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New Data on the Natural Environment of the Middle and Late Neopleistocene Interglacial Periods in the East of the European Subarctic Region of Russia

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Abstract—The data obtained from investigation of the Middle and Late Neopleistocene lake sediments in the European Subarctic Region of Russia are reported. Chirva, Rodionovo (Scklov), Sula (Mikulino), and Byzovaya (Leningrad) sediments were subject to palynological analysis and investigation of particle size distribution and mineral composition. The spore–pollen spectra of the Chirva sediments demonstrate two climatic optima: the lower optimum is dominated by the pollen of *Pinus sylvestris* and broad-leaved species (up to 10%); the upper optimum is dominated by *Picea* sp. and *Pinus sylvestris*, while the pollen of *Picea* sect. *Omorica* and broad-leaved species are sporadic. The Rodionovo flora is characterized by a more xerophilous composition relative to the Chirva flora and a higher pollen content of pine, birch, wormseed plants, and wormwood. The climatic optimum of the Sula interglacial is distinguished by boreal vegetation, including spruce, birch, and birch–spruce forests with sparse broad-leaved species. The Byzovaya interstadial is marked by seven stages of changes in the vegetation: from tundra and forest-tundra communities to taiga forests with some broad-leaved species. The natural climatic sedimentation conditions in the Middle and Late Neopleistocene interglacial periods are reconstructed. The mineral composition of sediments was largely formed owing to underlying deposits.

Keywords: lake sediments, Neopleistocene, interglacial period, interstadial, palynology, climate, granulometric and mineral composition

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INTRODUCTION

Sedimentation in lake basins occurs in slow-moving or stagnant water, where wind waves and flows cause disorderly oscillatory movements. The sediments are not marked by well-defined diagnostic signs and are identified by a set of their specific features. In most areas, the sedimentation sections are dominated by silt and clay with a thin horizontal and subhorizontal bedding. The lake sections are characterized by a regressive sequence corresponding to a gradual transition from subaqual clay and silt deposited by suspension flows, which are related to the underwater slumping of sediments from the delta coasts and slopes in a deep part of the lake and lying at the base of the lake cycle, to coarser sands and pebble–gravel sediments accumulated near the lakeshores and depositing at the top of the section (Boggs, 1995). The sediments, especially those formed below the wave base, are distinguished by a large lateral extension and bed consistency. The paragenetic relation to alluvium and bog soils is typical of the lake sediments. The sedimentation under lake conditions is confirmed by occurrence of abundant plant detritus.

Clastic, organic, and chemical sediments are deposited under the lake sedimentation environment. The types and compositions of the deposits are considerably dependent on the climatic conditions. The clastic sandy–clay material, occasionally with a banded lamination, is deposited in the northern areas with the cold climate suppressing the chemical processes. The deposits are enriched in organic residues and contain peat and sapropel interlayers in the freshwater lakes under the humid climate. The Quaternary sediments are commonly composed of sandy–clay deposits with a consistency from plastic to flowing. They often have a dark color either due to decomposition products of organic matter or due to the presence of sulfides, in particular, pyrite (*Sedimentologiya*..., 1980). In the east of the European Subarctic Region, the Neopleistocene sediments consist of Chirva (Likhvin), Rodionovo (Scklov), Sula (Mikulino), and Byzovaya (Leningrad) interglacial deposits.

RESEARCH METHODS

In order to determine the stratigraphic distinctive features and climatic conditions of the sedimentation, the lake sediments were studied by palynological analysis according to the generally accepted method (*Metodicheskie*…, 1986). All palynological diagrams presented in the paper were compiled by T.I. Marchenko-Vagapova.

In terms of lithology, the sediments in the east of the European Subarctic Region of Russia are almost unstudied. We tried to eliminate this gap by studying their granulometric and mineral composition. Obtaining the lithological characteristics of sediments is aimed at clarification of the sedimentation conditions, revealing the possibility of using the lithological data for stratigraphic classification and correlation of the sediments, performing paleogeographic reconstructions, and identification of geological bodies whose clastic material was the basis for formation of the studied sediments. The granulometric analysis was studied by screen and pipette analysis (Kachinsky, 1958). Average grain diameters (d_{av}) and sediment sorting factors (S_s) were calculated. The sediment sorting factor was expressed through a normalized entropy (Belkin and Ryazanov, 1972) that varied from zero to one and grew with increasing sorting index: at the worst sorting, $S_s = 0$; for uniformly graded sediments, $S_s = 1$. The mineral composition of fine-grained soil in the lake sediments was determined in a fine-grained sandy fraction (0.25–0.1 mm) most fully representing the material of feeding provinces, both local and transit and remote. This fraction was available for study and the most representative in relation to the composition of heavy minerals. In a number of cases, the mineralogical analysis was limited by an insignificant content of the fine-grained sandy material in the sediments. The important aspect of our work was investigation and systematization of the accumulation processes of heavy minerals in the studied sediments.

RESULTS AND DISCUSSION

In the east of the European Subarctic Region of Russia (Fig. 1), the lake sediments are largely composed of clastogenic deposits dominated by fine-grained clay differences with a horizontal bedding (Fig. 2).

Chirva (Likhvin) interglacial Horizon (Q_{II}^1č). The base of the Middle Neopleistocene section consists of the Chirva (Likhvin) interglacial Horizon composed largely of alluvial and lake sediments. They are confined to the buried paleovalleys and fill erosive cuts in the Pomusovo (Oka) and more ancient sediments. In the studied region, the Chirva sediments are commonly revealed by boreholes. In the coastal outcrops, they are exposed extremely rarely, and their thickness does not exceed 1–4.6 m. Lake sediments were identified and studied only in three outcrops: on the Laya River (outcrop 27), on the lower Pechora River (outcrop 250-Experimental Field), and on the Vychegda River (outcrop 208-Slobodchikovo).

The lake sediments are characterized by a relatively good preservation of pollen and spores, plant particles, diatom algae, sponge spicules, and other organic remains that make it possible to reconstruct the vegetation and climate development history. The relation of the studied sediments to the Chirva Horizon is determined on the basis of characteristic spore–pollen spectra obtained and studied in the interglacial sediments underlaying the Middle Neopleistocene complex in a number of borehole sections and in coastal outcrops. The palynological analysis made it possible to determine the Chirva age of the sediments at different times in the sections of the lower Pechora area and the Vychegda River (Duryagina and Konovalenko, 1993) and Kolva River (Loseva et al., 1992), on the coast of the Haipudyr Bay (Loseva and Duryagina, 1987), and in the Pai-Khoy Ridge (Duryagina, 1985). Occasionally, for example, in outcrop 248 near the Ust'-Tsilma Settlement, the interglacial sediments were assigned to the Chirva Horizon on the basis of the conformal overlying of the Pechora (Dnieper) moraine deposits dated with consideration of bone remains of small mammals. In addition, the peat bogs underlying the Pechora Horizon contained endocarps of reddish slender pondweed (*Potamogeton rutilus*) characteristic of the Likhvin floras (Guslitser and Loseva, 1979).

In recent years, the palynological analysis was involved in study of the Chirva lake sediments in outcrop 208-Slobodchikovo on the Vychegda River. A two-meter thick sequence of bluish gray silt with an interlayer of fine-grained gray sand was uncovered in a depth range of 9.8–9.6 m in the basement of a coastal cliff with a height of 10 m. It was overlain by a yellowish gray fine-grained sand layer with a thickness of 1.9 m, overlapped by a dark gray aleurite unit (1.25 m) with plant detritus and a peat interlayer (10–15 cm) in the base. The palynological analysis of aleurite made it possible to identify the spore–pollen complexes III–X corresponding to the Chirva Horizon (Fig. 3). A five-meter thick boulder loam stratum lay even higher.

The vegetation phases for each interglacial period were identified by generalization of our materials and published data of other researchers. Five vegetation phases were revealed in the Chirva interglacial in the east of the European Subarctic Region of Russia.

$Č_I$ is a phase of thinned-out forest communities represented by birch and pine–birch sparse forests and a variety of shrubby groups including *Betula* sect. *Fruticosae*, *Betula nana*, and *Alnaster* sp. Sphagnum bogs and Polypodiaceae fern communities are abundant. The vegetation is indicative of the relatively cold climatic conditions of the tundra zone.

$Č_{II}^1$ is a phase of spruce and pine forests with permanent *Betula* sect. *Albae*, *Betula* sect. *Fruticosae*, *Betula nana*, *Alnus* sp., *Alnaster* sp., and *Salix* sp., with xerophytic communities (up to 19% *Artemisia* sp., Chenopodiaceae) and plant associations. The spore plants are dominated by sphagnum moss and Polypo-

Fig. 1. Location of the studied sections. (*1*) outcrops, (*2*) boreholes.

diaceae ferns. The vegetation is indicative of the cool conditions.

$\check{C}_{II}^{2}$ is a phase of birch, pine–birch forest communities with spruce and various shrub groups. The herbaceous associations of mesophilic herbs and bog vegetation occur in abundance. The vegetation is indicative of the relatively cold climatic conditions.

$\check{C}_{II}^{3}$ is a phase of coniferous woods dominated by *Pinus sylvestris* and *Picea* sp., widespread birches, *Alnus* sp., *Alnaster* sp., Caprifoliaceae, and sporadic broad-leaved species (*Tilia* sp.). The pollen of herbaceous plants is dominated by miscellaneous herbs and aquatic plants. *Sphagnum* sp. is prevalent in the spore plants. The climate becomes more favorable.

Fig. 2. Horizontal bedding in the lake sediments (Vychegda River, outcrop 207-Ryabovo).

$\check{C}_{III}$ is a phase of pine, pine–spruce–birch, and birch forests. Broad-leaved species are not noted. This phase characterizes a temporary cooling.

$\check{C}_{IV}^{1}$ is a phase distinguished by predominance of coniferous forests with a great role of birch. *Picea* sect. *Omorica* is sporadic. Herbaceous communities are abundant. Sphagnum mosses are predominant among sporophytes.

$\check{C}_{IV}^{2}$ is a phase of dark coniferous forests dominated by spruce and pine, with birches and with rare broad-leaved species (*Carpinus* sp.). The environment is relatively favorable.

$\check{C}_{V}$ is a phase of pine, pine–birch, and birch forests, and birch is commonly observed as shrubs.

Hence, these phases reflect the forest flora in interglacial conditions. Two climactic optima are specified. The lower optimum $\check{C}_{II}^{3}$ is characterized by enrichment in pollen of *Pinus sylvestris* and sporadic broad-leaved species; the upper climatic optimum ($\check{C}_{IV}^{1}$–$\check{C}_{IV}^{2}$) is dominated by pollen of *Picea* sp. and *Pinus sylvestris*, while *Picea* sect. *Omorica* and broad-leaved species are rare.

The method by Klimanov (1976, 1985) was used for analysis of new and published palynological data aimed to perform paleoclimatic reconstructions and to establish paleotemperatures and amounts of paleoprecipitation in the Neopleistocene. At that time, the July temperature in the north of the studied region was 2–4°C higher than today and reached 14–16°C. In the south of the studied region, the average July temperatures reached 16–18°C, thus being higher than the current temperatures by 1–2°C. In warm weather, the amount of precipitation throughout the studied area was 255 mm, while in cold weather it did not exceed 50–75 mm, and it increased to 175 mm in the eastern direction (Andreicheva et al., 2006; Andreicheva and Marchenko-Vagapova, 2015).

According to the data of granulometric analysis (Table 1), the Chirva sediments are distinguished by a low total carbonate content (2.6–3.6%) and an average sorting grade of fine-grained earth (S_s = 0.31–0.43). The sediments vary from very thin clays in Borehole 611 on the Kolva River, where their average diameter (d_{av}) is only 0.004 mm, to silt with d_{av} = 0.042 mm in outcrop 208-Slobodchikovo, which is likely related to the position of the samples in the section: clay deposits could have been formed in a deep part of the lake, while silt could have developed in shallower waters.

A mineral composition of the lake sediments was studied in three sections, where the heavy fraction yield (HFY) was highly variably (Table 2). The assemblage of heavy minerals is dominated by epidote (28–33%), the garnet content is 12–18%, and the amphibole content of 10–20% decreases to 5% in the east of the studied region, in the Kolva River valley. The sediments are characterized by relatively high concentrations of ilmenite (4–9%), titanium minerals (rutile, titanite, and leucoxene) reaching 5–9%, and an elevated total content of metamorphic minerals (kyanite, staurolite, and sillimanite) reaching 5–10%. In the north of the studied region, the heavy fraction is marked by enrichment in pyrite and siderite, whereas in the south, in the Vychegda River basin, these minerals are absent.

Rodionovo (Scklov) interglacial Horizon (Q_{II}^{3} r). In the Rodionovo interglacial epoch, the Timan–Pechora–Vychegda Region was characterized by development of predominantly continental (alluvial and lake) sediments, widespread in occurrence, while the Rodionovo marine sediments with a thickness of up to 40 m were found only in the boreholes of the northern areas. The thickness of the Rodionovo sediments is up to 30 m, and their base within the Pechora lowland lies at absolute marks of 40–85 m. Almost everywhere, they overlap the Pechora moraine depos-

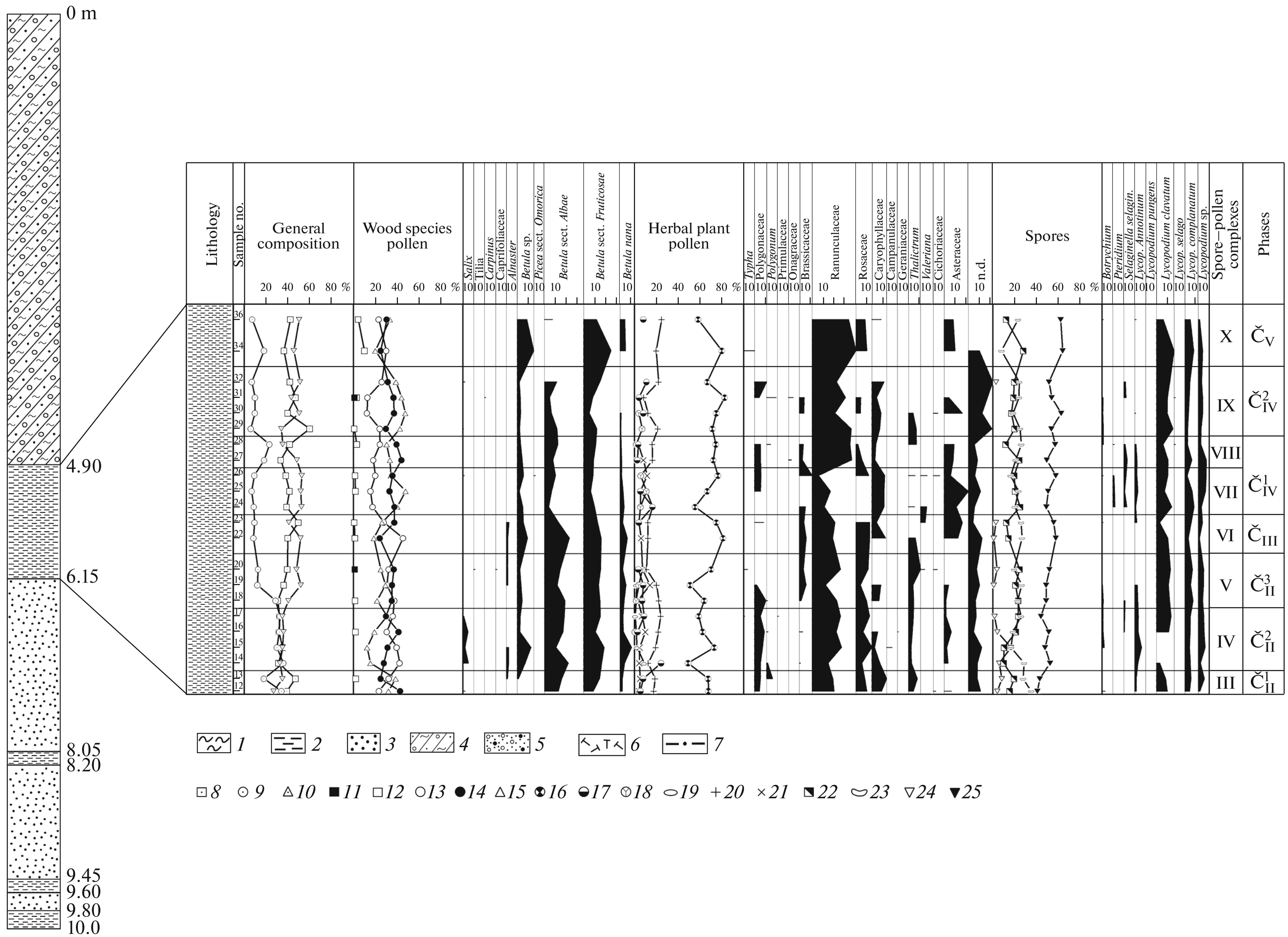

Fig. 3. The spore–pollen diagram of the Chirva sediments in outcrop 208-Slobodchikovo. (*1*) Clay, (*2*) silt, (*3*) sand, (*4*) moraine deposits, (*5*) pebble, (*6*) peat, (*7*) sand silt, (*8*) total pollen of woody species, (*9*) total pollen of herbal species, (*10*) total spore of higher sporophytes, (*11*) total pollen of broad-leaved species, (*12*) alder, (*13*) birch, (*14*) pine, (*15*) spruce, (*16*) total pollen of miscellaneous plants, (*17*) gramineous plants, (*18*) heath, (*19*) sedge, (*20*) wormwood, (*21*) pigweed, (*22*) club moss, (*23*) fern, (*24*) green moss, and (*25*) sphagnum moss.

Table 1. Granulometric composition of lake sediments in the Timan–Pechora–Vychegda Region

River	Horizon index	Outcrop, borehole no.	Carbonate content, %	Fraction content, %; size, mm				Average diameter d_{av}, mm	Sorting factor S_s
				>1.0	1.0–0.1	0.1–0.01	<0.01		
Laya	$Q_{II}^1 č$	27, 3U	3	0.8	22.6	49.8	27.5	0.037	0.43
Kolva		611, 712	2.6	0.4	13.1	46.1	40.5	0.027	0.31
Pechora		250, 301	2.5	0.2	12.4	47.2	40.3	0.033	0.37
Ilesha		21	3.6	0	1	60.5	38.4	0.012	0.32
Vychegda		208	3	0	20	60.2	19.8	0.042	0.41
Laya	$Q_{II}^3 r$	334, 15, 27, L-29	1.9	1.8	32.5	40.5	24.8	0.047	0.30
Shapkina		9-1, 9-2, 10, 13-1	2.7	0.2	32.5	46	21.5	0.045	0.37
Pechora		246-a, 105, 216, 301	3.2	0.4	8	41.7	50.1	0.019	0.33
Kolva		611, 712, 4-G	2.3	1.2	13	48.9	37.5	0.025	0.27
Seida		8	10.8	0.3	0.9	75.5	23.2	0.024	0.33
Izhma		12a	6.5	0	19.2	73.1	7.7	0.053	0.41
Ilesha		21	5.1	0.1	7.2	31	61.7	0.006	0.31
Vychegda		205	2.6	0.2	24.4	50.9	24.5	0.046	0.30
Pechora	$Q_{III}^1 s$	H-1	4.4	0	11.7	60.1	28.2	0.023	0.33
Laya		L-8, L-11, L-14	1.3	2	50.4	35.0	12.3	0.097	0.42
Shapkina		7-3, 7-v	3.5	0.1	20.9	56.4	22.7	0.035	0.47
Bolshaya Rogovaya		15, 17, 18-2, 27	3.5	3	43.2	35.6	18.3	0.105	0.33
Chernay	$Q_{III}^3 bz$	Ch-3, Ch-4-1, Ch-11-1, Ch-14	4.8	2	13.6	62.2	22.3	0.032	0.35
Ilesha		21	8		6.1	27.7	66.2	0.004	0.38
Vychegda		207, Kur'yador	6.6		7.1	58.9	34	0.015	0.23

its, and they are studied more thoroughly than other interglacial horizons. The Rodionovo age of these sediments is confirmed by very characteristic spore–pollen spectra (Duryagina and Konovalenko, 1993) and also by their occurrence between the Upper Pechora and the Lower Vychegda periglacial alluvium dated using the remains of small mammals. The stratotype of this interglacial is outcrop 211-Rodionovo in the Middle Pechora area (Loseva and Duryagina, 1973; Konovalenko, 1985).

The Rodionovo interglacial sediments were identified and studied by palynological analysis in fourteen sections. In addition to outcrop 211-Rodionovo in the Middle Pechora area, they were found in borehole 341 in the Laya and Yur'yakha interfluve area in the center of the Bolshaya Zemlya tundra (Loseva and Duryagina, 1980), in outcrop 21 (10) in the middle flow of the Shapkina River (Guslitser et al., 1985), in borehole 21 in the watershed of the Pinega and Ilesha rivers (Andreicheva and Konovalenko, 1989), in outcrop 20 on the right bank of the Laya River in its middle flow, in outcrop 437 on the Adz'va River near its mouth, in borehole 611 in the Kolva River basin, in outcrop 205-Ust'-Pozheg in the lower Vychegda area (Duryagina and Konovalenko, 1993), in outcrop 8 on the Seida River (Andreicheva and Duryagina, 1999), in the northwestern Timan area in boreholes 502 and 3 (Loseva and Duryagina, 1989), in Boreholes 754 and 755 (Loseva et al., 1992), and in outcrop 908 on the Moreyu River.

The spore–pollen spectra were studied in outcrop 10 (outcrop 21, after the predecessors) on the Shapkina River (Andreicheva et al., 2015). The lake sediments form the submorainic stratum in a depth range of 14.65–10.75 m and have the following structure. Light gray sands with a thickness of 1 m are overlain by cryoturbated clay (0.7 m) with sand nests and humified material inclusions, overlapped by a half-meter unit of peaty clay with peat interlayers. Up the section, there is a blue-gray clay gradually turning into dense sandy loam with peat inclusions (0.8 m). Brown clayey sand lies even higher (1 m). The described stratum of sandy–clay deposits is covered by a four-meter unit of moraine deposits overlain, with a horizontal contact, by gravel–sand sediments with a thickness of about 6 m. The section is crowned by a half-meter sequence. The palynological diagram shows five palynocomplexes (Fig. 4) demonstrating the replacement of vegetation phases.

R_I is a phase of vegetation typical of present-day tundra and forest tundra. The wood flora is dominated by pollen of *Betula humilis*, while *Betula nana*, *B.* sect. *Albae*, *Alnaster* sp., *Pinus* sp. are sporadic. Cyperaceae, Gramineae, Chenopodiaceae, and *Artemisia* are pre-

Table 2. Mineral composition of heavy fraction of lake sediments

River	Pechora	Kolva	Vychegda	Chernaya	Laya	Pechora	Usa	Seida	Izhma	Vychegda	Khongurei	Laya	Shapkina	Bolshaya Rogovaya	Chernaya	Ilesha	Vychegda
outcrop, borehole no.	301	712	208	Ch-15	L-29	301	4-G	8	12a	205	H-1	L-8, L-11, L-14	7	15, 22, 27	Ch-3	21	207
horizon index	Q_{II}^{1}č			$Q_{II}^{3}r$							$Q_{III}^{1}s$				$Q_{III}^{3}bz$		
HFY, %	1.02	0.43	0.32	0.70	0.29	0.03	1	0.08	0.29	0.63	0.52	0.46	0.49	0.93	0.31		1.1
Magnetite	0.3	2.5	0.1	2	0.7			0.03	0.5	0.7	0.3	7.5	1.4	0.3	0.04		0.7
Hematite		0.6	0.3	2.1				0.02		0.7	1.6	0.4	0.3	0.3	0.5		0.8
Ilmenite	8.9	4.2	5.6	30.8	3.5	5.2	5	8.6	8.1	8.1	8.6	9.6	3.2	5.7	0.3	2	5.8
Epidote	32.7	29	28.3	13.6	42	32.9	30	36.2	21.7	22.7	25.7	33.6	37.4	40.3	26	23	19.3
Amphibole	10.2	5	19.6	9.6	12.3	12		6.3	33.4	22.9	17.9	7.3	11.9	7.7	13	45	22.9
Garnet	12	13.5	18.1	14.6	10.2	27.3	35	9.3	22.3	21.3	20.7	18.5	7.4	10	7.9	15	25.4
Pyrite	9.1	7.9		17	0.3		3	1.6				0.1	0.9	3.3	1.3	1	5.6
Siderite	10.9	15.7		1.1	4.8	0.7	20	11.7			0.1	0.2	8	9.6	30.2		15.9
Zircon	0.6	1.2	1.4	1.1	3	0.4		6.2	1	2.5	1.5	2.1	5.2	1.7	0.3		1.5
Rutile	0.4	0.2	0.8	1.2	0.8	0.6	2	0.4	1.5	1.4	1.1	0.7	0.9	0.7	0		0.7
Titanite	4.2	1.5	1.8	1	2.6	6	u.v.	1.4	2.2	2.3	3.3	3.8	2.9	2.1	1.0		1.1
Leucoxene	4.1	3.4	3.8	0.6	10.2	3.2	5	10.8	3.1	3.7	3.1	8.9	5.1	7.5	1.3		2.5
Ti mineral group	8.7	5.1	6.4	2.8	13.6	9.8	7	12.6	6.8	7.4	7.5	13.4	8.9	10.3	2.3	2.5	4.2
Kyanite	1.4	1.6	8	0.04	2.4	1.1	occ.	0.4	2.1	3.2	3.1	5.5	0.6	1.3	2.5		5
Staurolite	1.2	3.8	1.9	0.2	0.2	0.7		occ.		1.2	0.7	0.6	0.1	0.03	0.6		2.1
Sillimanite	2.4		0.2	0.04		0.2				0.2	0.2			0.03			0.3
Metamorphic mineral group	5	5.4	10.1	0.3	2.6	2		0.4	2.1	4.5	3.8	6.1	0.7	1.3	4.5	5	7
Tourmaline	1.1	0.9	1.2	1.1	0.9	1.3		0.4	occ.	0.9	1.4	1.1	1.3	1.6	0.6		1.4
Apatite	1.1	4.4	3.3	3.3	0.5	2.2	occ.	0.6	1.9	2	3.9	1.4	0.9	0.7	0		1.4
Pyroxene	0.1	0.6	5.1	0.1	0.5	1		5.6	occ.	2.4	5.8	0.7	1.2	0.5	0.1		4.3
Limonite		0.02	0.5	0.3	5.6	5.2	occ.		2.2	3.9	0.9	1.9	10.1	3	12.4		2.8

(HFY) heavy fraction yield; (occ.) occasional.

dominant in the herbaceous cover. Ground vegetation is composed of green moss. The climate was relatively cold and dry.

R_{II} is a phase of birch–pine and birch–spruce forests with sporadic cedar and broad-leaved species (oak, elm, and horn beech), which developed in the moderately warm climate.

R_{III} is a phase of sparse forests including birch with pine and spruce. The role of subarctic components increases: *Betula nana*, up to 10%; *Alnaster fruticosus*, up to 16%. Shrub and bog associations became widespread under the general cooling of the climate.

R_{IV} is a phase of birch–spruce forests with pine. *Spruce* sect. *Omorica* and nemoral *Quercus* sp., *Ulmus* sp., *Carpinus* sp., *Corylus* sp. are few. The herbal plants are diverse: along with xenophytes (Chenopodiaceae, *Artemisia* sp.), there are mesophilic and aquatic plants (family Nymphaea). The soil cover contains *Osmunda* sp. and *Diphazium complanatum*. The vegetation is indicative of relatively warm and wet climatic conditions.

R_V is a phase of birch–spruce sparse woods, shrub groups and marshes under the general cooling of the climate.

The established phases characterize in general the vegetation of the interglacial period with two optima (R_{II} and R_{IV}). Specific features of the flora and the presence of *Picea* sect. *Omorica* pollen indicate sedimentation in this part of the section in the Rodionovo interglacial. According to the obtained data on the palynological complexes, the climatic optima in the north of the Timan–Pechora–Vychegda region were presumably characterized by an average July temperature of 14–16°C, exceeding the current temperature by 4°C. In the south of the Komi Republic, the July temperature was 16–18°C, which is also higher than present-day temperatures by 1–2°C. The amount of precipitation throughout the studied area was 300–400 mm in the warm period and 175–200 mm in the cold period (Andreicheva et al., 2006; Andreicheva and Marchenko-Vagapova, 2015).

According to the data on the grain size distribution, the Rodionovo sediments are composed of clay and silt (d_{av} = 0.006–0.053 mm) with occasional insignificant impurity of gravel material (Table 1). Dark gray sediments with a bluish or yellowish brown shade and an average sorting grade are predominant (S_s = 0.27–0.41). The amount of material soluble in 2% hydrochloric acid varies, but the lake sediments from outcrop 8 on the Seida River are characterized by a high total carbonate content (10.8%, on average), which, apparently, is due to the underlying Pechora moraine deposits, where the carbonate content reaches 17.5%.

The heavy fraction yield in the Rodionovo sediments is highly variable (Table 2): from negligible 0.03–0.08% in Borehole 301-Kushshor and in outcrop 8-Seida to 1.01% in Borehole 4-G on the right bank of the Usa River. The composition of the mineral spectra by area also varies, but they are based on epidote almost everywhere. Its maximum concentrations are confined to the center of the Bolshaya Zemlya tundra where 30–42% of the heavy fraction is epidote. Southwards, on the Izhma and Vychegda rivers, the epidote content does not exceed 22–23%, suggesting generation of the Rodionov sediments from the Pechora moraine (Andreicheva et al., 2015, Table 7). The amphibole and garnet contents are highly variable in the region; their lowest values are recorded in the Seida River valley, which is also typical of the underlying Pechora moraine. On the Chernaya River, almost a third of the heavy fraction is ilmenite (30.8%), which is not explained at this stage of investigation.

Sula (Mikulino) interglacial Horizon (Q^1_{III}s). The lake sediments of this horizon are represented by clastic deposits with a diverse grain size distribution: evidently predominant silt and also clay, loam, fine-, medium-, and uneven-grained sand (Andreicheva and Marchenko-Vagapova, 2013, 2014). The sediments are dark gray with different shades: from brownish to bluish and blue-gray; some sediments are peaty. A few sections were assigned to the Sula Horizon on the basis of the palynological data: on the coast of Khaipudyr Bay (Loseva and Duryagina, 1987), in Borehole 502 of the Northwestern Timan area (Loseva and Duryagina, 1989), and near the lower Pechora area (Berdovskaya, 1976).

In the south of the investigated region, the sediments of supposedly Sula age were studied in outcrop 6-Vym' located on the right bank of the Vym' River, 3.5 km below the mouth of the Pok'yu River (Andreicheva and Marchenko-Vagapova, 2014). The base of the section with a total thickness of 5.2 m is composed of pebble–gravel–sand sediments (0.25 m) overlapped by a ten-centimeter layer of gray fine-grained sand. It is overlain by heavy lake blue-gray loam with a thickness of 0.6 m devoid of fragmental material. Up the section, there is a unit 1.75 m in thickness composed of brown fine-grained sand with inclusions of gravel, pebble, boulders, and brown-gray loam. The section is completed by a 0.9-m-thick loam stratum overlapped by a soil–vegetation layer. Spores and pollen found in gray fine-grained sand and in lake loam (Fig. 5) characterize only one of the Sula interglacial stages (S).

The spore–pollen complexes identified in other sediment sections indicate the interglacial conditions and characterize the following vegetation phases:

S_I is a phase of maximum of the coniferous species (lower maximum).

S_{II} is a phase of birch and pine.

S_{III} is a phase of pine forests with spruce, birch, larch, and broad-leaved species (oak *Quercus* sp., horn beech *Carpinus* sp., and hazel *Corylus* sp.).

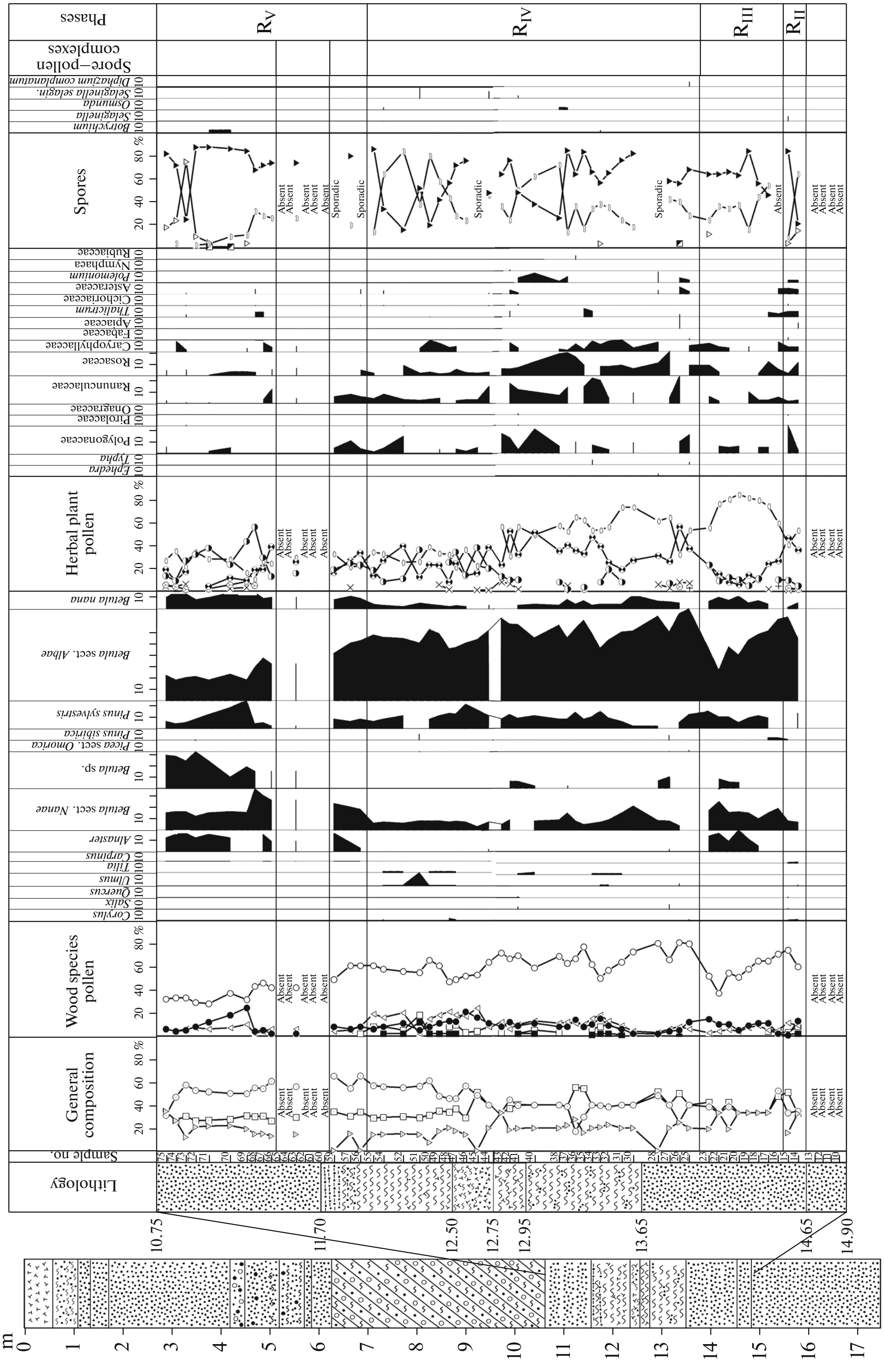

Fig. 4. The spore–pollen diagram of the Rodionovo sediments in outcrop 10-Shapkina. Legend is given in Fig. 3.

S_{IV} is a phase of birch devoid of the broad-leaved species.

S_V is a phase of maximum of the coniferous species (upper maximum of spruce).

S_{VI} is a phase of forest-tundra vegetation dominated by spruce and birch with an important role of dwarf birch.

The materials obtained generally correspond to the palynological criteria of the Sula interglacial (Duryagina and Konovalenko, 1993). They are characterized by falling out of a number of plant phases, although general regularities in changes of the plant communities are retained. The maxima of coniferous species are not always recorded in the climatic optimum period. The alder optimum maximum characteristic of the central and western regions of the Russian Plain is also absent (Grichuk, 1989). The climatic optimum is expressed as the boreal vegetation including birch (mostly *Betula* sect. *Albae*) and birch–spruce and, occasionally, spruce forests with rare broad-leaved species in the north and dark coniferous spruce forests with sporadic broad-leaved species such as oak, elm, linden, hazel, horn beech, and also *Osmunda cinnamomea* L. in the south of the studied region.

The spore–pollen complexes are indicative of an average July temperature of 14–16°C in the north, which is about 3°C higher than present-day temperatures. In Arkhangelsk Region, the average July temperature was 16–18°C, which is 1–2°C warmer than today. In the Sula interglacial epoch, the amount of precipitation reached 350–400 mm in the warm period, and it decreased to 150–175 mm in the cold period.

According to the data on the granulometric composition of the Sula sediments, the area size distribution is characterized by some regularity (Table 1). The finest grain size is characteristic of the Sula sediments in the north of the studied region, in outcrop H-1 in the lower reaches of the Pechora River and in the Shapkina River valley. The average grain diameter d_{av} is 0.023 and 0.035 mm, respectively. In the Laya and Bol. Rogovaya river valleys, enriched in both silt and sand, occasionally with gravel, the sediments are characterized by the largest average diameter of fine earth: d_{av} = 0.092–0.103 mm on the Laya River, 0.105 mm on the Bol. Rogovaya River, and 0.221 mm in some samples.

The heavy fraction content varies from 0.46 to 0.93% (Table 2). The heavy mineral assemblages are also variable. The lake sediments overlapping the Vychegda moraine are dominated by epidote with an average content of from 26% in the northwest of the studied region to 40% in the northeast; these variations are also characteristic of the underlying Vychegda moraine: the epidote concentration varies from 17 to 49% in the same direction (Andreicheva, 2002). The HFY reaches 2.5% in some gravel–sand samples from the shallow-water facies on the Bol. Rogovaya River, and 47% of heavy minerals is epidote. In the north of the region (outcrop H-1) and in the Laya River basin, the heavy fraction of limnic deposits is enriched in garnets amounting to 21 and 19%, respectively. The leucoxene content in the lake sediments increases eastwards, which is also noted for the Vychegda moraine. The leucoxene concentration is 5% on the Shapkina River, increases to 8% in the valley of the Bol. Rogovaya River, and reaches 18% in some sections, while the siderite content is 10% in the area under consideration. The elevated leucoxene content (9%, on average) in the Laya River sediments is likely related to the fact that formation of the underlying Vychegda moraine was considerably affected by the Timan Ridge rocks enriched in leucoxene (Kochetkov, 1967). The limnic deposits in the Laya River valley are distinguished by a high average magnetite content (7.5%). In some sections, the amount of this mineral is "off the scale" (up to 19%) for unclear reasons.

Byzovaya (Leningrad) interglacial Horizon (Q_{III}^3bz). It was established in the Chernaya and Vychegda river valleys and in the Ilesha and Pinega interfluve area in Borehole 21. The sediments of this horizon are composed of bluish gray, occasionally brownish silt and clay with inclusions of vegetable detritus and small peat nests with plant roots. The sediments are not laminated or they have an unclear stratification owing to lenticular inclusions of light gray fine-grained dense sand. They were studied by palynological analysis in the far north in the outcrops of the Chernaya River (Fig. 6) and in the south of the region in the Vychegda River valley (Fig. 7). The seven identified vegetation phases (Bz_I–Bz_{VII}) correspond to the warming and cooling periods (Marchenko-Vagapova, 2012; Andreicheva and Marchenko-Vagapova, 2014).

Bz_I is an initial phase characterizing the initial stage in development of the Byzovaya vegetation. The spore–pollen spectra are dominated by non-woody components: spores and herbs. Birch pollen dominated by *Betula* sect. *Nanae* (up to 24%) plays the most important role in the identified woody species. The contents of coniferous species *Pinus sylvestris* and *Picea* sp. are not high. As for the herbal plants, the contents of gramineous and marshy plants are high at a somewhat lower content of wormwood. *Ephedra* sp. is rare. Sphagnum moss is predominant.

The vegetation composition reflects the existence of rarefied sparse forests during this period with major birch and minor pine and spruce. The abundant shrub and herbal associations include marshy, gramineous, and wormwood plants. The complex is indicative of cooling and possible aridization of the climate.

Bz_{II} is a phase of early warming. The content of woody plants increases to 37–45% in the general composition of the spore–pollen spectra at a relatively high content of spores and herbs. The woody species are dominated by pollen of birch *Betula* sect. *Albae* (up

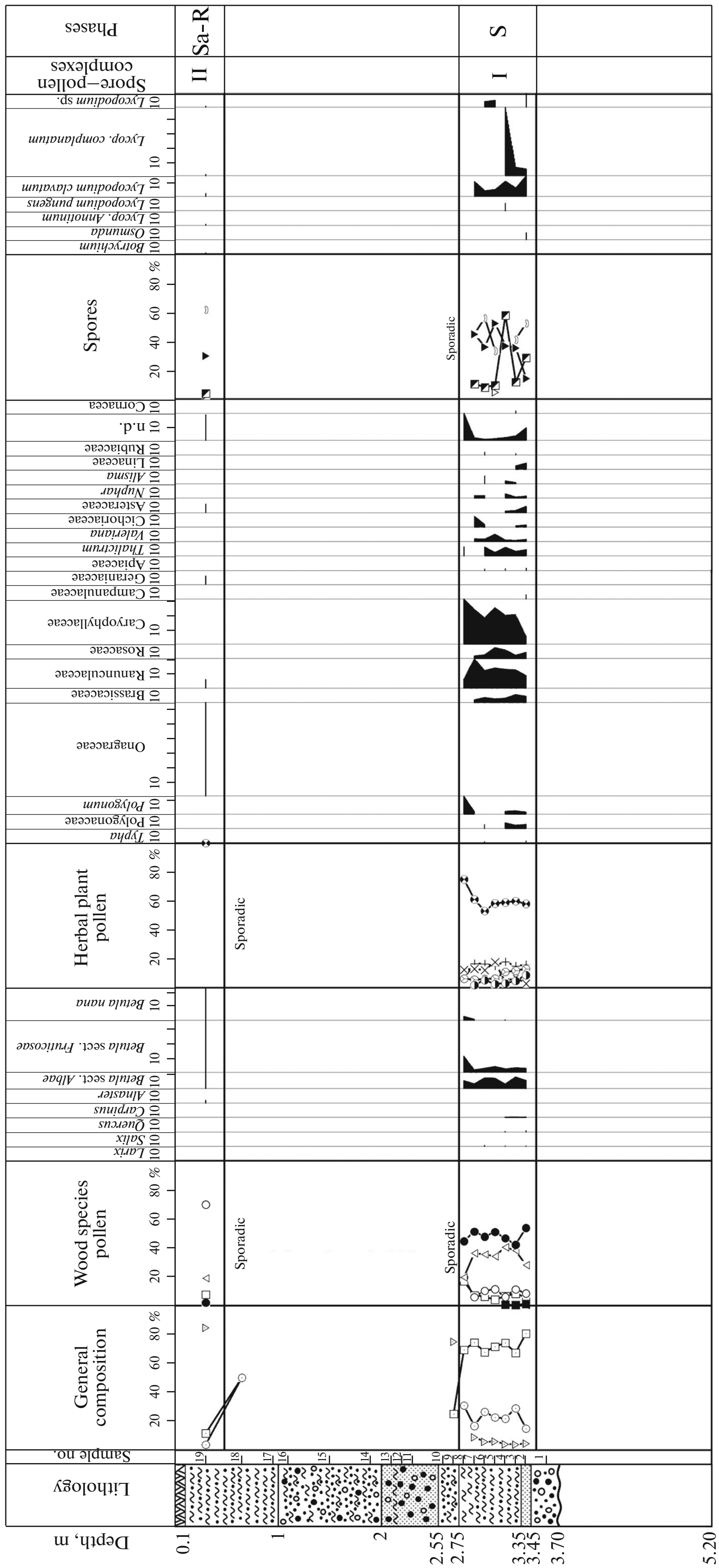

Fig. 5. The spore–pollen diagram of the Sula sediments in outcrop 6-Vym'. Legend is given in Fig. 3.

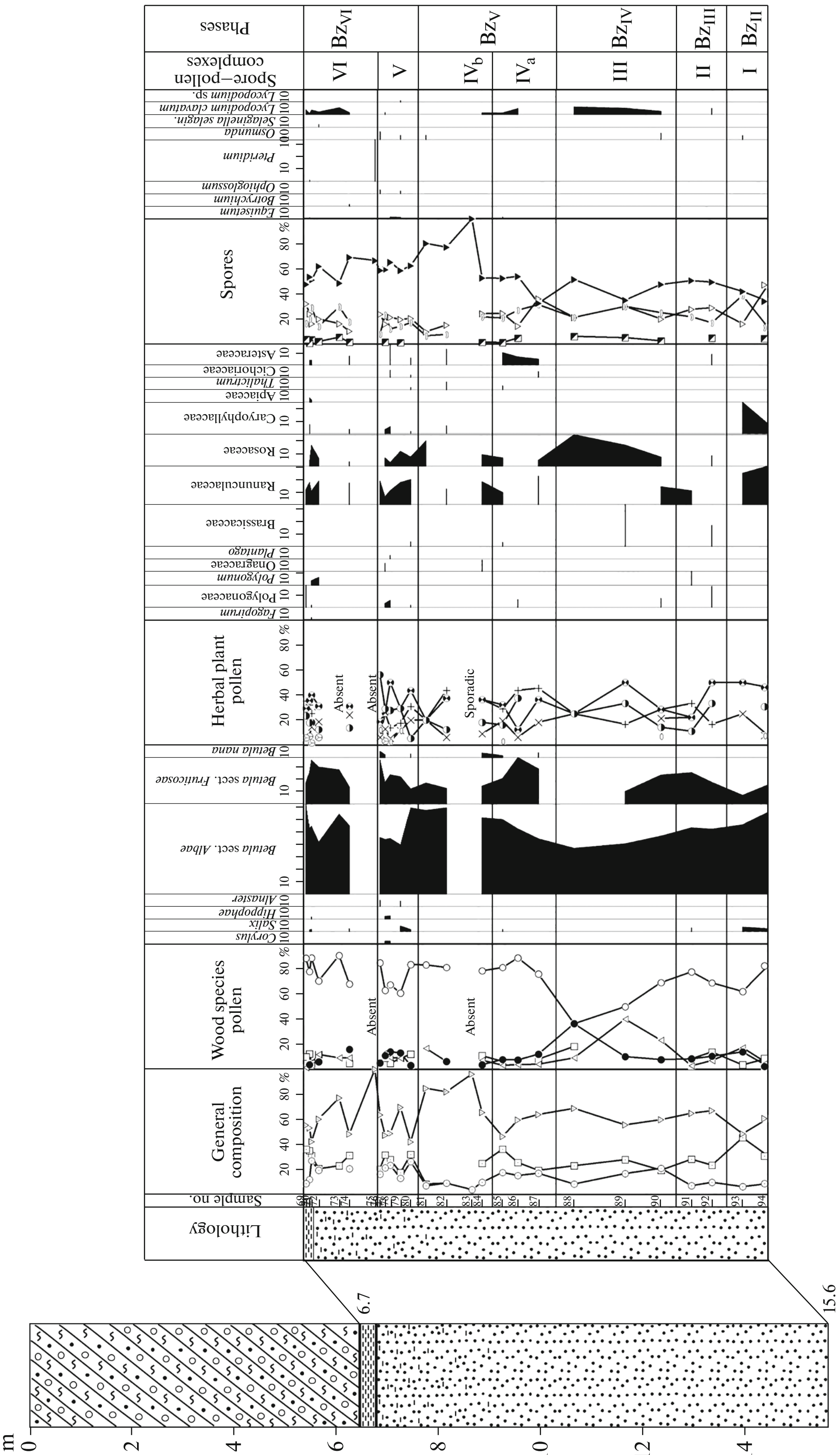

Fig. 6. The spore–pollen diagram of the Byzovaya sediments in outcrop 3-Chernaya. Legend is given in Fig. 3.

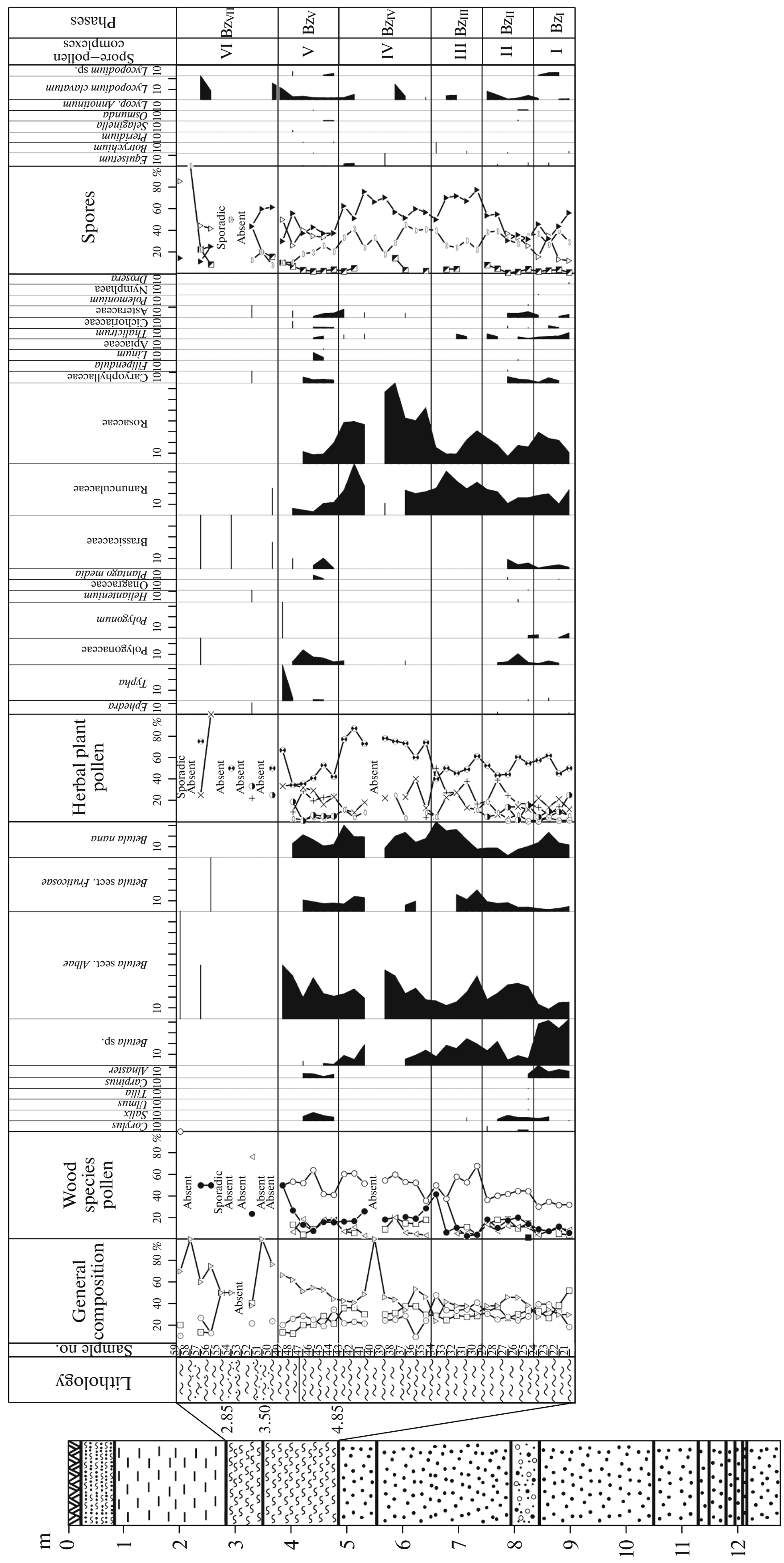

Fig. 7. The spore–pollen diagram of the Byzovaya sediments in outcrop 207-Ryabovo. Legend is given in Fig. 3.

to 65% in the north of the studied area). The content of *Betula* sect. *Fruticosae* is low but constant at a depletion in *Betula* sect. *Nanae*. The role of coniferous species *Pinus sylvestris* and *Picea* sp. becomes more important at an increasing content of spruce in the northeastern direction. The spectra of the southern section are characterized by rare and few pollen grains of broad-leaved *Tilia* sp., *Ulmus* sp., and *Corylus* sp. The herbal plants are dominated by Gramineae. Green and sphagnum mosses and ferns are predominant. *Osmunda cinnamomea* is rare.

The spore–pollen complex is indicative of some warming and wider occurrence of spruce–birch, spruce–pine, and birch forest groups. The flora includes both boreal and hypoarctic and xerophytic periglacial components.

Bz_{III} is a phase of early cooling. The general composition of the spore–pollen spectra is again dominated by herbal pollen and spores. The content of *Betula* sect. *Nanae* increases (to 30% in some samples), while the content of *Betula* sect. *Albae* and *Betula* sect. *Fruticosae* decreases. The pollen contents of spruce and pine gradually decrease in the complex and become negligible in the north of the area. Wormwood becomes more and more important again in the herbal plants (up to 50%) at an abundance of pigweeds and a sporadic occurrence of gramineous plants and sedge. Green and sphagnum mosses and ferns are predominant.

The forest groups lost their dominant position and were replaced by a sparse forest including birch, pine, and spruce. Shrub and herbal associations of open habitats became widespread in occurrence. Abundant marshy–tundra species developed along with xerophytic communities including wormwood, pigweeds, and gramineous plants. The climate was relatively cold and humid.

Bz_{IV} is a phase of moderate warming. The content of woody species increases to 44% in the general composition of the spore–pollen complexes. *Betula* sect. *Albae* (about 60%) is predominant, *Betula* sect. *Fruticosae* (up to 25%) is somewhat less abundant, and *Betula nana* is sporadic. Pollen of coniferous species *Picea* sp. and *Pinus sylvestris* is noted. Some samples contain pollen of broad-leaved species: elm, linden, and hazel. The pollen composition of herbal plants is relatively uniform in the south of the area. Pollen of mesophilic miscellaneous plants is predominant. Wormwood, pigweeds, and sedges are negligible, whereas the contents of xerophytic periglacial flora components become higher to the north. All samples are dominated by sphagnum and green mosses. The composition of ground pines is diverse.

In the region, birch forests occurred in abundance along with spruce and pine. Free spaces were occupied by meadows, as well as xerophytic periglacial communities. Marshes occupied considerable areas. The climate was relatively humid and cold.

Bz_V is a phase of late cooling. The general composition of the spore–pollen spectra is dominated by spores and herbs. In the south of the area, the pollen content of woody species decreases to 13%; in the north, this pollen is either absent or present in negligible amounts. The species of the family Betulaceae (up to 60%) are predominant among the trees. The coniferous species are minor. In the southern areas, pine becomes more frequent in occurrence (up to 50%). *Artemisia* is often predominant, and the contents of gramineous plants and pigweeds are high at a low sedge content. In general, the composition of miscellaneous plants remained almost unchanged relative to the previous complex. Green and sphagnum mosses are predominant.

The basic components of the vegetation cover likely included thinned-out forest communities including birch, pine, and sporadic spruce, and also diverse shrub groups. The marshy–tundra species were widespread along with xerophytic communities. The climate was cold, but relatively wet.

Bz_{VI} is a phase of late warming. The pollen contents of woody species drastically increase (37%) in the general composition of the spore–pollen spectra, despite the predominance of sporophytes. The wood group is dominated by birch pollen. The contents of coniferous species become higher in the southern spectra, where spruce is 26% and pine is 27%. The herbaceous plants are dominated by gramineous plants. Sphagnum mosses occur in abundance.

The vegetation cover was likely represented by various sparse forest groups: birch, birch–spruce, and birch–pine in the south of the area and birch, pine, and spruce sparse forests in the north. The climate was warmer relative to phase Bz_V.

Bz_{VII} is a final phase characterized by the dramatic cooling. The general composition of the spore–pollen spectra is dominated by spores and herbs; the pollen content of woody species becomes much lower or wood pollen is completely absent. The wood pollen is dominated by birch. The role of the coniferous species becomes less important. The representatives of xerophytes are rare in occurrence (wormwoods and pigweeds), while gramineous plants are predominant. Sporophytes are dominated by green and sphagnum mosses. *Selaginella selaginoides* plants are sporadic.

The flora composition of that time confirms the fact that the main components of the vegetation cover included thinned-out birch forests and various shrubby groups. Hygrophilous herbaceous associations, characteristic of the forest-tundra and tundra zones, grew everywhere. Spiridonova (1989) believes that such spectra are related to the final stages of the Early and Middle Valday and are confined to the sediments preceding the glaciation maxima.

Hence, the conducted studies of the spore–pollen complexes of the Byzovaya sediments confirm the earlier conclusion that the climate was interstadial in the

Middle Valday time, much colder compared to the current climate (Guslitser and Duryagina, 1983; Andreicheva and Duryagina, 2005). The found Byzovaya vegetation phases are analogous to the phases of the Middle Valday interstadial sections in the Shapkina River basin (Arslanov et al., 1977) and the stratotype section Grazhdansky Prospekt (Arslanov et al., 1975; Spiridonova, 1983).

In the Byzovaya time, the July temperatures in the north of the region were 10–14°C, thus being consistent in general with the present-day temperatures. In the south of the Republic of Komi, the temperatures were the same (10–14°C), thus being colder by 2–6°C than today. The amount of precipitation reached 350–400 mm in the warm period and decreased to 200 mm in the cold period.

The Byzovaya sediments were subjected to lithological studies in the Chernaya and Vychegda river valleys and in borehole 21 in the Ilesha and Pinega interfluve area (Table 1). The degree of sorting of the lake sediments is $S_s = 0.23–0.38$; their average diameter is highly variable: from 0.004 to 0.032 mm. The total carbonation of the lake sediments is also not constant, varying within a wide range from 4.8 to 8%.

A high content of heavy minerals (1.1%) is noted in the Byzovaya sediments in the Vychegda River basin, while on the Chernaya River, it is 0.31% (Table 2). The basic components of the mineral spectrum include epidote, amphibole, garnet, and siderite. But their various contents are related to different mineral assemblages of the heavy fraction: Chernaya River, limonite (12%)–amphibole (13%)–epidote (26%)–siderite (30%); and Vychegda River, siderite (16%)–epidote (19%)–amphibole (23%)–pomegranate (25%). The lake sediments of the Ilesha and Pinega interfluve area are characterized by a garnet (15%)–epidote (23%)–amphibole (45%) heavy mineral assemblage.

CONCLUSIONS

In the Middle Neopleistocene, during the Chirva interglacial, the regional climate was warm with two climatic optima. The first optimum was characterized by a warm and wet climate and development of spruce and fir–spruce forests with sporadic pine and birch at 10% of broad-leaved species. The second optimum was drier and cooler, while broad-leaved and exotic trees grew sporadically. The natural landscapes had the appearance of tundra at the final interglacial phases.

The Rodionovo interglacial was also characterized by two climatic optima. The first climatic optimum was less wet than the first optimum of the Chirva interglacial, but warmer and wetter than the Holocene optimum. The second optimum was cooler and xerophilic. At that time, the area was covered with dark coniferous forests of the southern taiga type with broad-leaved and exotic species. The following climatic deterioration was characterized by birch open woods and then by tundra.

In the Late Neopleistocene, in the Sula period, the vegetation of the climatic optimum was similar to that of the southern taiga and was represented by ordinary boreal species with broad-leaved components.

In the Byzovaya interstadial during warming, the woody plants were dominated by arborescent birch *Betula* sect. *Albae* in the north of the region. The role of the coniferous species *Pinus sylvestris* and *Picea* sp. was great, and the spruce content increased in the northeastern direction. The pollen of the broad-leaved species such as elm, linden, hornbeam, hazel, and alder was rare in the spectra of the southern and northwestern sections in the area. Xerophytic flora components were also present in the area in addition to boreal flora components and bog and meadow plants. The climatic conditions of the warming periods were similar to the present-day environment. As for the cooling periods, the spore–pollen complexes were indicative of forest-free landscapes. In the north, woody plants became much rarer: they were either absent in the complex or noted in small amounts. The basic components of the vegetation cover likely included thinned-out wood communities of birch–pine components with rare spruce and diverse shrub groups of dwarf birch and willow at a constant occurrence of *Selaginella selaginoides* spores. That period, along with the pollen of the tundra and forest-tundra plant species, was marked by abundant pollen of xerophytes (wormwoods and pigweeds). The climatic conditions of that time were cold and dry.

The granulometric composition of the studied sediments was variable, which was likely due to formation in different parts of the lake: subaquatic clay and silt were deposited in a deep part of the lake, while sand and pebble–gravel were accumulated in its shallower parts.

Despite some changes in the mineral composition of the lake sediments depending on the area, it is relatively uniform in the section. This phenomenon is likely related to location of the drifting areas and uniform sedimentation conditions throughout the lake stratum development. The mineral composition of the lake sediments was formed largely owing to the material of the underlying moraine deposits.

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