrata* (Lyngbye) Kützing et v. *intermedia* Grunow
T. flocculosa (Roth) Kützing
Tetracyclus emarginatus (Ehrenberg) W. Smith

Diatoms found sporadically

Achnanthes biasolettiana (Kützing) Grunow (3.4 m)
A. hauckiana v. *elliptica* Schulz (4.4 m)
A. hungarica Grunow (6.2 m)
A. marginulata Grunow (3.0 m)
A. oestrupii v. *minuta* Skvortzov (2.6 m)
A. stricta v. *rostrata* Skabitsch (4.8 m)
Karayevia clevei (Grunow) Round & Bukhtiyarova (= *Achnanthes clevei* Grunow) (4.3 m)
Amphora mongolica v. *gracilis* Skvortzov (5.0 m)
Caloneis alpestris (Grunow) Cleve (5.0 m)
C. silicula v. *tumida* Skabitsch (5.8 m)
Cyclotella bodanica Eulenst. (3.6 m)
C. operculata (Ag.) Kützing (3.0 m)
Cymbella acuta f. *beicalensis* Skvortzov (2.6 m)
C. angustata (W.Smith) Cleve (4.2 m)
C. cistula (Hemp.) Grunow (4.2 m)
C. inaequalis (Ehrenberg) Rabenhorst (= *C. ehrenbergii* Kützing) (3.8 m)
C. helvetica Kützing (6.0 m)
C. subcuspidata Krammer (= *C. heteropleura* v. *minor* Cleve) (3.8 m)
C. pusilla Grunow (2.8 m)
Encyonema lacustre (Agardh) D. G. Mann (= *C. lacustris* (Agardh) Cleve) (3.2 m)
Diatoma hiemale (Lyngbye) Heiberg (2.8 m)
D. vulgare v. *vulgare* Bory (= *D. vulgare* v. *productum* Grunow) (2.8 m)
D. anceps (Ehrenberg) Kirchner (2.6 m)
Diploneis elliptica v. *ladogensis* Cleve (3.8 m)
D. finnica v. *clevei* (Fontell) Hustedt (3.0 m)
D. subovalis Cleve (4.8 m)
Epithemia hyndmanii W. Smith (= *E. intermedia* Fricke) (2.6 m)
E. ocellata Kützing (3.8 m)
Eunotia sudetica O. Müller (2.6 m)
Eucocconeis onegensis Wisl. & Kolbe (2.6 m)
Fragilaria. intermedia Grunow (2.6 m)
Pseudostaurosira brevistriata (Grunow) Williams & Round (= *Fragilaria brevistriata* Grunow) (3.8 m)
Staurosirella lapponica (Grunow) Williams & Round (= *Fragilaria lapponica* Grunow) (2.6 m)
Frustulia rhomboides (Ehrenberg) De Toni (3.4 m)

Gomphonema acuminatum v. *coronatum* (Ehrenberg) W. Smith (4.6 m)
G. vibrio v. *bohemicum* (Reichelt et Fricke) R. Ross (= *G. bohemicum* Reichelt et Fricke (3.6 m)
G. gracile v. *auritum* (A. Braun) Cleve (3.2 m)
G. dichotomum Kützing (= G. *intricatum* v. *dichotomum* (Kützing) Grunow) (4.0 m)
G. vibrio v. *pumilum* (Grunow) R.Ross (= *G. intricatum* v. *pumilum* Grunow) (3.2 m)
G. olivaceum v. *calcareum* Cleve (3.6 m)
Aulacoseira lirata (Ehrenberg) R. Ross (= *Melosira distans* v. *lirata* Ehrenberg (3.0 m)
Aulacoseira ambiqua (Grunow) Simonsén (= *Melosira ambiqua* (Grunow) O. Müller) (3.2 m)
M. undulata v. *normanii* (Arnott) De Toni (4.2 m)
Navicula cari Ehrenberg (5.2 m)
N. grimmei Krasske (3.2 m)
N.capitata Ehrenberg (= *N. hungarica* v. *capitata* Cleve) (2.8 m)
N. capitata v. *hungarica* (Grunow) R. Ross (= *N. hungarica* Grunow) (2.8 m)
N. hustedtii Krasske (3.0 m)
N. jentzii Grunow (3.0 m)
N. laterostrata Hustedt (3.2 m)
Navicula mutica var. *ventricosa* (Kützing) Cleve) (2.8 m)
N. pupula Kützing (3.0 m)
N. schoenfeldii Hustedt (= *N. obtusangula* Hustedt) (3.2 m)
N. scabitschewskyi (Skabitsch.) Zablina (3.4 m)
N. tuscula v. *intermedia* I. Kiss (3.4 m)
N. tuscula f. *minor* Hustedt (3.4 m)
N. tuscula f. *rostrata* Hustedt (5.8 m)
Cavinula pseudoscutiformis (Hustedt) Mann (=*Navicula pseudoscutiformis* Hustedt) (3.0 m)
Sellaphora pupula (Kützing) Mereschkowsky (= *Navicula pupula* Kützing) (3.0 m
Nitzschia angustata (W. Smith.) Grunow (3.8 m)
N. angustata v. *acuta* Grunow (3.2 m)
N. sublinearis Hustedt (3.2 m)
Pinnularia borealis Ehrenberg (2.6 m)
P. bogotensis (Grunow) Cleve (2.8 m)
P. gibba Ehrenberg (3.0 m)
P. interrupta W. Smith (2.6 m)
P. biceps f. *petersenii* R. Ross (= *P. interrupta* f. *minor* J. B. Petersen) (3.6 m)
P. lata (Brébisson) W. Smith (2.8 m)
Synedra famelica Kützing (5.2 m)
T. lacustris Ralfs) (3.2 m)

Siligoflagellates

Dicttyocha fibula Ehrenberg (9.4 m, 10.2 m)
Distephanus speculum (Ehrenberg) Haeckel (8.8 m, 9.0 m, 9.2 m, 9.4 m, 9.6 m, 10.0 m, 10.2 m, 10.4 m, 10.6 m, 10.8 m and 11.6 m)

The new names for diatom were determined on the basis of the following publications:

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