Chapter 2
Late Pleistocene Geologic-Paleoecological Events in the North of European Russia

Relationship between Land and Sea Areas during the Mikulino Interglacial in Northern Eurasia

The main object to be considered is sediments of the Eemian (Mginsk) or Boreal, transgression. Some general trends of their distribution and biostratigraphic evidence are presented. These sediments have been long studied by many researchers, and the aim of this chapter is to summarize the results.

According to (Lavrova and Troitsky, 1960), the Boreal basin was mostly shallow. Coastal sandy facies contained a rich molluscan fauna with dominating boreal species (*Cyprina islandica, Astarte borealis, Mactra elliptica* and others), Lusitanian elements (*Anomia striata, Cardium edule*), which suggests the high water salinity, positive winter temperatures, and active aeration of the basin. Of sublittoral diatoms the warm-water benthic and semibenthic forms are especially abundant (Polyakova, 1997). The climate of the Boreal transgression was one of the warmest in the second half of the Pleistocene. Coniferous forests dominated the coastal vegetation, and broad-leaved species grew on the southern shore of the White Sea. Glaciers disappeared from the Scandinavian mountains and the Kola Peninsula (Geology of Quaternary deposits of the north-western European part of the USSR, 1967).

The results of investigations and published data allow conclusion that the sediments of the Boreal transgression spread continuously from the Gulf of Finland to the White Sea. Therefore the transgression can be considered to be a significant event, which changed relationship between the land and sea areas. The sea transgression spread along valleys of large rivers (Severnaya Dvina, Mezen′, and Pechora). The White Sea was connected with the Gulf of Finland by a strait between the Baltic crystalline shield and the Russian Plate. For a short time Scandinavia became a huge island (Fig. 2.1) (Lavrova and Troitsky, 1960; Biske, 1959; Znamenskaya and Cheremisinova, 1962; Geomorphology and Quaternary deposits of the north-western European part of the USSR, 1969; Lavrushin and Spiridonova, 1995). According to the available geological data, the oldest non-glacial Quaternary deposits of the White Sea coast are the marine sediments of the Mikulino time. This fact allows suggestion that the White Sea was originated at that time (Lavrushin

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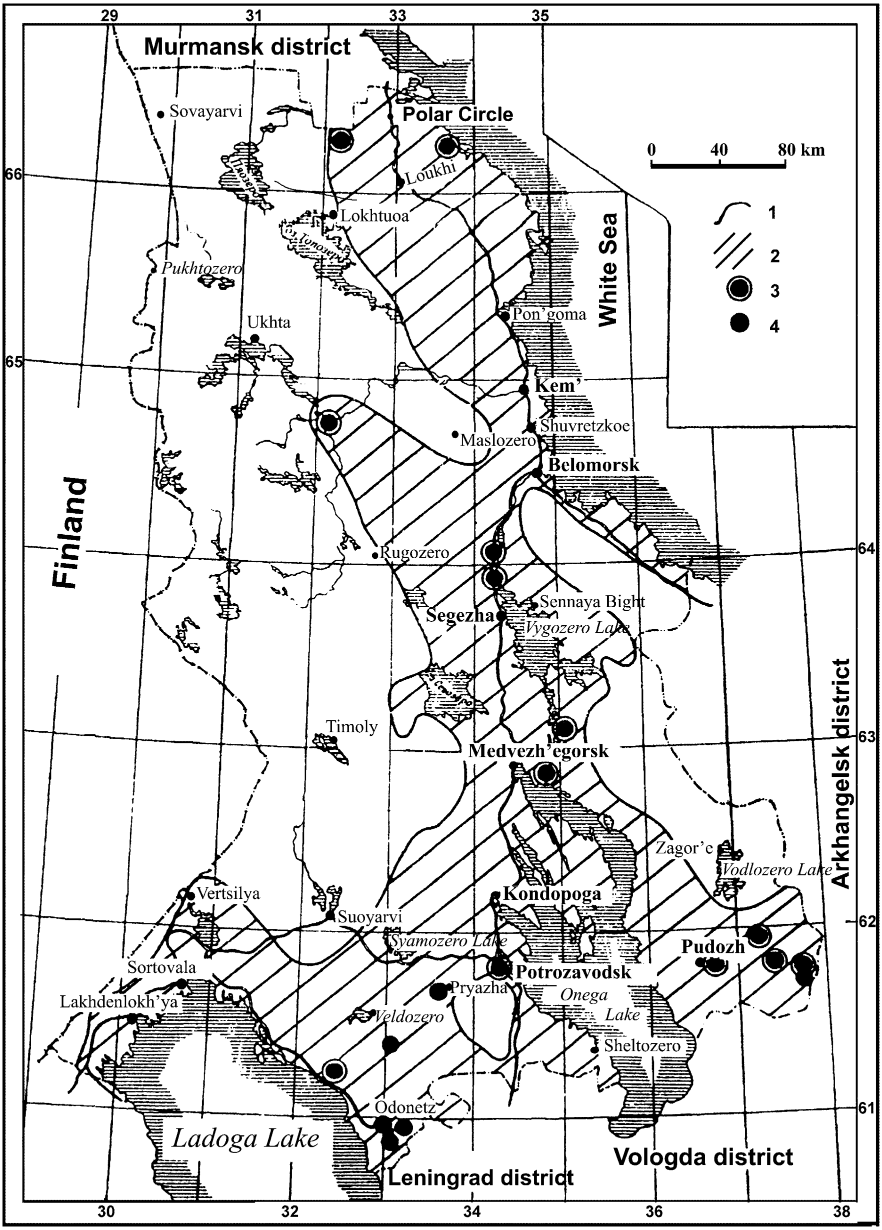

Fig. 2.1 Schematic distribution map of the Karelian Interglacial sea (Biske, 1959). 1 – coast lines; 2 – sea; 3 – locations of interglacial sedimentary sections with paleontological characteristics; 4 – locations of interglacial sedimentary sections without paleontological characteristics

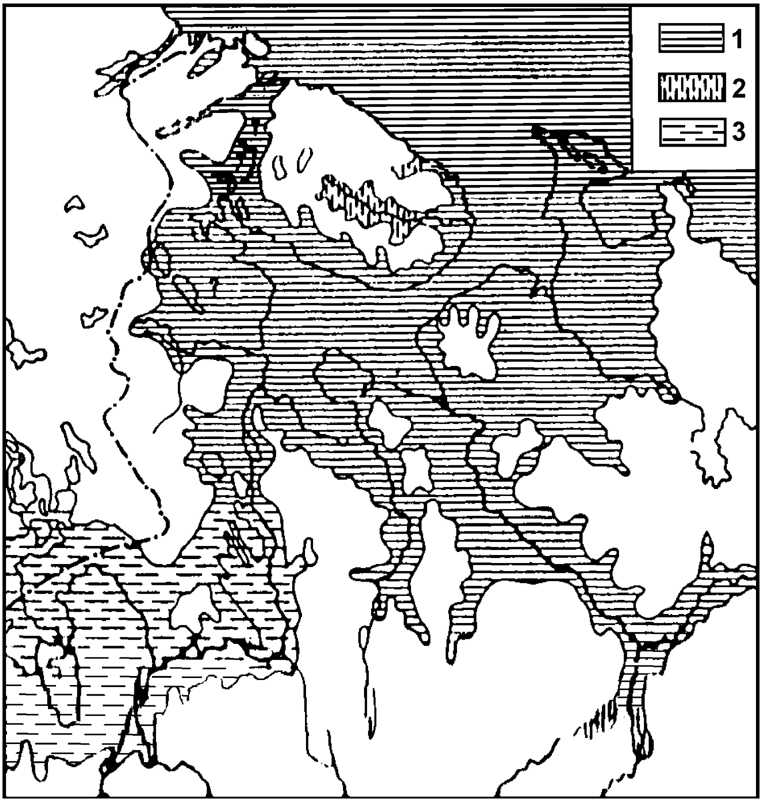

Fig. 2.2 Distribution of the interglacial boreal transgression (Lavrova and Troitsky, 1960). 1 – marine boreal transgression waters; 2 – freshened bays; 3 – waters of Eemian transgression

and Spiridonova, 1995). The Mikulino marine sediments are also the oldest ones in grabens filled by the Ladoga and Onega lakes and the grabens may be formed through the early Mikulino (early Eemian) neotectonic processes (Garetsky et al., 1999).

In the south of the East European Platform the Mikulino time is marked by liman sedimentation during the Late Karangat transgression of the Black Sea and the Late Khazaria transgression of the Caspian Sea.

Thus, two interrelated events took place in the Mikulino time. The intensive neotectonic graben formation occurred at the contact of the Russian Plate and the Baltic crystalline shield in the north and northwest of European Russia. The origination of the recent tectonic structures coincided with the Eemian (Mginsk) sea transgression, which essentially effected the relationship of land and sea areas (Figs. 2.1, 2.2, 2.3).

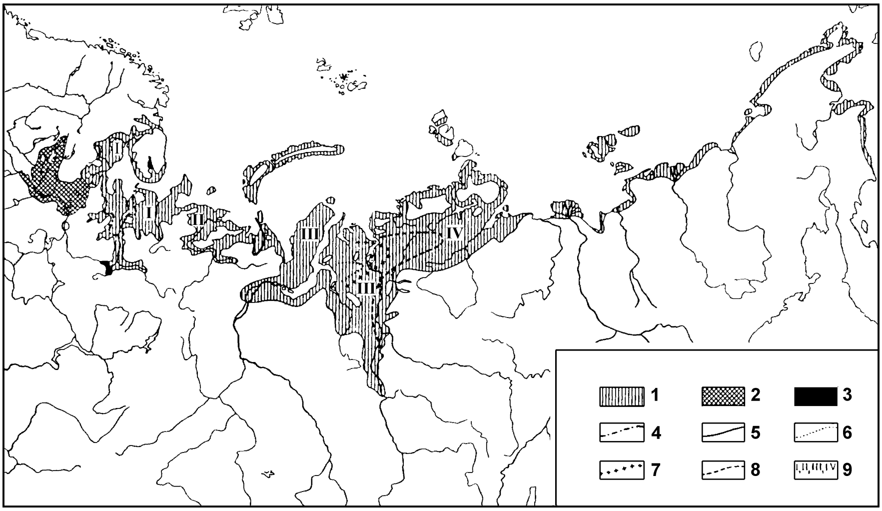

Fig. 2.3 Boreal sea on the Russian North (according to S.L. Troitsky (1964)). 1 – territories covered by boreal sea during the maximal transgression; 2 – Baltic Basin during the transgression maximum; 3 – freshened areas; 4–8 – boundaries of distribution of zoogeographic groups and individual species of mollusks and barnacles: 4 – Lusitanian (south-boreal) species; 5 – *Mactra elliptica,* 6 – *Cardium edule,* 7 – *Pholas crispatus,* 8 – *Cyprina rina islandica;* 9 – basins (I – White Sea, II – Pechora, III – West Siberia, IV – Taimyr)

Genetic Types of Continental Sediments

Besides the marine sediments, many continental sequences of the Mikulino Interglacial were discovered in European Russia. The most widespread are lacustrine and boggy deposits; buried soils are abundant in the south. Alluvial and proluvial sediments are less common.

The lacustrine-boggy sediments are characteristic of the northern and central regions of European Russia (to the south from the sea basin). This suggests a high level of ground waters, which might be caused by the sea transgression. Southwards, in the present zone of forest-steppe and steppe, there are numerous horizons of buried soils, which evidence of weak slope denudation, and local proluvial formations. Less is known about specific features of alluvial sediments. A deltaic sequence of the Severnaya Dvina is 70 m thick. Accumulation of so thick sequence during the short-time Boreal Eemian (Mginsk) transgression speaks of an avalanche sedimentation. However, at some distance from the sea the plain river alluvium formed sequences of usual thickness and facies relationship.

Thus, the distribution of the continental sediment types shows that the specific feature of the Mikulino sedimentation stemmed from the high level of ground waters in the land area was a wide bog formation.

Marine Sediments of the Boreal Transgression in the North of European Russia

The sediments of the Boreal transgression correlative with the Eemian one, were distinguished by M.A. Lavrova and S.L. Troitsky (1960). They have a number of characteristic features. The most important features are as follows.

1. The Boreal transgression was produced by two different (Arctic and Boreal (Eemian)) water masses penetrating far into the land area. This was reflected in mixed composition of marine biota.
2. Changes of the genetically different biotic assemblages upward the sequences suggest an alternation of dominating water masses in the Boreal basin. Some strata contain predominantly the Arctic fauna with single boreal forms, but others enclose an increased amount of the latter. So, the penetration of the Arctic waters into the land may occur in colder climatic conditions similar to the stadial ones. The noticeable increase of the boreal forms may evidence of the interstadial climate in the adjacent land. The predominance of the Lusitanian (boreal) fauna indicates the interglacial environment as confirmed later by palynological studies.
3. The study of some boreal marine sequences revealed that they experienced significant glaciotectonic action. Certainly, the glacio-dislocations considerably hamper reconstruction of the boreal sedimentation.
4. The Boreal sea sequences demonstrate distinct signs of sea level fluctuations, which point to complicated dynamics of the transgression.

Below some sections of the Boreal transgression are described whose lithological and biostratigraphical characteristics reflect one or several mentioned features.

The Pas'va and Koleshki sections at the Vaga River were studied by many researchers (Devyatova, 1982; Zhuze and Poretsky, 1937; Liyvrand, 1981; Loseva, 1978; Lavrushin and Spiridonova, 1995; and others). The sediments of the Boreal transgression lie between thin peat beds and represented by greenish-gray clay with plant remains and shells of marine mollusks. Thickness of the sediments is 3.5–4.0 m.

According to palynological data of E.D. Lyivrand and E.A. Spiridonova, the top of the marine strata and the overlapping peat bed correspond to a climatic optimum of the Mikulino Interglaciation, which is reflected by the following palynological zones (Grichuk, 1961):

- M4 – zone of oak, elm and fir; the beginning of maximal abundance of alder-tree and filbert;
- M5 – zone of oak and elm with an admixture of linden and hornbeam; the end of the maxima of filbert and alder-tree; fir maximum;
- M6 – zone of fir and hornbeam.
- M7 and M8 zones were established by E.A. Spiridonova (Lavrushin and Spiridonova, 1995) above the climatic optimum.

Thus, the presence of the peat beds under and above the marine sediments suggests a high level of ground waters in the adjacent land during both the transgressive and regressive phases of the Boreal sea.

In the Koleshki section the eroded upper peat bed was overlain by a thin sandy member containing molluscan shells. Its presence can evidence of repeated sea level changes, i.e., the next transgressive phase.

The palynological zones of V_1, V_2, V_3, V_4, V_5, and V_6 were distinguished in the Lower Valday strata. The overlaying Middle Valday sediments correspond to Svd_{1-7} zones (Spiridonova, 1983).

In these sections the Lower and Middle Valday deposits are represented by fluvial sediments with many signs of washing out and located in the river valley, which cuts almost across the terminal moraine ridge of the Kalinin glaciation (Map of Quaternary deposits of European part of the USSR and adjacent territories, 1971). Nevertheless, above the Mikulino deposits of the Pas'va section there are sediments of the Late Volga Interstadial (V_2) reflecting a predominance of thin birch-pine forest; the birch forests became prevailing in the Late Brerup Interstadial (V_4) (Lavrushin and Spiridonova, 1995).

E.I. Devyatova (1982) reconstructed paleolandscapes of the Onega River valley at the Boreal sea coast. The succession of vegetation phases are as follows: periglacial vegetation (grass, bushes); dominating birch forests; coniferous forests (fir, pine); mixed forests (combination of pollen maxima of broad-leaved species and those of birch and alder) during the climatic optimum; coniferous-birch forests; fir forests; periglacial vegetation (grass, bushes, birch) at the end of the interglaciation.

In the east, the sediments of the Boreal transgression increased in thickness up to 60–70 m. They were recovered by drilling at the lower course of the Severnaya Dvina River. Palynological analysis of the sequence (about 40 m) of Hole 15 near the Lake Izhmy (Pleshivtzeva, 1972) showed the typical pattern of appearance and culmination of the broad-leaved plants (oak – elm – filbert – hornbeam) during the optimum of the Mikulino Interglaciation, in spite of some differences from the southern regions. The broad-leaved species occurred as insignificant admixture in the forest of firs and birches. The hypo-Arctic species *Betula nana* was associated with some thermophilic elements. Significantly, the climatic optimum of the Mikulino Interglaciation was recorded at the depth of 90.0–76.1 m, whereas the base of the Boreal transgression sequence was at the depth of 91.0 m.

The initial short-term phase of the Boreal transgression may proceed in cold climatic conditions, which were probably formed by the cold Arctic waters penetrating into the land.

The similar succession of vegetational phases was discovered in sections of some other holes drilled at the lower course of the Severnaya Dvina River. The lower part of the Boreal strata (up to 14 m) contains shells of *Portlandia arctica* (Gray), *Yoldia arctica* Gray, *Yoldia hyperborea* (Loven), *Macoma calcarea* (Chemn.). Sediments of the climatic optimum recovered at the lower course of Severnaya Dvina and in the Mezen and Pezy river valleys enclose Arctic-boreal (to 50%) and boreal (to 30%) molluscan species, Arctic forms are single. The prevailing boreal species are *Carbula gibba* Olivi, *Cardium echinatum* L., *Cardium paucicostatum* Beck, *Mactra* *elliptica* B., *Cyptina islandica* L., *Panopea norvegica* Speng., *Buccinum undatum* L., *Littorina littorea* (L.), *Nucella lapillus* (L.).The most frequent boreal-Lusitanian element is *Cardium edule* L. Analogous but thicker walled shells were found in the coastal sandy-gravel-pebble deposits.

The described assemblages reflect only one of the regressive phases of the Boreal sea. The high-Arctic thick-walled species *Serripes grönlandicus* (Chemn.) was found in brownish-gray sandy loams of the Peza River outcrop (near the Bychie Village), which overlie coastal-marine sediments enclosing mollusks of the climatic optimum. Occurrence of this form most likely indicates a short-term penetration of the Arctic waters into the land and related cooling. Palynological data indicates a predominance of northern taiga in the coasts at that time (Geology of Quaternary deposits of the north-western European part of the USSR, 1967). Special investigations and geological mapping in the Mezen and Peza valleys revealed that the maximal level of the Boreal transgression approached the present-day hypsometric mark of approximately 100 m. The lithofacies composition reflects repeated sea level fluctuations and changes of sedimentation regime.

To the northwest, in the Kola Peninsula, the sediments of the Boreal transgression called Ponoy Layers were recognized in outcrops at the Varzuga, Chapoma and Panoy rivers, and in cliffs of the Svyatonossk Bay.

The Ponoy Layers are represented by loams and clays (up to 9.5 m) varying in color from black to light gray and containing abundant marine mollusks (Table 2.1) as well as foraminifers and diatoms (Gudina and Yevzerov, 1973; Cheremisinova, 1952; Lavrov, 1960).

According to V.I. Gudina, the foraminiferal assemblage is composed by "Lusitanian, boreal, Arctic-boreal, boreal-Arctic and Arctic forms. Boreal and Arctic-boreal species are prevailing. Lusitanian and boreal-Lusitanian forms: *Lenticulina orbicularis, Amphicoryna scalaris f. compacta, Globulina inaequalis, Guttulina lactea, Sigmomorphina undulosa, Fissurina latistoma, Discorbis punctulatus, Gavelinopsis praegeri, Rosalina globularis, Hyalinea balthica, Elphidium excavatum, Trifarina angulosa* (12 species or 15% of the assemblage); boreal forms: *Pyrgo williamsoni, Lagena gracillima, L. semilineata, L. sulcata, Polymorphina novangliae, Oolina hexagona, Buccella troitzkyi, Paromalina bilateralis, Elphidium boreale, Bulimina aculeata, Bolivina pseudoplicata, Cassidulina laevigata,* etc. (23 species or 28.5%); Arctic-boreal forms: *Quinqueloculina arctica, Pateoris hauerinoides, Lagena apiopleura, Oolina globosa, Fissurina laevigata, F. latistoma, F. marginata, F. serrata, Eponides wrightii, Cibicides rotundatus, Astrononion gallowayi, Nonionella auricula, Bolivina pseudopunctata,* etc. (18 species or 22%). Warm-water species (Lusitanian, boreal-Lusitanian, boreal and Arctic-boreal) compose 65.5% of the assemblage (53 species). Cold-water elements (Arctic and boreal-Arctic species) are in subordinate amount (26%). The boreal-Arctic species: *Quinqueloculina borea, Tappanella arctica, Buccella inusitata, Nonionellina labradorica, Cribroelphidium granatum, Cr. goesi, Elphidiella arctica, Globigerina pachyderma, Cassidulina subacuta, Islandiella islandica,* etc. (11 species or 14%); the Arctic species: *Dentalina baggi, D. frobisherensis, D. ittai, Globulina glacialis, Buccella hannai arctica, Patellina corrugata, Cribrononion obscurus,*

Table 2.1 Composition and the distribution of mollusks, barnacles and brachiopods in the interglacial sediments of the Kola Peninsula [*Gudina, Euzerov*, 1973]

Species	Location and number of cross-section																		
	Varzuga River, 1		Chavanaga River , 2	Kamenka River, 3	Strelna River, 4	Chanoma River, 5		Pyalitsa River, 7		Big Kumzhevaya River 9	Ludyanoy Stream, 10	Ponoy River, 13a	Branch of Pakhtenny Stream 13б	Ponoy River, 13в	Popov Stream , 13г	Small Kachkovka River, 14	Top of the St.Nose Bay, 15		
	Ponoy Layers	Loam lens				Ponoy Layers	Strelna Layers										Ponoy Lay-ers		Strelna Layers
																	owner part	Middle part	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Boreal–Lusitanian																			
Cardium edule L.												+		+	+	+			
Boreal																			
Acmaea virginea Müll.																+			
Anomia ephippium L.	+													+					
Buccinum undatum L.													+		+	+			
Cardium elegantulum Beck.						+													
C. echinatum L.												+		+		+			
C. fasciatum Mont.	+	+										+		+	+	+	+		
Arctica(-Cyprina) islandica (L.)	+		+			+		+				+	+	+	+	+	+		+
Dentalium entalis L.		+	+			+						+		+			+		
Hydrobia ulvae Pennant.																+			
Littorina littorea L.														+					

Table 2.1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Lucina borealis L.												+		+			+		
Mactra elliplica Brown.											+	+	+		+	+	+		
Mya arenaria L.														+					
Panopaea norvegica Spengl.	+	+			+	+											+		
Balanus balanoides L.		+																	
B. hameri Asc.		+	+			+											+		
Mainly Boreal																			
Anomia squamula L. var. *aculeata* Müll.												+		+					
Astarte borealis Chenm. var. *arctica* Gray					+							+	+			+			
Lacuna divaricata Fabr.																+	+		
Lora trevelliana (Turt.)		+																	
Modiolus modiolus (L.)	+											+	+	+	+	+	+		
Mytilus edulis L.	+													+	+				
Neptunea despecta L.		+				+						+		+	+				
Arctic-Boreal																			
Acribia (Amauropsis) islandica (Gmel.)	+														+	+			
Anomia squamula L.						+					+	+	+	+	+	+	+		
Astarte elliptica Brown.	+	+	+		+	+	+				+	+	+	+	+		+		
Boreonatica clausa (Brod. et Sow.)	+										+				+	+	+		
Hiatella arctica (L.)	+		+			+					+	+	+		+	+	+	+	
Leda pernula (Müll.)	+	+				+											+	+	+

Table 2.1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
L. minuta (Müll.)						+						+		+					
Lepeta coeca (Müll.)	+																+		
Macoma calcarea Gmel.	+	+				+		+				+		+			+	+	+
Margarites cinereus (Couth.)															+	+			
M. groenlandicus (Chemn.)	+														+	+			
Musculus laevigatus (Gray)												+							
Mya truncata L.	+	+			+	+		+			+	+	+		+	+	+		
M. truncata var. *uddevalensis* Hanc.														+	+		+		
Nucula tenuis (Mont.)	+																	+	+
Chlamys islandicus (Müll.)	+	+		+		+				+	+	+	+	+	+	+	+	+	
Euspira pallida (Brod. et Sow.)						+						+		+		+	+		
Puncturella noachina (L.)						+								+		+	+		
Sipho islandicus (Chemn.) (?)																	+	+	
Boreotrophon truncatus (Ström.)																+			
Velutina undata Brown.																+			
Balanus balanus L.		+									+				+				
B. crenatus Brug.		+				+						+							
Mainly Arctic																			
Admete viridula Fabr.	+					+													
Astarte borealis Chemn.	+	+			+	+		+		+	+	+	+	+	+	+	+		
A. crenata (Gray) var *crebricostata* Andr. et Forb.	+	+	+	+		+											+		

Table 2.1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A. montagui (Dillw.)	+	+				+				+	+	+	+	+	+		+		
A. montagui Dillw. var. *striata* Leach.	+					+								+			+		
A. montagui (Dillw.) var. *warhami* Leche											+	+							
Lora harpularia (Couth.)												+		+					
L. scalaris (Möll.)																	+		
Margarites groenlandicus (Chenm.) var. *umbilicalic* Brod. et Sow.															+				
Boreotrophon clathratus L.															+				
Trichotropis borealis Brod. et Sow.																	+		
Arctic																			
Acmaea rubella Fabr.												+			+	+			+
Bathyarca glacialis Gray										+							+		
Astarte borealis (Chemn.) var. *placenta* Morch.					+		+										+		
A. crenata (Gray)	+	+	+	+		+		+		+	+				+		+		+
Cardium ciliatum Fabr.	+	+								+						+			
Yoldiella lenticula (Möll.)																		+	
Propeamussium groenlandicum Sow.																		+	+
Hemithiris psiltacea (Gmelin)	+					+													
Serripes groenlandicus (Chemn.)	+				+	+										+	+		

Protelphidium orbiculare, etc. (10 species or 12%). Unidentified species amount to about 10%. Thus, the assemblage is mainly constituted by moderate-cold-water species (50.5% of boreal and Arctic-boreal forms) with the significant portion of warm-water elements (15% of Lusitanian and boreal-Lusitanian forms). Such composition indicates a boreal character of the assemblage. The enclosing sediments were accumulated predominantly in the lower sublittoral zone of the open sea characterized by normal oceanic salinity and positive bottom temperatures" (Gudina and Yevzerov, 1973; pp. 52–54).

Now the general situation in the eastern regions, in particular, at the lower course of the Pechora River, should be considered. The section called Vas'tyansky Kon' was studied by many researchers and described in literature (Gol'bert et al., 1973; Lavrova, 1949a; Lavrova and Troitsky, 1960; Popov, 1963; Troitsky, 1964, 1966; Epstein, 1990; and others). This section is of interest due to specific features of structure and morphology. First, it is characterized by glacial dislocations. Second, along with the Mikulino marine sediments, the Middle Valday alluvial and alluvial-deltaic deposits are exposed above the Pechora shoreline. Third, the section cuts the terminal moraine of the last glaciation along its strike.

S.L. Troitsky suggested that the alluvial sandy sequence of the middle part of the section had been transformed by glacial thrusts into blocks separated by moraine loam interbeds (Gol'bert et al., 1973). The lower marine sequence of dark gray clay seems to experience essential glaciotectonic action as well. This action was pronounced in breccia-like structure of the clays with gliding planes and, as it will be shown below, glacial thrusts. A.V. Gol'bert with co-authors (1973) subdivided the clayey sequence into three members. At the base of Member 1 there is a block of till 1×1.5 m in size; its basal interbed 3–4 cm thick includes abundant thin-walled shells. Granulometric changes are observed upward Member I due to an increase of silt material. The clays (about 8 m) contain a cold-water boreal-Arctic assemblage of marine bivalves. According to V.I. Gudina, the mollusks were associated with foraminifers; the Arctic species *Elphidium subclavatum* being most abundant (64%). The foraminiferal assemblage was the Arctic deep water (depth of 150–200 m) one, which lived at temperatures $0 \pm +1$°C. A boreal-Arctic foraminiferal assemblage was found higher up the section.

Member 2 consists of four thin interbeds of fine-grained sands enclosing sandy-clayey balls. Signs of local gaps and erosion of the top are observed. The authors (Gol'bert et al., 1973) united Members 1 and 2 into a single sedimentation cycle. This interpretation does not seem confident. Member 2 contains no molluscan shells, but a noticeable amount of foraminifers, which form, according to V.I. Gudina, a boreal-Arctic assemblage including euryhaline forms, elfides and nonionides. The presence of warm-water and shallow-water *discorbis, noniones, buccella* is explained by a small depth of the basin and proximity of the delta. According to the microfaunal data, depth of the basin was less than 50 m, salinity did not exceed 30–32%, and temperature of bottom waters was +2 or +3°C.

Overlying Member 3 was subdivided into three parts (3a, 3b, 3c) (Gol'bert et al., 1973).

Table 2.2 Chronostratigraphy and vegetation of the North-Eastern European part of Russia in the late Neopleistocene (according to [*Lavrov, Potapenko*, 2005])

Age, ka	Cronostratigraphy			Cross-sections	Vegetation: Lower Pechora	Vegetation: Mezen-Vychegda Basin
	Interstadial	Warming			Sparse growth of spruce-birch	
30, 32		Deep cooling	3352+470(ЛУ-513A) 34540+1570 (ЛУ-513B)	Tyrybei, Soz'eva-1	Periglacial tundra	
34, 36	Interstadial	Tyrybeiskoe warming	37990+440(ЛУ-609) 38320+1630(ЛУ-518) 38400+640(ЛУ-517A) 38670+870(ЛУ-512A) 39840+570(ЛУ-512B)	Nebedino, Shashkina-3	Sparse growth of spruce-birch, association of wormwood, cereals, sedges	Pines and sparse growth of spruce-birch, association of cereals and motley grass
38		Cooling		Shashkina-2	Sparse growth of birches, tundra-steppe	
40, 42		Urdynzhskoe warming	39170+440(ЛУ-588) 40650+7(ЛУ-550) 40680+1180(ЛУ-1113) 42040+1900(ЛУ-1119) 42660+970(ЛУ-519) 42810+1200(ЛУ-533)	Urdyuga-1, Soz'eva-1	Sparse growth of birch and spruce	Pine and birch-spruce forests
44		Deep cooling	43240+1040(ЛУ-394) 4580+1200(ЛУ-515B)		Pereglacial tundra and forest-tundra	
46		Shapkinskoe warming		Shashkina-1	Sparse growth of birch and spruce	Birch-spruce forest
	Interstadial	Warming	46880+2090(ЛУ-624)	Kyltovka, Bor	Forest-tundra	Sparse growth of pine and spruce
48, 50		Anorginskoe warming	47210+1270(ЛУ-674) 47520+1000(ЛУ-566) 49930+1420(ЛУ-1051)	Chornaya (Angora)	Birch-spruce forests / Forest-tundra	Pine-spruce forests
52		Deep cooling	>50150(ЛУ-671) >53000(KE-1050)	Elkino, Kipievo	Tundra / Pereglacial forest-tundra	
Mikulino Interglaciation				Sula		

Member 3a is composed by coarse-grained sand with gravel, pebbles, small boulders, and lenses of coquina. Among the mollusk shells S.L. Troitsky identified boreal, predominantly boreal, Arctic-boreal and Arctic species. A.V. Gol'bert et al. (1973) noted on allochthonous occurrence of the thanatocenosis, which combines biotic elements from different depths and sedimentation environments. They explain this combination by sedimentation processes but it may be also caused by glaciotectonic events.

Member 3a yielded four new species of foraminifers, three of which are boreal and one (*E. subclavatum*) is Arctic (Gol'bert et al., 1973). The first appearance of *Quinqueloculina oviformis* known from the Kazantsev sediments of West Siberia indicates the Late Pleistocene age of this member. As a whole, the foraminiferal assemblage can be described as Arctic-boreal. Depth of the basin was less than 20 m, salinity 30–32‰, and temperature of bottom waters +2 or +3°C. Thickness of Member 3a is approximately 0.2 m.

Member 3b is represented by unsorted loam similar to till. Its thickness is about 0.2 m. There are no mollusks. Foraminiferal assemblage includes Arctic-boreal species from Members 3a and 3c (Gol'bert et al., 1973).

Member 3c is gray clay. A molluscan assemblage characteristic of the middle sublittoral zone is succeeded by biocenosis of middle and lower sublittoral zones and then by a deep-water assemblage. A foraminiferal assemblage also indicates the basinal deepening down to 150–200 m. The assemblage has some specific features. According to V.I. Gudina (Gol'bert et al., 1973), elfidides are prevailing forms (60–80%), and *Cassidulina subacata* occurs most frequently in the middle part of the member. Arctic-boreal species show maximal abundance. In general, the assemblage suggests a considerable increase of water and air temperature, which confirms a conclusion on the Mikulino age and boreal origin of the foraminifers. Thickness of Member 3c is approximately 7–8 m.

Let us summarize the data on the marine clayey sequence subdivided by interbeds of predominantly sandy material (Members 2 and 3a) into two units. It is a common opinion of all those, who studied the Vast′yansky Kon' section, that the units correspond to the regressive stage of the Boreal sea. In other words, their accumulation was attributed to the sedimentation factor related to sea level fluctuations. Our investigations revealed that the two-unit structure of the sequence was mainly resulted from glaciotectonic activities. In the Vast′yansky Kon' section the clayey sequence is well exposed in the frontal part of an embankment facing the Pechora course. In the lateral part of the embankment sandy Members 2 and 3a are dipping at 45° to the north-north-east (dipping azimuth is 10°). This allows supposition that the sandy (or sandy gravel) sediments with marine shells were brought by glacial thrust into the middle part of the sequence. Initially they lay under the clays and were a coastal-marine facies. Thus, the clayey sequence acquired the two-unit structure because of the glaciotectonic activities. The breccia-like texture of the clays and gliding planes can be also explained by the same activities.

The marine clayey deposits are overlain by the thick sequence of predominantly sandy alluvial sediments. At its base there is a unit of sand enclosing shells of boreal mollusks, which was previously considered by many (including us) to be accumulated during the regressive phase of the Boreal transgression (Zarkhidze et al., 1970). However, the occurrence of reindeer bones in the unit has not been taken into consideration. Ferruginous sandy pebbled sediments of the pra-Pechora midstream alluviual facies were described from the base of the unit. In general, the entire alluvial sequence is subdivided by numerous glacial thrusts into separate scales, thus complicating the structure of the terminal moraine ridge. Therefore it can be assumed that the sandy unit with the marine mollusks represents also the coastal-marine sediments of the transgressive phase of the Boreal transgression, which were brought by steeply dipping glacial thrusts, as convincingly shown by A.V. Gol'bert et al., (1973). Our investigations confirmed S.L. Troitsky's opinion that the scales appeared as a result of subdividing the sandy sequence by glacial thrusts, which brought the till interbeds into the bases of blocks (Gol'bert et al., 1973). Later slightly differing ideas on the glaciotectonic origin of the Vast'yansky Kon' Ridge were published by O.G. Epstein (1990), A.S. Lavrov and L.M. Potapenko (2005). The total thickness of the deformed alluvial formation varies in outcrops from 35 to 50 m.

Granulometric analysis of the sandy sequence showed that sands were well sorted, predominantly fine-grained (fraction of 0.1–0.25 mm constitutes 80%); amount of coarse silt varies from 1.2 to 30% at the absence of clay and fine silt fractions. More silt was discovered near the alluvial peat interbeds.

According to A.V. Gol'bert et al. (1973), mineral composition of the sands is persistently uniform: ilmenite and magnetite – 30–33%, amphiboles – 8–10%, garnet – 12%, tourmaline – 1–2%, zircon – 4–5%.

The mineral composition of the sandy sequences differs from that of the underlying marine clays. The latter contain less ilmenite, magnetite, zircon, garnet, rutile, but more amphiboles and minerals of epidote-zoisite group.

A specific feature of the sandy sequence is the presence of allochthonous sandy-peaty lenses, which allow the radiocarbon dating. Previously the lenses were dated by V.L. Yakhimovich by the radiocarbon method. Five dates have been obtained. The oldest date (11 m above the lower boundary of the sandy sequence) is 29470±450 (Bash GI-7), and the youngest one (30 m above the alluvium base) is 24790±500 (Bash GI-8). Later the radiocarbon dating of several peat samples yielded the out-of-limit ages: ≥47910 (LU-1491), ≥48040 (LU-1487), ≥48050 (LU-1484), ≥52120 (LU-1481), ≥53690 (LU-372), although one date (42560±1080 – LU-1489) was final. There are different but final estimations of age of the mammoth incisor from the sandy sequence 32440±850 (LU-3973) and 39000±850 (T-13200). The data published by J. Mangerud et al. (1999) cannot provide accurate dating of the sequence. The express mass spectrometry yielded out-of-limits dates for majority of samples, whereas final radiocarbon dates were from 31.6 to 43.1 ka.

The TL and OSL methods provided considerably different dates for the sandy sequence: 30000±3000 (TL); 26000±3000, 25000±2000, 27000±3000 and 66000±7000 (OSL) (Tveranger et al., 1995). Dates obtained by the OSL method in another laboratory appeared to be considerably older (63±5, 62±5 и 58±7 ka) (Mangerud et al., 1999). These dates were close to one of those published by

J. Tveranger. This, however, did not make the obtained age more reliable. Nevertheless, basing on a number of final radiocarbon dates A.S. Lavrov and L.M. Potapenko (2005) referred these sediments to the early Middle Valday (Table 2.2). They explained inaccurate radiocarbon dates for the plant remains by allochtonous occurrence of the latter as a result of reworking of different-aged peats during the accumulation of the sandy sequence. Therefore taking into consideration the final dates (except for evidently younger dates obtained in the Bashkirian laboratory), we can agree with A.S. Lavrov and L.M. Potapenko (2005), who inferred the early Middle Valday age of the sandy sequence from careful studies of sections in the north of European Russia, their correlations and geological mapping. It is necessary to keep in mind that the youngest date (31.6 ka) as well as the visible part of the alluvium sequence does not reflect the final phase of the deposition. Undoubtedly, the upper part was cut off and assimilated by the overlying Upper Pleistocene moraine, as evidenced by the presence of alluvial outliers in it. The latter is of significance because it definitely indicates shifts of the glacial sheet edge during the formation of the Vast'yansky Kon' terminal moraine. This conclusion is supported by the presence of till brought with glacial thrusts and by the mentioned analogous glaciotectonic features of the Boreal sea sequences.

Summing up the preliminary notes on the Boreal transgressive deposits, it should be added that no thorough palynological studies have been conducted in the Pechora Lowland in contrast to the western areas and therefore climate variations during the Boreal transgression have not been studied well. In this respect, the mentioned microfaunistic studies of V.I. Gudina seem to be very promising. They show small changes in the foraminiferal assemblages under an alternating effect of the high Arctic and boreal waters. Certainly, the water changes also influenced climatic conditions, but they cannot be directly correlated with the Upper Pleistocene stadials and interstadials.

In the stratigraphic scheme of the northeast of European Russia the Boreal transgressive sediments and contemporaneous continental deposits are united into the Sulina Horizon (Andreicheva, 2002). The Sulina alluvium reflects one climatic optimum and two maxima of coniferous species. During the climatic optimum there was the southern taiga where *Picea, Pinus silvestris, Betula sect. Albae, Alnus* were associated with single *Quereus, Ulmus, Corylus, Tilia, Carpinus* (Duryagina and Konovalenko, 1993).

It should be noted that most of the radiocarbon dates for the Vast'yanskiy Kon' alluvium indicate its intensive redeposition. Therefore results of previous palynological studies are ambiguous. Of interest is another Late Pleistocene chronostratigraphic scheme for the northeast of European Russia (Lavrov and Potapenko, 2005), which shows climatic and vegetation changes during the interval of 52–30 ka ago (Table 2.2). The scheme presents a complex dynamics of landscapes and glacial events during the Middle Valday, although being inconsistent with some available dates for individual sections. This fact is not of critical importance at the present stage of investigations. An attempt to produce such generalization is very useful and can serve as a base for developing a refined scale of the Late Pleistocene events in the north of European Russia.

Noteworthy is that the Kalinin glaciation in this region was not described in the summarizations (Lavrov and Potapenko, 2005; Andreicheva, 2002), although considerable cooling was reported by these authors. L.N. Andreicheva (2002) described the periglacial sediments of the Kalinin glaciation without indicating distribution of the glacial sediments.

A moraine of the Early Valday (Kalinin) Glacial (MIS 5b) was recovered in quarries of the Kola Peninsula and core sections of bore holes in the northern piedmont of the Lovozero Mountains. Unfortunately, there is no reliable data to outline even approximately the area of this glaciation.

Some signs of the Early Valday (MIS 4) glacial sheet were found in the Sokli Massif of northern Finland near the Russian boundary, but its limits are still unknown.

The scheme of L.N. Andreicheva (2002) shows seven climatic phases in the Middle Valday (the Byzov Stage, 48–33 ka ago), which correspond to variations in the landscape development (Duryagina and Konovalenko, 1993). At the initial phase (Bz_{I}) dominating hypo-Arctic mesophytes typical of the present-time tundra were associated with the Arctic and Arctic-Alpine species as well as steppe xerophytes. There were also dark-coniferous-taiga associations and elements of periglacial vegetation. The climate was cold and arid. The radiocarbon date for this phase is about 48000 (Andreicheva, 2002).

The phase of early warming (Bz_{II}) was characterized by dark-coniferous-taiga and boron vegetation in combination with birch and fir woods. A landscape was of northern taiga type, with fir and birch sparse growths. Sedges and cereals prevailed in the grassy cover. The time range of this phase is estimated as 47–45 ka ago.

The phase of early cooling (Bz_{III}) was similar in vegetation to phase Bz_{I}. Shrub and grass associations dominated, but boggy-tundra associations with xerophytic communities were spread widely. The climate was more humid.

In the middle warming phase (Bz_{IV}) northern taiga forests prevailed in the north of the region and fir and pine forests in the south. Many cereals and different grasses.

The phase of late cooling (Bz_{V}) is similar to phase Bz_{III}.

The phase of late warming (Bz_{VI}) was characterized by prevailence of northern taiga forests. It is estimated to range 42500–38000 (Andreicheva, 2002).

In the terminal phase of sharp cooling (Bz_{VII}) there were open landscapes with elements of periglacial flora and small islands of rare birch forests.

These climatic rhythms reflect an attempt to develop the Middle Valday climatostratigraphy of the northeast of European Russia. It is quite clear that so called terminal cooling phase of the Byzov time is not the last one. In the range from 38000 to 23000 there were several more climatic rhythms which appeared to be of global significance. However, the above publications mentioned nothing about them. This means that either the climatostratigraphic units do not reflect a complete pattern of climatic variations or the radiocarbon dates for some units are in disagreement with palynological data.

In general, the Middle Valday scheme of A.S. Lavrov, L.M. Potapenko is not well agreed with that of L.N. Andreicheva. Nevertheless, a direction of further investigations has been outlined.

In the north of European Russia a marine transgression of the Middle Valday terminated at about 35 ka (Lavrushin and Epstein, 2001). A cliff of the Madakha River (the Kanin Peninsula) exposes two coastal-marine sequences separated by a peat interbed. The radiocarbon age of the latter is 42 ka. This structure fixed a short-term regression of the Middle Valday sea and, at least, two transgressive phases of the Barents Sea. The second phase was about 7 ka long. In the Kolguyev Island sediments of the same transgression are overlain by a moraine of the last glaciation. They are represented by deltaic deposits in the coasts of the Kolakolkov Inlet and

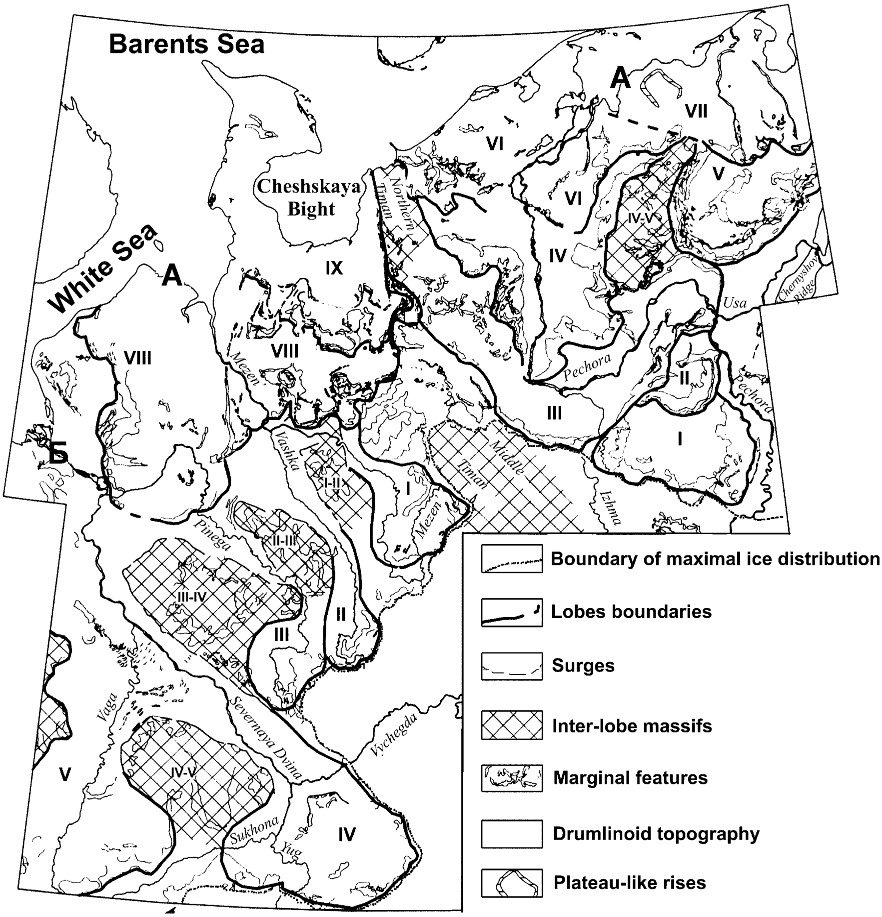

Fig. 2.4 Extension of the Late Valday Ice Sheet during the deglaciation (Lavrov and Potapenko, 2005), simplified. *A* – Barents Sea-Novaya Zemlya-Kara Sea Ice Sheet. I–IX – lobes: I – Kozhvinskaya; II – Lyzhskaya; III – Laisko-Izhemskaya; IV – Pechorskaya; V – Kolvinskaya; VI – Malozemel'skaya; VII – Bol'shezemel'skaya; VIII – Kuloisko-Mezenskaya; IX – Chöshskaya. *B* – Scandinavian Ice Sheet. I–V – lobes: I – Verkhnemezenskaya; II – Vashskaya; III – Pinezhskaya; IV – Severodvinskaya; V – Vazhskaya

the Bolvansky Nose Cape and by alluvial and alluvial-lacustrine sediments upstream the Pechora River (Lavrushin and Epstein, 2001).

Finally, some short-time geological events of the terminal Late Pleistocene (Ostashkov) Glacial should be mentioned. The QUEEN project results cast doubts upon previous views on limits of the last glaciation in the north of European Russia. The doubts appeared from numerous dates obtained by different methods for fossiliferous sediments underlying the relief-forming moraine. Analysis of these dates by A.S. Lavrov and L.M. Potapenko (2005) convincingly showed that there were no reasons to revise the existing views on the last glaciation limits (Fig. 2.4). So, it is unlikely expedient to discuss this problem herein. Another moment is of greater importance. During the last glaciation, as well as the previous ones, the Arctic shelf basins disappeared almost entirely because of sea level fall. In the remaining deepest parts of the basins there may be some bays ”sealed up” by the glacier ice. The relationship between land and sea areas essentially changed due to a noticeable enlargement of the former. Large ice-dammed basins appeared in valleys of the north-flowing rivers. At the final phase of the last glaciation (Late Glacial Maximum) the accumulated water masses run off from the basins. An intensive glacioeustatic transgression contributed to the process by destroying the ice cover and greatly accelerating the deglaciation. These are main differences in the process of deglaciation between the glacial paleoshelves and adjacent land.

One more problem of the Late Pleistocene glacial history in the north of European Russia remains unsolved. It concerns the Kalinin Glaciation correlative to the Zyryan Glaciation of West Siberia.

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