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Stratigraphy, paleogeography and paleoclimates of the Pleistocene in the north of European Russia

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The research of the Quaternary in the north of European Russia has been made by using lithological methods for studying composition of deposits and also paleobotanical and paleozoological remains. It allowed to reconstruct landscapes and climates during the Neopleistocene and to establish the stages of environmental history which correspond to sedimentological cycles in the Quaternary sequence. Glaciation centers are identified for different Pleistocene epochs based on lithological criteria. The general tendencies in spatial and temporal variability of the glacial beds composition of different ages were revealed. This allows correlating the glacial deposits. Paleogeography and climatic conditions during interglacial epochs of the Middle–Late Pleistocene and Holocene were reconstructed. Variations in vegetation development, temperature and humidity were found for the first time in Timan-Pechora-Vychegda, Arkhangel'sk and Vologda regions. A conclusion is made about the tendency of climate cooling in the north of European Russia during the Pleistocene.

Key words: Pleistocene, Holocene, correlation, glaciation, interglacial epochs, climate, lithology, palynology

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INTRODUCTION

During the last 60 years the Laboratory of Cenozoic Geology at the Institute of Geology of the Komi Science Center has been occupied with the complex researches of the Pleistocene and Holocene geology in the north of European Russia (Fig. 1). Quaternary sediments are widespread here and a clear rhythmic structure is observed in the Pleistocene sequence. These sedimentary rhythms are caused by the climatic oscillations in the region, i. e. alternations of long cool epochs and relatively short warm episodes (Table 1). These rhythms are recognized by interbedding of glacial deposits – tills and interglacial sediments of different origin: alluvial, lacustrine and marine facies bearing fragmented and intact molluscan shells. The distinction of discrete sedimentological cycles is extremely important for solving the debatable problems of paleogeography and stratigraphy of Pleistocene continental sediments. The cycle's structure reflects the sedimentation in a certain sequence: glaciation–deglaciation–interglacial. Every sedimentary cycle is represented by a paragenetic association of deposits – upwards from glacial to interglacial sediments. The glacial and glaciofluvial sediments are regionally widespread and stable, while interglacial facies usually occur only as lens-shaped interbeds or isolated lenses (Fig. 2).

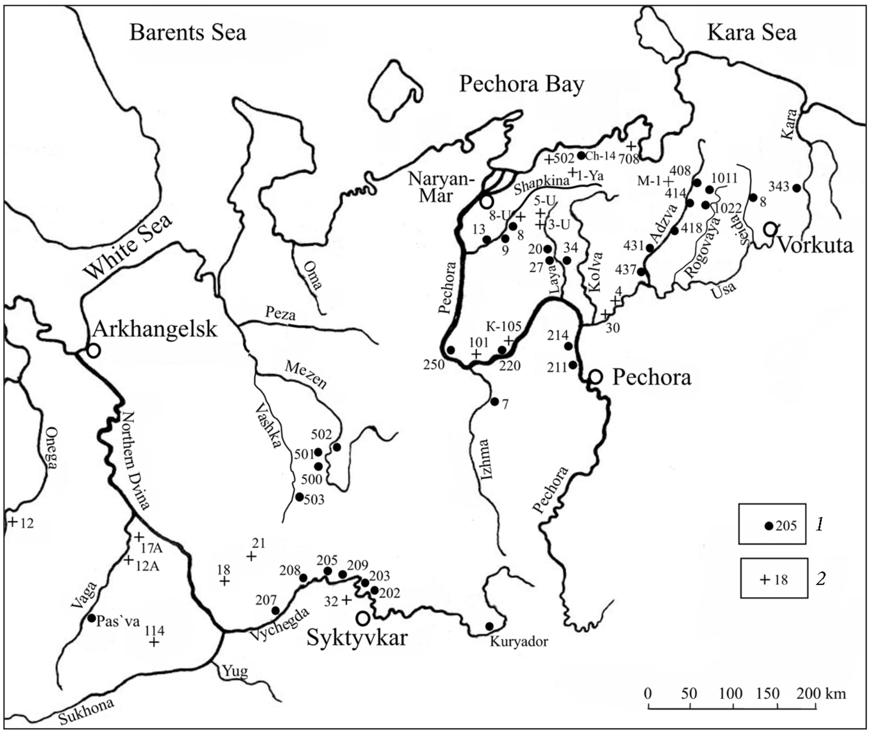

Fig. 1. Map of the study area. Sections are marked with numbers. *1* – outcrops, *2* – boreholes
1 pav. Tyrimų ploto žemėlapis. Nuogulų pjūviai pažymėti numeriais. *1* – atodangos, *2* – gręžiniai

Table 1. **Comparison of regional and interregional stratigraphic charts of Quaternary sediments on the Russian Plain (Krasnov, Zarrina, 1986)**

1 lentelė. **Rusijos lygumos kvartero nuogulų regioninių ir tarpregioninių stratigrafinių schemų palyginimas**

Series	Stage	Regional stratigraphic chart of Quaternary sediments of the Timan-Pechora-Vychegda region		Regional stratigraphic chart of Quaternary sediments of the North and North–East in the East European Craton		Interregional stratigraphic chart of Quaternary sediments in the East European Craton	
		Suprahorizon	Horizon	Suprahorizon	Horizon	Suprahorizon	Horizon
Neopleistocene	Q_{IV}		Holocene		Holocene		Holocene
	Upper Q_{III}	Nenets	Polar (Q^4_{III}) Byzovaya (Q^3_{III}) Laya (Q^2_{III})	Valday	Ostashkov (Upper Valday) Leningrad (Middle Valday) Podporozh'e (Lower Valday)	Valday	Ostashkov glacial Leningrad interglacial Podporozh'e glacial
			Sula (Q^1_{III})		Mikulino		Mikulino interglacial
	Middle Q_{II}	Timan–Ural	Vychegda (Q^4_{II}) Rodionovo (Q^3_{II}) Pechora (Q^2_{II})	Middle Russian	Moscow (Babushkino) Gorka Dnieper (Vologda)	Middle Russian	Moscow (Sozh) glacial Shklov interglacial Dnieper glacial
			Chirva (Q^1_{II})		Likhvin (Trubaika)		Likhvin interglacial
	Lower Q_I	Komi–Perm	Pomusovka (Q^6_I) Vishera (Q^5_I) Bereza (Q^4_I)		Oka (Pichuga) Svirsk	Byelorussian	Oka (Berezinsk) glacial Belovezh'e (Muchkap) interglacial Don (Dzuki) glacial
			Tum (Q^3_I) Kam (Q^2_I)	Vilnius	Paisk Prionezhe		Il'in interglacial Pokrov glacial Mikhailov interglacial

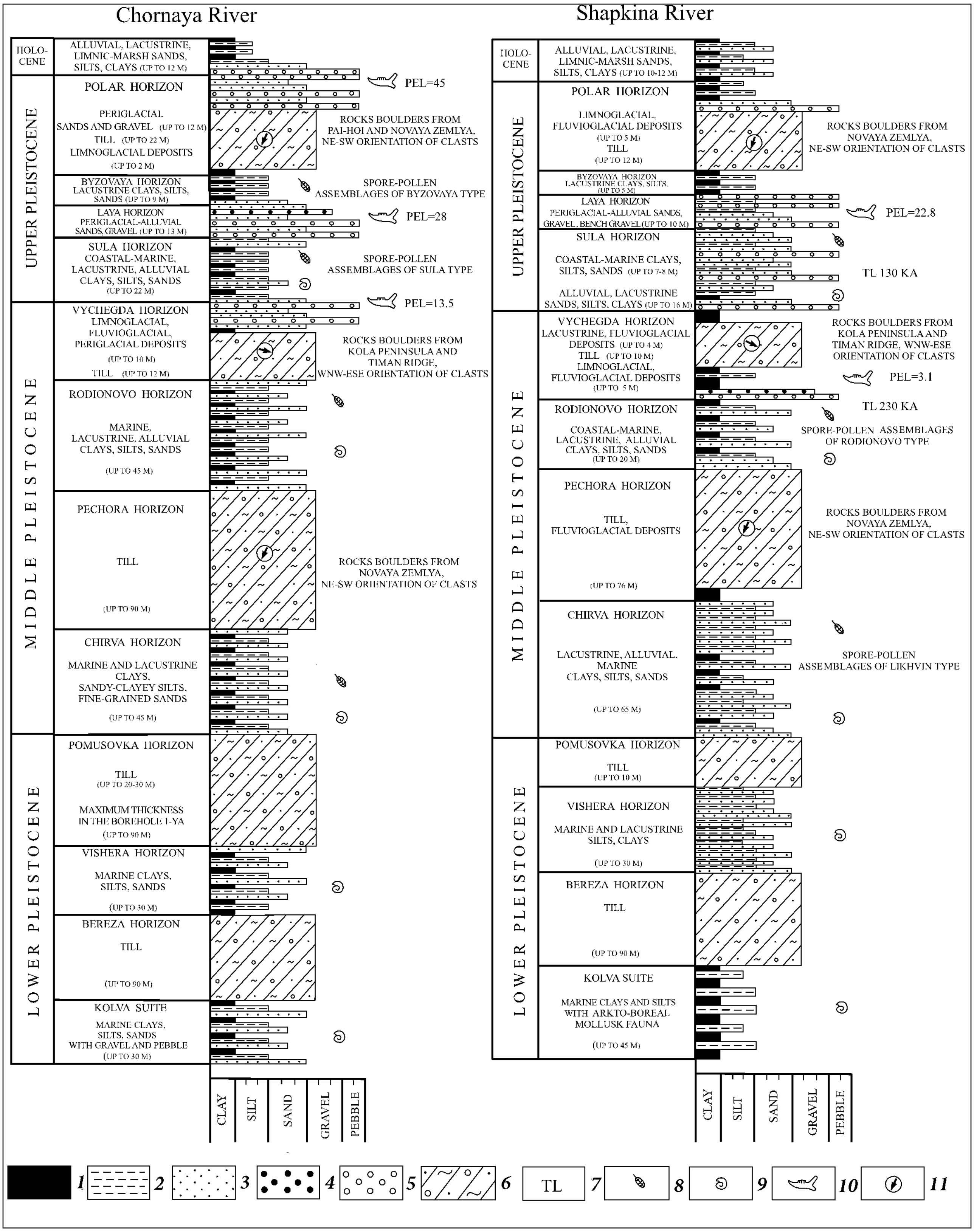

Fig. 2. Composite outcrops of the Quaternary sediments in the European north-east of Russia.
1 – clay, *2* – silt, *3* – sand, *4* – gravel, *5* – pebble, *6* – till, *7* – TL-dates, *8* – spore and pollen, *9* – mollusks, *10* – micromammals, *11* – clast fabric

2 pav. Europinės Rusijos šiaurės rytų kvartero nuogulų suvestinės atodangos. *1* – molis, *2* – aleuritas, *3* – smėlis, *4* – žvirgždas, *5* – gargždas, *6* – moreninis priemolis, *7* – TL datos, *8* – sporos ir žiedadulkės, *9* – moliuskai, *10* – mikrožinduoliai, *11* – uolienų nuolaužų orientacija

The Cenozoic history of the region is studied to a different extent. Nevertheless, available data makes it possible to define six separate rhythmic units in the Pleistocene sequence, corresponding to certain sedimentary cycles: Late Pliocene–Early Pleistocene, Pomusovka–Chirva, Pechora–Rodionovo, Vychegda–Sula, Laya–Byzovaya and Polar–Holocene (Fig. 3).

The boundaries between main stratigraphic units in the Pleistocene are usually placed along the bottom of interglacial sediments inside the sedimentological cycles (Krasnov, Zarrina, 1986). In our opinion, it is better to draw those boundaries along the bottom of glacial sediments, which are much more laterally stable (Gaigalas, 1979; Grigor'ev, 1987; Lavrov, Potapenko, 2005). The lower part of the cycle, as a rule, is made of a glacial sediments association which is the obligatory part of a cycle – till and glaciofluvial sediments. The upper part of a cycle consists of a polyfacies assemblage of interglacial deposits. A complete cycle usually has fluvio- and glaciolacustrine deposits of ice advance, underlying the till, and sediments of lacustrine-glaciofluvial origin overlying the till and corresponding to the deglaciation period.

MATERIALS AND METHODS

Field works were carried out practically along the whole territory of the Komi Republic from the Barents Sea coast in the north to the Vychegda River in the south, and also in some areas of Arkhangelsk and Vologda regions (Fig. 1). Quaternary deposits lie as a cover over depressions, forming terrace-like surfaces, and make foothill slopes.

Quaternary deposits, exposed in outcrops and boreholes in the Timan-Pechora-Vychegda region and in the northwest of European Russia (the southern part of the Arkhangelsk region and the northern part of the Vologda region), were studied by different methods (Andreicheva, 1992, 2002, 2007; Andreicheva et al., 1997). The lithological method included the analyses of granulometry (more than 4 500 samples) and mineralogy (1 500 samples), petrography of till's matrix (3 500 microsections of diamictons), petrographic composition of pebbles from tills of different age (900 samples) and also clasts fabric in tills (more than 40 000 measurements).

Small mammal fauna, sometimes found in periglacial Quaternary sediments, was studied by a special quantitative morphological method, worked out in the Laboratory of Cenozoic Geology of the Institute of Geology. This method allowed to stratify the Quaternary sequence by a special measure – "Parameter of Evolutionary Level" (PEL) of micromammals (collared lemmings) (Kochev, 1993). Unfortunately, the localities of micromammalian remains are quite rare.

An interest to the paleoclimatic studies has grown in the recent decades (Velichko et al., 1997 a). In this connection the investigations of the Quaternary climates and vegetation in the region are especially important because they may help understanding climate changes in the future. In the region the reconstructions of paleoclimates during interglacial periods of the Pleistocene and Holocene were carried out by D. A. Duryagina and L. A. Konovalenko (1993), T. I. Marchenko-Vagapova (Marchenko-Vagapova, 2012; Andreicheva, Marchenko-Vagapova, 2003, 2004), Yu. V. Golubeva (Golubeva, 2008; Andreicheva, Golubeva, 2008; Andreicheva et al., 2006). One of the most effective methods for studying Quaternary stratigraphy and environments is the palynological method, which was used in about 40 sections in the region. The information-statistical analysis developed by V. A. Klimanov (1985) was applied to obtain quantitative climatic characteristics: mean temperatures of January and July, and mean annual precipitation. Nevertheless, the problems of Quaternary stratigraphy, paleogeography, and sedimentology still remain the subject of sharp and incessant discussions.

LITHOSTRATIGRAPHY

The reconstruction of ice sheets, their structure and dynamics made it possible to reveal spatial-temporal peculiarities of composition of different age tills. Those specific features of tills allowed defining stratigraphic units and correlating them within the limits in the north of European Russia (Table 2). The possible positions of glacial centers (provinces) and the main directions which ice sheets followed during different epochs of Pleistocene were suggested on the basis of lithological criteria. It was shown that till horizons of different age are connected with different glacial centers (provinces):

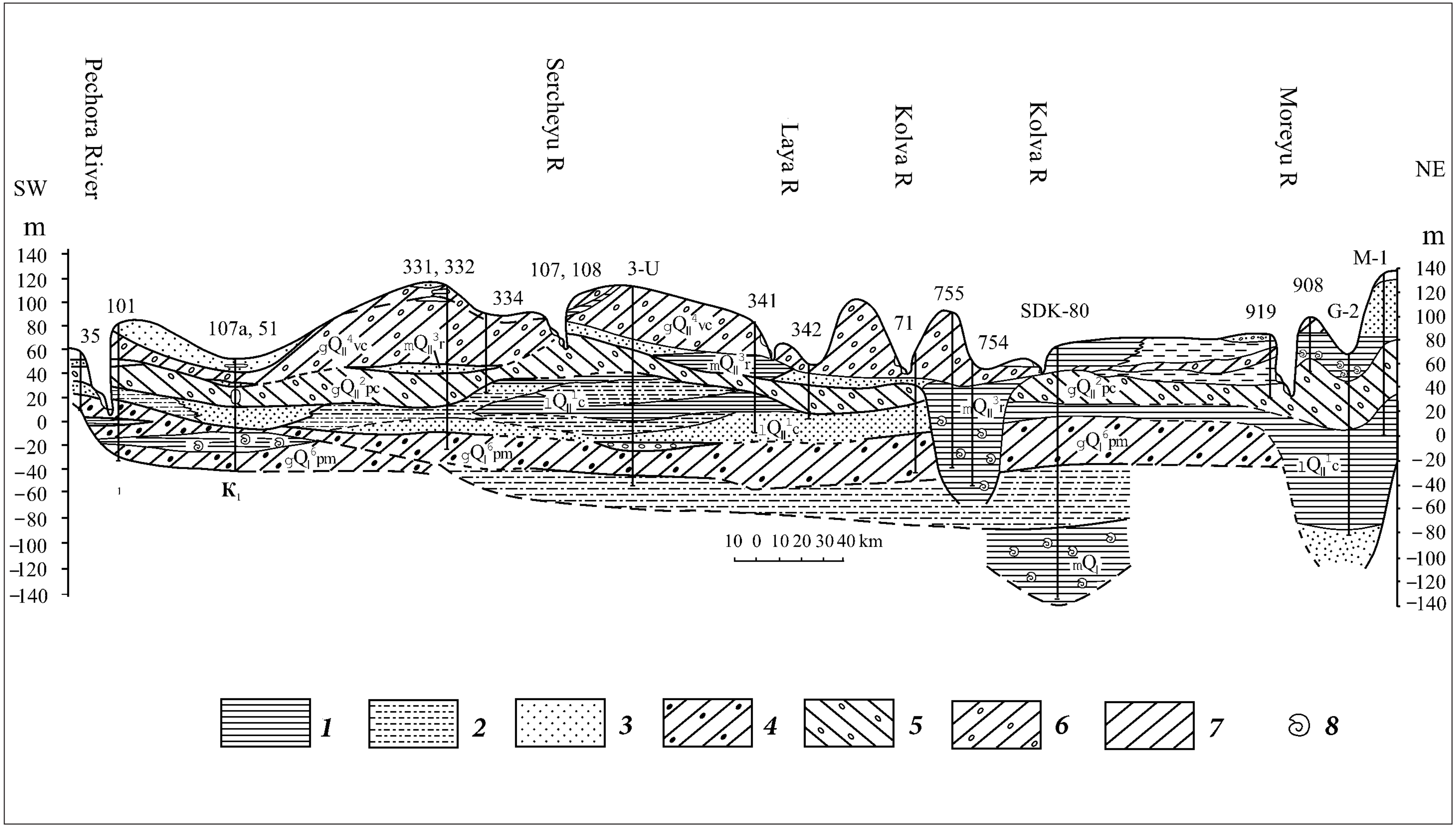

Fig. 3. Generalized geological section of the Pleistocene sediments of the Pechora Lowland.
1 – clay, *2* – silt, *3* – sand, *4* – Pomusovka till, *5* – Pechora till, *6* – Vychegda till, *7* – Polar till, *8* – mollusks and foraminifers

3 pav. Pečioros žemumos pleistoceno nuogulų apibendrintas geologinis pjūvis. *1* – molis, *2* – aleuritas, *3* – smėlis, *4* – Pomusovkos morena, *5* – Pečioros morena, *6* – Vyčegdos morena, *7* – Poliarinė morena, *8* – moliuskai ir foraminiferai

Table 2. **Lithological criteria for subdivision and correlation of the Upper–Middle Pleistocene tills in the north-east of European Russia**

2 lentelė. **Europinės Rusijos šiaurės rytų viršutinio–vidurinio pleistoceno moreninių nuogulų skaidymo ir koreliacijos litologiniai kriterijai**

Region		Index of horizon	Petrographic composition						Indicator boulders, other specific rocks	Fabric analysis	Isotopic dating, Ma		Specific mineral associations and minerals	Mean grain diameter, mm
			*I	*II	*III	*IV	*V	*VI			Rock-flower	Boulders		
Pechora lowland	North–West	Q^4_{III} p	23	22	19	15	9	12	Pink limestones from Novaya Zemlya	NNE 0–60°			**$E_{21}S_{20}G_{15}A_{11}P_9I_4$	0.008
		Q^4_{II} vc^v	14	22	30	15	8	11	Fennoscandian rocks	WNW 290–330°	498–534	1 775	$E_{23}G_{21}A_{19}I_8S_6P_4$	0.024
		Q^2_{II} pc^v	22	14	36	14	4	10	Pink limestones from Novaya Zemlya	NNE 0–45°	288–448		$E_{24}G_{18}A_{13}S_{13}P_8I_8$	0.016
	North–East	Q^4_{III} p	28	14	19	15	14	12	Pink limestones from Novaya Zemlya	NNW-NNE 350–20°			$E_{22}S_{15}P_{14}G_{14}I_{10}A_9$	0.015
		Q^4_{II} vc^v	14	14	26	20	14	12	Rocks from the Polar and Subpolar Urals	ENE-ESE 80–105°			$E_{31}S_{12}G_{10}I_{10}P_9A_8$	0.021
		Q^2_{II} pc^v	11	29	23	17	7	13	Pink limestones from Novaya Zemlya	NNW-NNE 340–60°		245	$E_{25}S_{17}P_{16}G_9I_8A_8$	0.013
	East	Q^4_{II} vc^v	15	13	19	22	15	18	Rocks from the Polar and Subpolar Urals	ENE 40–60°			$E_{36}A_{17}G_{12}S_7P_4I_4$	0.030
		Q^2_{II} pc^v	19	18	27	11	10	15		NNE 0–40°			$E_{37}S_{19}G_{13}I_8A_6P_5$	0.039
The South of region		Q^4_{II} vc^v	9	42	14	15	9	11	Fennoscandian rocks	WNW 285–330°	540–660	1 600–2 020	$A_{40}G_{20}E_{19}I_3P_3S_2$	0.029
		Q^2_{II} pc^v	14	14	38	10	9	16	Pink limestones from Novaya Zemlya	NNE 20–60°	361–435		$E_{22}S_{17}G_{15}A_{13}P_9I_6$	0.036

* I – Paleozoic dark gray limestones and dolomites, II – Paleozoic light gray and white limestones and dolomites, III – local terrigenous rocks, IV – transit terrigenous rocks, V – distant igneous and metamorphic rocks, VI – distant quartzites and quartzitic sandstones.

** E – epidote, G – garnet, A – amphibole, S – siderite, P – pyrite, I – ilmenite.

* I – tamsiai pilki paleozojaus klintis ir dolomitas, II – šviesiai pilki ir balti paleozojaus klintis ir dolomitas, III – vietinės terigeninės uolienos, IV – tranzitinės terigeninės uolienos, V – tolimosios vulkaninės ir metamorfinės uolienos, VI – tolimieji kvarcitas ir kvarcitinis smiltainis.

** E – epidotas, G – granatas, A – amfibolas, S – sideritas, P – piritas, I – ilmenitas.

Northeastern and Northwestern (Andreicheva, 1992, 2002; Lavrov, Potapenko, 2005, 2012).

Thus, the *Pomusovka* (*Oka*) ice sheet has deposited the till, connected with the Scandinavian center. It is indicated by the presence of Scandinavian rocks and by the northwestern orientation of clast fabrics in this diamicton (Fig. 4). The presence of native silver in the heavy fraction of minerals is also one of the important indications of till's northwestern origin. The most probable source for silver is the deposit of non-ferrous metals (copper, gold, and silver), well known since Ivan the Terrible's times. This deposit is located to the northeast of the Ust-Tsilma settlement and was developed during the 15th century.

According to the petrographic composition of boulders and the orientation of clasts, the *Pechora* (*Dnieper*) till in the Timan-Pechora-Vychegda region is connected with the Pai-Khoi-Novaya Zemlya center. The typical feature of the Pechora till is the constant presence of pyrite and siderite among heavy minerals and glauconite among light minerals. Glauconite is very typical for Mesozoic formations underlying the Quaternary sediments almost over the entire region. The total content of these minerals varies in different sections but their proportions are quite stable: siderite always dominates pyrite. The petrographic composition of boulders demonstrates an essential portion of local underlying terrigenous rocks. In the northern and western parts of the region the share of the Cretaceous and Jurassic sandstones and siltstones is 30–46% of all macroclastic material; in the eastern part (Rivers Adz'va, B. Rogovaya, Seyda and middle Pechora) underlying rocks – Triassic sandstones, gravelites, siltstones make up 34–40% of boulders. The Pechora till contains a considerable part of sedimentary and metamorphic rocks of the Polar Urals and Pai-Khoi origin, single fragments of pink marble-like crinoid-bryozoan limestones of Ordovician-Early Silurian age – typical rocks of

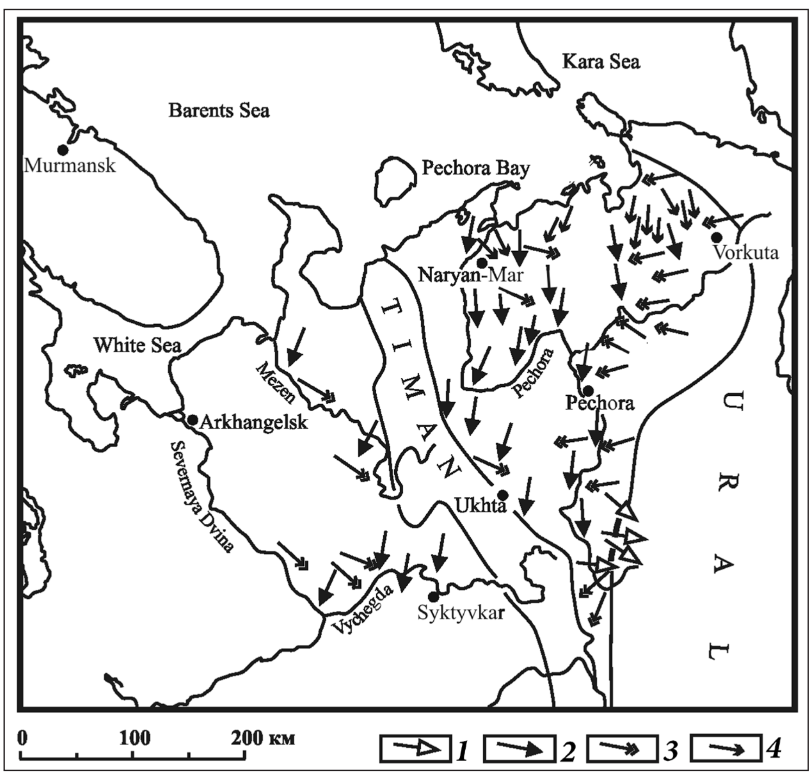

Fig. 4. Linear clast fabric in the tills of the European north of Russia. *1* – Pomusovka (Oka) till, *2* – Pechora (Vologda) till, *3* – Vychegda (Babushkino) till, *4* – Polar (Ostashkov) till

4 pav. Europinės Rusijos šiaurės moreninių nuogulų uolienų nuolaužų orientacijos kryptys. *1* – Pomusovkos (Okos) morena, *2* – Pečioros (Vologdos) morena, *3* – Vyčegdos (Babuškino) morena, *4* – Poliarinė (Ostaškovo) morena the Novaya Zemlya archipelago. Another important trait of the Pechora till is a stable orientation of fabrics axes from the north–northeast to the south–southwest (340–60°) observed in the most part of the territory. In the eastern part the clastic material is oriented towards 20–60°.

To the northeast of the Vychegda River mouth, between the Pinega and Ilesha Rivers, this till is found in boreholes. Here it is also connected with the Pai-Khoi-Ural-NovayaZemlya glacial center (Fig. 1). To the west of the Northern Dvina River at its left bank, the *Pechora* (*Dnieper*) till was deposited with the clastic material of Fennoscandian origin (Andreicheva, 2006, 2013). The zone of coalescence between northwestern and northeastern ice flows can be drawn between the Pinega and Northern Dvina Rivers extending from northwest to southeast.

The Vychegda (*Moscow*) glaciation was developed from two centers that influenced the lithologic and structural features of tills of different parts of the area (Table 2, Fig. 4). A considerable part of Komi Republic, including its central and southern parts, was covered with the Fennoscandian ice sheet. In comparison with the Pechora till, the Vychegda diamicton has a rather high mean share of amphibole and garnet among heavy minerals in most areas; part of pyrite and siderite is negligible and their proportions are variable. Glauconite is represented by grains smaller in size and also its portion is several times less than one of the Pechora till. The clasts of Scandinavian igneous rocks are often found in the Vychegda diamicton, their portion is up to 20%. These are granite-gneisses, granites, amphibolites, gabbro and their metamorphic variants. There are also nepheline syenites and agate-bearing basalts of the Northern Timan Ridge, which can be considered as index rocks for this till. Fabric clasts are oriented from west–northwest to east–southeast that together with the petrographic composition evidentely speaks about the clastic transport from Fennoscandia and the Northern Timan Ridge. The Babushkino (Moscow) till in Arkhangelsk and Vologda regions was also deposited by the Fennoscandian ice sheet (Andreicheva, 2013, in print).

The eastern part of the research area comprising far northeast of European Russia (Adz'va, B. Rogovaya, Seyda Rivers) and the middle of the Pechora River basin was the territory, where another ice sheet developed. This ice sheet had its center in the Polar and Subpolar Urals (Andreicheva, 2012). The direction of Vychegda ice flow from the Urals is supported by the orientation of the clastic material from east to west (80–105°).

During the *Laya* (*Podporoz'e*) time climate was considerably colder than at present but glaciation did not develop over the continent. Sediments assigned to this interval are represented by periglacial alluvial pebbles and sands with ice wedges casts, other cryogenic structures and lemming remains. Landscapes of typical shrub tundra followed by arctic tundra developed in the northern part of the territory.

The last *Polar* (*Ostashkov*) glacial interval is known for the most severe climate. The northern part of the Bolshezemel'skaya Tundra was covered by the ice sheet, advancing from the north–northeast. To the west, the ice sheet limit sharply moved southwards where ice blocked the Pinega basin; some of its lobes reached the latitude of the Vologda town. The clastic material for the *Polar* till at the most part of the Timan-Pechora-Vychegda region was transported from the Pai-Khoi-Novaya Zemlya, and, probably, from the Barents and Kara Seas shelf (Fig. 4). Carbonate rocks (37%) dominate among the boulders, the portion of the local Mesozoic terrigeneous rocks is relatively small (18%). The share of transit sedimentary rocks of Permian and Triassic age is 20%, and distant igneous and metamorphic rocks together with quartzite and sandstones make up in sum 25%. The specific petrographic feature of the Polar till is the constant presence of single boulders of marble-like pink crinoid-bryozoan limestones. These rocks are the indicator rocks for the Novaya Zemlya area. The orientation of clasts from north–northeast to south–southwest (azimuth 550–60°) supports the suggestion that Pai-Khoi-Novaya Zemlya was the center of the ice sheet (Fig. 4). Only in the lower Pechora and Shapkina Rivers and also in the Arkhangelsk and Vologda regions the lithology of the Polar till is different, indicating its connection to the Fennoscandian glaciation center.

Thus, glacial beds of each sedimentary cycle are characterized by specific lithological traits, resulted from the total influence of source areas of clastic material for glacial sediments. Some of these source areas are distant, some transit and some of them are local. The correlation of tills is based exclusively on their lithology (heavy mineral associations, petrography of boulders and matrix, clasts fabric) (Table 2). However, sometimes it is questionable because of the lithological variability of diamictons. It is suggested that such correlation is possible only using lithological and paleogeographical zoning of the study territory according to the characteristics of source clastic material for the tills. In the result of such a classification of the research area 30 lithological regions were separated in the European northeast. Within the limits of each lithological region the correlation of tills is easily made in any direction. The map of lithologic-paleogeographic zoning (Fig. 5) is the main ground for lateral regional and interregional correlations of glacial beds (Andreicheva et al., 1997; Andreicheva, 2008).

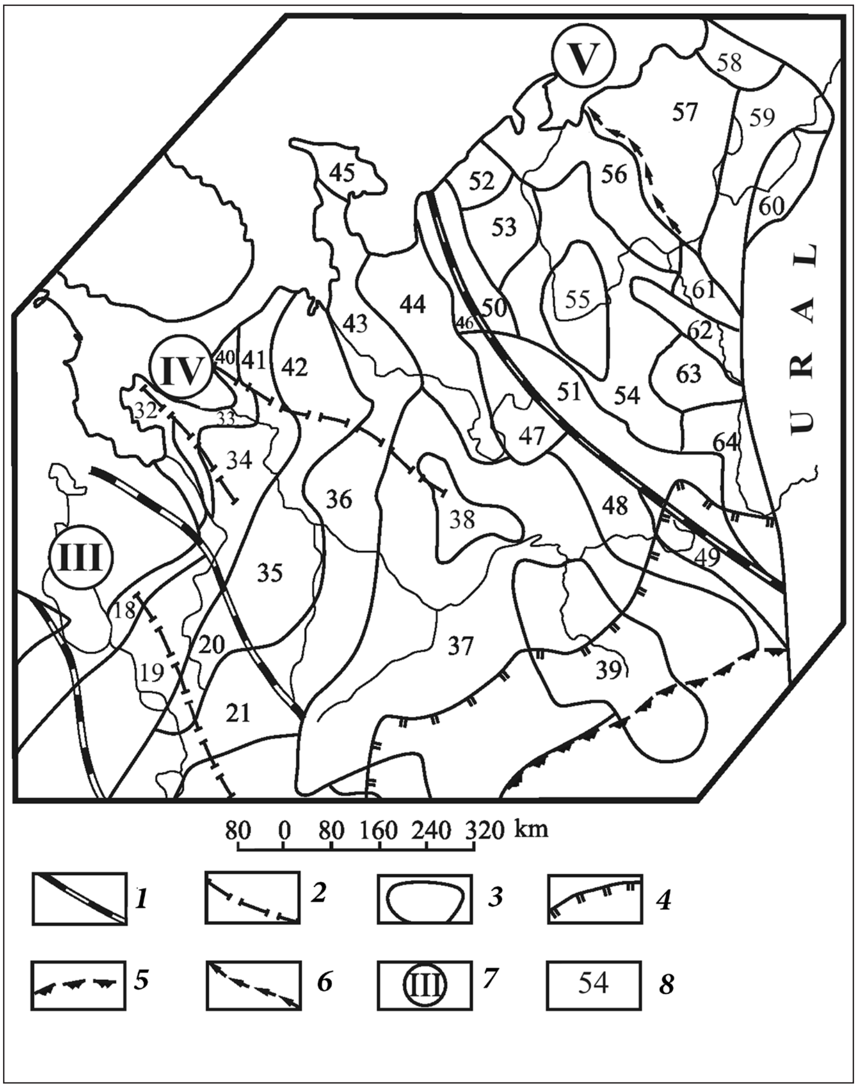

Fig. 5. The lithoregions of the European north of Russia. *1–2* – the boundaries between different ice sheets: *1* – between ice flows, *2* – between ice lobes or glacier tongues, *3* – the lithoregion's boundaries, *4* – the limit of the Vychegda (Moscow) glaciation, *5* – the limit of the Pechora (Dnieper) glaciation, *6* – the hypothetical coalescent zone of the Vychegda glaciers, *7* – lithosectors, *8* – lithoregions

5 pav. Europinės Rusijos šiaurės litoregionai. *1–2* – ribos tarp atskirų ledyno skydų: *1* – tarp ledyno srautų, *2* – tarp ledyno plaštakų ar ledyno liežuvių, *3* – litoregionų ribos, *4* – Vyčegdos (Maskvos) apledėjimo riba, *5* – Pečioros (Dniepro) apledėjimo riba, *6* – hipotetinė Vyčegdos ledynų susiliejimo zona, *7* – litosektoriai, *8* – litoregionai

THE AGE AND THE LIMITS OF THE LAST GLACIATION

At present there are several models of the last glaciation in the Russian Arctic concerning its time and extent. According to the model suggested by A. A. Velichko and his colleagues (Velichko et al., 1997 b, 2000) the glaciation was limited and advanced on the land. There were several separated ice sheets centered in the archipelagoes of the Barents and Kara Seas shelf and in the Polar Urals. Due to the low sea level the Kara Sea was an ice-free continent.

Another glaciation model, based on the interpretation of aerial photo-mapping, was suggested by M. G. Grosswald (Grosswald, 1988; Grosswald, Hughes, 2002). According to this model, the Arctic glaciation was continuous; it spread over both the sea and the continent and covered a significant part of the European northeast. The glaciation center was located in the Kara Sea, and the Kara ice sheet was formed earlier than all other Eurasian ice sheets but melted later. This ice sheet existed until 8.5 kyr, i. e. the Marhida stage.

The third model has taken its final shape in the last years. It was proposed in the frames of the Russian-Norwegian project "PECHORA" (Palaeo Environment and Climate History of the Russian Arctic). According to this model, in the far northeast of Europe the last glaciation reached its maximal extent during the Early Valday interval (100–60 kyr) but not the Late Valday (25–10 kyr). There were no huge ice sheets during the Late Valday (Mangerud et al., 1999; Svendsen et al., 2004). The supporters of this model suggest that the Late Valday ice sheet did not move to the continent from the Barents Sea shelf and the dimensions of this glaciation in the region are strongly overestimated. It is believed that there were two independent ice advances in the Early Valday: 80–90 kyr and about 60 kyr (Astakhov et al., 2007). During its maximum stage glacial covers were represented by continental ice sheets, with centers accumulated over the dried shelf of Barents and Kara Seas. The main ice masses advanced from the shelf where ice caps reached their maximal volume (Astakhov et al., 1999).

In our opinion, no one of the existing models is indisputable. In spite of the grown interest to this problem among the international scientific community, it is still far from the final solution. We still believe that the Barens-Kara ice sheet did not cover Bolshezemel'skaya Tundra during the Early Valday. This point of view is based on the integrated research of the Quaternary sequence by different methods: lithological, palynological and paleozoological. There are periglacial alluvial pebbles and sands with ice wedge casts and other cryogenetic structures and also with small mammal remains exposed in river outcrops. The "Parameter of Evolutionary Level" (PEL) of collared lemmings, excavated from these beds, is 28, that is believed to be of the Early Valday (lower than the Late Valday value, proved by radiocarbon dates). It is important to mention that any sediments assigned to the *Laya* till are still not found in the region. According to our data: lithological, palynological, paleozoological, the Late Valday (*Polar*, *Ostashkov*) glaciation was greatest during the Late Pleistocene. There are glacial deposits assigned to this till, overlying by fluvioglacial and periglacial sediments with collared lemmings molars of PEL 45. Fossil assemblages comprising collared lemmings of such an evolutionary level, for example the Medvezh'ya cave, are dated by radiocarbon to the Late Valday or even Lateglacial (Kochev, 1993). In general, the ice limit coincides with the outer belt of marginal formations proposed by A. S. Lavrov (Lavrov, 1977a, b). Several lobes of the *Polar* ice sheet extended: one of them covered the upper and middle Shapkina Valley, another one covered the upper River Kolva. The Laya Valley remained ice free but in the Adz'va Valley the ice limit is drawn at the middle of the river.

RESULTS OF POLLEN ANALYSIS

Every separate interglacial is characterized by its specific palynological assemblage, typical only for that one interval. More or less reliable paleoenvironments were reconstructed only for the later part of the Pleistocene starting from the *Vishera* (*Belovezh'e*) interglacial period. *Vishera* deposits have been investigated by D. A. Duryagina and L. A. Konovalenko (Duryagina, Konovalenko, 1993) in the two outcrops in the far northeast of the region (in outcrop 343, the Pai-Khoi Ridge and in the Moreyu River basin) and also in the southern part – in borehole 32 in the Vychegda River basin (Fig. 1). During the *Vishera* interglacial there were several climatic and vegetation phases without any clearly pronounced warm interval (climatic optimum). Forest-tundra followed by northern taiga developed in the first half of the *Vishera* time. Subsequent amelioration of climate led to the further distribution of taiga with some share (up to 25%) of broad-leaved trees (linden, elm, oak, hornbeam). Our materials are supported by the data on paleotemperatures and paleoprecipitation (Andreicheva et al., 2008). July temperatures in the region reached 18–20 °C, 2–4 °C higher than modern values in the south and 6 °C in the far northeast of the region (Fig. 6). Precipitation varied with the season: from 350–400 mm during the warm season and 150–175 mm in the cold one. Generally climate of the *Vishera* interglacial was warmer than recent climate.

The analysis of the climatic optima vegetation of the *Chirva*, *Rodionovo* and *Sula* interglacial periods in the north of European Russia has shown that climate was warmer than in modern times. As a result, coniferous forests with broad-leaved species extended far to the north up to the Barents Sea coast. Due to the climatic changes, the northern limit of the forest vegetation migrated north–south to some extent, in comparison with its modern position. Each interglacial period was characterized by the successive change of climatic conditions, typical for only this interval, and, consequently, by the vegetation change.

During the *Chirva* (*Likhvin, Trubaika*) interglacial, climate of the region was generally warm, with two climatic optima found in some sections (Duryagina, Konovalenko, 1993). During the first optimum, climate was warmer and more humid than now; spruce and fir-spruce forests with pine and birch grew; the part of broadleaved trees was up to 10%. The second climatic optimum was drier and cooler than the first one. Tundra landscapes developed during the final phases of the interglacial. Mean July temperatures in the north of the region were 14–16 °C, 2–4 °C warmer than today. The precipitation values during the warm season were 350 mm. In the south of Komi Republic, in Arkhangelsk and Vologda regions mean July temperatures reached 16–18 °C, 1–2 °C higher than the modern values (Fig. 6). The amount of precipitation (warm season) was 255 mm. During the cold season the precipitation did not exceed 50–75 mm growing eastward up to 175 mm.

Also two climatic optima are found during the *Rodionovo* (*Shklov, Gorka*) interglacial. The climate of the first (earliest) of them was warmer and more humid even in comparison with the climate of the Holocene optimum, the second optimum is known for a cooler and drier climate. During the second optimum the entire territory was occupied by coniferous forests of the southern taiga with broadleaved and exotic trees. The followed cooling is characterized by the development of open birch woodlands and then tundra. The *Rodionovo* age is also supported by uranium-thorium isotope dates of 186–242 kyr obtained for peat from the stratotype section "Rodionovo" (Arslanov et al., 2005). Mean July temperatures in the north of the

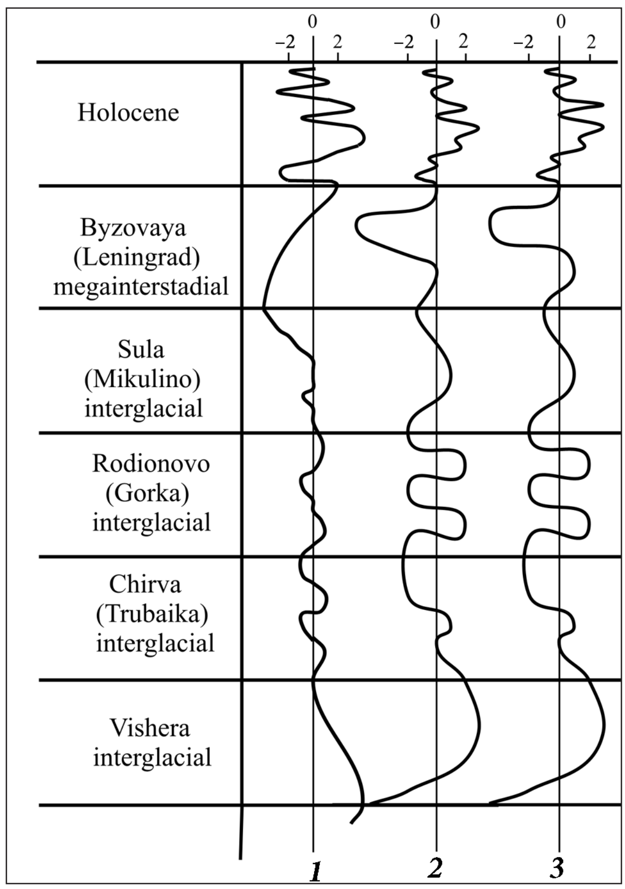

Fig. 6. Temperature fluctuations in the climatic optima of interglacials. *1* – the central part of the Timan-Pechora-Vychegda region, *2* – the southern part of the Timan-Pechora-Vychegda region, *3* – Arkhangelsk and Vologda regions

6 pav. Tarpledynmečių klimatinių optimumų temperatūros svyravimai. *1* – Timano-Pečioros-Vyčegdos regiono vidurinė dalis, *2* – Timano-Pečioros-Vyčegdos regiono pietinė dalis, *3* – Archangelsko ir Vologdos regionai

Timan-Pechora-Vychegda region were 4 °C higher than recent ones – about 16 °C. In the southern part of Komi Republic, in Arkhangelsk and Vologda regions mean July temperatures exceeded modern values to 1–2 °C, accounting for 16–18 °C (Fig. 6). The precipitation over the entire territory was about 300–400 mm during warm seasons and 175–200 mm during the cold seasons.

During the quite warm *Sula* (*Mikulino*) interglacial period, the lacustrine and alluvial sediments were formed except for the northern part (to the latitude of the Shapkina valley and middle of the B. Rogovaya River) where sands and clays of the littoral-sublittoral and transitional zones with abundant sea mollusk fauna were deposited. *Mikulino* deposits were palynologically studied by L. A. Konovalenko only in the one outcrop "Pas'va", situated in the south of the Arkhangelsk region (Duryagina, Konovalenko, 1993). One climatic optimum and two coniferous trees maxima are found in the *Mikulino* interval. Mean July temperatures in the north were 14–16 °C, 3 °C warmer than at present. In the Arkhangelsk region they were 1–2 °C warmer than today and accounted for 16–18 °C (Fig. 6). Precipitation values during the warm season reached 400 mm, falling to 150–175 mm during the cold seasons.

The *Byzovaya* (*Leningrad*) interstadial period was essentially colder than previous interglacials (Andreicheva, Marchenko-Vagapova, 2012). The problem of the status of this warming (whether it is an interglacial or interstadial) still remains unsolved. In our opinion, it is not even an interglacial but a megainterstadial (Andreicheva, Duryagina, 2005). The *Byzovaya* beds are represented by alluvial, lacustrine, and lacustrine-boggy sediments with interbeds of peat, cryogenic structures, and small mammal fauna. The deposits make up the bottom of the first river fill terrace sequences, and higher terraces in the north of the region where they are overlain by *Polar* (Upper Valday) glacial sediments. Byzovaya sediments are well-dated by the radiocarbon method, Paleolithic artifacts and fauna of small mammals. In the beginning of this megainterstadial the northern part of the territory was occupied by the tundra and forest-tundra, but southern part by dark coniferous forests. The climatic and vegetational features were approaching the modern characteristics during the warm intervals. Spore-pollen diagrams of the entire period do not show any climatic optima. Mean July temperatures in the north accounted for 10–14 °C, equal to the modern values. In the south of Komi Republic they were the same (10–14 °C), 2–6 °C colder than at present. Precipitation values during the warm season reached 350–400 mm and 200 mm during the cold seasons. In Arkhangelsk and Vologda regions temperatures of July reached 14–18 °C, 1–2 °C warmer than in modern times (Fig. 6). The precipitation was about 350 mm during the warm season decreasing to 100 mm during the cold seasons.

The five main intervals are usually separated in the chronology of the Holocene: Preboreal, Boreal, Atlantic, Subboreal and Subatlantic (Nikiforova, 1980). These periods are characterized by repeated climatic and environmental changes. An analysis of palynological data shows that the Antlantic period (8 000–5 000 kyr) was the warmest and the most humid period with the optimum during the Late Atlantic time, when the borders of all natural biomes were moved northwards to their maximal positions (450–550 km) (Golubeva, 2008; Andreicheva et al., 2008). Forests occupied nearly the entire region displacing tundra and forest-tundra. The middle taiga with an admixture of alder, fir and some broad-leaved species (up to 6%) developed in the north. The coast of the Barents Sea was occupied by the northern taiga. In the south of the region spruce forests were replaced by the southern taiga with fir and larch; the pollen of broad-leaved trees reached 14% and even 25% in the east (Marchenko, Duryagina, 1996). Mean July temperatures during the Early Atlantic were 15.5–16.5 °C in the north of the region and 16.5–17 °C in the south. During the Middle Atlantic the mean temperature decreased a little (0.5 °C) but the highest temperatures, exceeding modern to 2.5–3.5 °C, as well as the precipitation values were during the last third of the period (Andreicheva, Golubeva, 2008).

CONCLUSIONS

Thus, an integrative study of the Quaternary deposits exposed in river outcrops and boreholes in the European North of Russia made possible the stratigraphic subdivision of the Pleistocene and the reconstruction of sedimentary conditions. The deposits of four glacial associations:

Pomusovo (Oka), Pechora (Vologda, Dnieper) Vychegda (Babushkino, Moscow) and Polar (Ostashkov, Upper Valday) are revealed and studied in detail. These associations represent four glacial sedimentary cycles. The deposits of each cycle have a specific set of lithological characteristics, formed by the balanced influence of three different glacial provinces: distant, transit and local.

Specific lithological features of tills confirm the connection of the Pomusovo till with the northwestern glacial province. Pechora (Vologda) till in the Timan-Pechora-Vychegda region is associated with the Ural-Pai-Khoi-Novaya Zemlya glacial center, and with the Fennoscandian glacial center to the west from the Northern Dvina. The Vychegda (Babushkino) till is the most widely distributed till over the study area. This till was formed of the material originated from different provinces: Fennoscandian in the center and in the south of the Timan-Pechora-Vychegda region and in the Arkhangelsk and Vologda regions; the Polar and Subpolar Urals – in the eastern part of the region. The source provinces for the material of the Polar (Upper Valday) till is situated in the Pai-Khoi-Novaya Zemlya, and, probably, in the shelves of the Barents and Kara Seas. In the north-west of the Timan-Pechora-Vychegda region and in the Arkhangelsk and Vologda regions this till is connected with the Fennoscandian ice sheet.

Palynological data allowed reconstructing the climatic conditions during the Pleistocene interglacial periods. The comparison of the spore-pollen assemblages and phases of the vegetation development with palynological criteria developed by D. A. Duryagina and L. A. Konovalenko (1993) for every interglacial allowed determining the relative ages of interglacial beds.

Considering the Holocene as a model of modern interglacial period and comparing it with the climatic rhythms of previous Pleistocene interglacial periods in the region, we came to the conclusion that the present climate of the European North of Russia is somewhat cooler than in previous Quaternary interglacials. Temperatures during climatic optima were higher than the temperature of the Holocene optimum. At present, a stable tendency to climate cooling is observed. Since the duration of the interglacials is tens of thousand years, the climate, apparently, cannot stay invariable during such a long time. Therefore, an alternation of relatively short warm and cold episodes happened during the interglacials. Today's climate warming is possibly connected to such a short episode. In spite of this temporary warming and anthropogenic impact, undoubtedly influencing the climate change, this tendency, in our opinion, will remain in the near future. According to A. A. Velichko (1999), the optimum temperature of every followed interglacial is colder approximately by 1 °C than climate of the previous one. Academician V. M. Kotlyakov suggests that the warmest peak of the present interglacial has already been passed 5–6 kyr ago. After this maximum the temperature keeps on falling and will do the same in the future. Paleogeography of the Holocene is very similar to the one of the past interglacial epochs when every interglacial is regularly and rhythmically replaced by glacial. This fact gives the basis to assume that gradual cooling of climate will go on in the future, and in perspective the possibility of new glaciation can not be excluded.

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PLEISTOCENO STRATIGRAFIJA, PALEOGEOGRAFIJA IR PALEOKLIMATAS EUROPINĖS RUSIJOS ŠIAURĖJE

Santrauka

Kvartero tyrimai europinės Rusijos šiaurėje buvo atlikti taikant litologinius nuogulų sudėties, taip pat paleobotaninių ir paleozoologinių liekanų tyrimo metodus. Tai leido atkurti neopleistoceno kraštovaizdį ir klimatą bei nustatyti aplinkos istorijos etapus atitinkančius kvartero storymės sedimentologinius ciklus. Pagal litologinius kriterijus buvo nustatyti skirtingų pleistoceno epochų apledėjimų centrai, buvo atskleistos įvairaus amžiaus ledyninių nuogulų sluoksnių sudėties kaitos erdvėje ir laike bendros tendencijos, ir tai leidžia koreliuoti ledynines nuogulas. Rekonstruotos vidurinio–vėlyvojo pleistoceno tarpledynmečių epochų ir holoceno paleogeografinės ir klimato sąlygos. Pirmą kartą Timano-Pečioros-Vyčegdos, Archangelsko ir Vologdos regionuose nustatyti augalijos raidos, temperatūros ir drėgmės kaitos skirtumai. Daroma išvada apie klimato šaltėjimo tendenciją pleistoceno metu europinės Rusijos šiaurėje.

Raktažodžiai: pleistocenas, holocenas, koreliacija, apledėjimas, tarpledynmečiai, klimatas, litologija, palinologija