Russian Geology and Geophysics © 2019, V.S. Sobolev IGM, Siberian Branch of the RAS
Vol. 60, No. 8, pp. 911–925, 2019 DOI:10.15372/RGG2019056
Geologiya i Geofizika

Marine Isotopic Stage 3 in Northeastern Europe: Geochronology and Events

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Received 27 December 2017; received in revised form 24 June 2018; accepted 26 July 2018

Abstract—The paper presents new lithological, geochronological, and biostratigraphic data on the studied sections of the Middle Valdai interstadial sediments in the sections of two terraces in the basin of the Severnaya Dvina River and on the southern coast of the Kola Region and in its southwestern part. The obtained data are correlated with the data available for other regions of northeastern Europe. The Severnaya Dvina River was found to have flowed into a marine reservoir existed in the White Sea basin throughout the Middle Valdai time corresponding to Marine Isotopic Stage 3 (MIS 3). The alluvial sedimentation in the river catchment area occurred in the environment of base level instability and permanently changing climate. In northeastern Europe, the warmest (optimum) intervals are related to the time spans of 47–43 and 31.3–29.2 cal. ka BP. In general, the available data point to 12 warming and cooling episodes in northeastern Europe.

Keywords: late Neopleistocene, MIS 3, northeastern Europe, geochronology, events, Severnaya Dvina basin, White Sea

INTRODUCTION

The late Neopleistocene is referred to as the last interglacial-glacial cycle. More than half a century has been marked by the diversity of researchers' opinion regarding the age of its various stage-subdivisions and their saturating events (Kind, 1974; Zubakov and Polevaya, 1974; Arslanov et al., 1981; Arslanov, 1992; Velichko et al., 2011; and others). Despite the appearance of a global "metronome" in the form of marine oxygen isotope stages (Jansen, 1989) with age limits determined quite exactly based on astronomical tuning (Imbrie et al., 1984), the problems of chronometry still remain controversial for the last interglacial-glacial macrocycle in the north of European Russia. The same problem concerns the Middle Valdai interstadial because of insufficient data on chronology and paleogeographic settings of that time in the regions covered with the last Scandinavian ice sheet, which had an erosional impact on the underlying ground surface. Consequently, the studies of geological records and the geomorphological structure of the territories that were under extraglacial conditions during the last glacial epoch have special relevance to paleogeographic and geochronological reconstructions of the Middle Valdai period. It particularly concerns the regions adjacent to the Last Glacial Maximum (LGM) ice limit. Correlation of data on the periglacial regions will enable us to define the sequence of events more adequately in the glacial areas.

During our recent studies in the north of the Russian Plain (also called as the East European Plain), we managed to obtain a new data set in the Severnaya Dvina basin related to the Middle Valdai period, mainly for areas that were under extraglacial conditions. Some data are available for the territory adjacent to the water-receiving basin, i.e., the White Sea, which was completely covered by the last glaciation. The main goal of the study was to compare the chronometric and biostratigraphic data obtained for the separate fragmentary sections of northeastern Europe for their consecutive chronometry. It was also aimed at determining the series of events typical for the ice-free late Neopleistocene, which appears to be the Middle Valdai interstadial (MIS 3). To achieve the objective, the bank of data on geochronology and paleogeography of the Subarctic and Arctic Regions has been extended, the Middle Valdai time has been determined for the Severnaya Dvina basin, and it has been correlated with the stages of marine and/or freshwater sedimentary environments in the White Sea depression. The relation between variously ranked events of the Middle Valdai time and global climate changes of the late Neopleistocene has been also found, and its continuous records have been reconstructed for the Vychegda–Severnaya Dvina fluvial system.

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RESEARCH HISTORY AND CURRENT STATE OF THE PROBLEM

The late Neopleistocene was initially subdivided into time or event intervals based on the concepts, where glaciations and the sediments correlating with them were taken as a "reference point" (Zubakov and Polevaya, 1974), while a certain global continuous last glacial event in the Earth history was considered to be the Pleniglacial.

However, since radiocarbon dating, which only "works" for organogenic sediments, came into active use, the warming periods ("thermochrons") corresponding to definite layers/horizons ("thermomers") had been in favor. In the early 1970s, representative data on the age of different stages of the last glaciation were accumulated (Zubakov and Polevaya, 1974). The concept of the late Neopleistocene division also changed, i.e., a warmer epoch was placed between two cold epochs, and that was assigned to the interglacial period or to an interstadial (Kind, 1974). The age subdivision detalization of the last glacial epoch tended to improve with cumulation of geochronological data. Moreover, palynological data acquisition resulted in a better understanding of the climate type domination at its stages. Finally, I.K. Ivanova (1966) concluded that two late Neopleistocene glaciations were not divided by the interglacial period, but by a long-lasting epoch with changeable climate, which she called as "the Middle Wurm with oscillations".

In the mid-1970s the age subdivision chart of the last Glaciation period (Valdai Epoch) was developed, and it supposed splitting into several warm and cold phases. According to (Kind, 1974) several interstadials (warming periods) were defined: Amesfoort (about 66–65 ka BP), Brorup or Karakyulass (about 61 ka BP), Hengelo or "Grazhdanskii Prospect" (about 40 ka BP), Denekamp or Dunaevo (about 30 ka BP). The Early Valdai and the last (Late Valdai) glacial maximums dated back to 50–60 ka BP and (approximately) 20 ka BP, respectively. The nonglacial interval with changeable climate was placed between these maximums. E.P. Zarrina (1970) was the first to call this stage as "the Middle Valdai". That time, the age was determined in radiocarbon (^{14}C) dates, because their calibration was not adopted as a compulsory procedure and did not come into common use for geochronological research.

In the early 1980s the discussion about the rank of the Middle Valdai, which preceded the LGM, was resumed. It was characterized as the second late Neopleistocene interglacial period, a cold interglacial period, a megainterstadial or as a part of the whole "Pleniglacial" comprised of multiple short stages and interstadials forming the cold but ice-free stage of the Valdai Glaciation epoch lasting from 80 to 23 ka BP (Arslanov et al., 1981). That time a chart of the Middle Valdai subdivision was proposed for the central and northwestern Russian Plain. The chart included four short-time stages of cooling and three longer stages of warming, which merged into one sedimentation and climatic megarhythm. Its ^{14}C chronological framework was determined in the range of 50 to 24–23 ka BP. The Middle Valdai was positioned as a megainterstadial in accord with its duration, stratigraphic framework and paleogeographic conditions (Arslanov et al., 1981). When considering the data on the twenty sections of northeastern Russian Plain, E.A. Spiridonova (1983) identified seven pollen zones corresponding to sequential climate warming and cooling periods. The odd zones were characterized by the growth of birches with periglacial flora elements. The zones receiving even numbers were distinguished by the dominance of pines and fir-trees, and also by the intensive growth of alder and broad-leaved species.

The development of marine geology and Greenland and Antarctic ice cap geochemistry have greatly influenced the further evolvement of a new concept of the Middle Valdai chronological subdivision. Grading and refining of the SPECMAP marine isotope-oxygen scale (Imbrie et al., 1984; Jansen, 1989) allowed identifying the isotope stages globally corresponding to glaciations, interglacial periods and interstadials. In this case, the Middle Valdai was correlated with the Marine Isotope Stage 3 (MIS 3). Consequently, its lower time limit shifted to 60–58 ka BP, and the total duration reached 32–35 ka. Nevertheless, in Russia, researchers returned to the scheme of 3:2 (three warming and two cooling periods) (Arslanov, 1992; Velichko et al., 2011).

The conclusion concerning the sharp climatic warming from the west to the east is quite essential, because the warming periods appeared to be typical interstadials in the central and western parts of the Russian Plain, but in the northeast (Arkhangelsk Region and Republic of Komi) their reconstructed paleoenvironment were more like interglacial periods (Arslanov, 1992).

According to the Regional Chart of North, northwestern and northeastern European Russia, the Leningrad and Byzovo Horizons of the Valdai Superhorizon correspond to the Middle Valdai and comprise the sediments at the age of 57–29 ka BP (Map…, 2013). Despite the uncertainty of the present-time stratotype of the Leningrad Horizon (Resolution…, 2002) determined from Grazhdanskii Prospect core in St. Petersburg (Arslanov et al., 1981), this is the third step of the upper Neopleistocene link according to the formal General Quaternary Stratigraphic chart of Russia. Moreover, the considered time interval mainly corresponds to MIS 3 and has a rank of an interstadial.

Significant climatic variations and sea level fluctuations were reconstructed for MIS 3 (Lambeck and Chappell, 2001; Helmens et al., 2007, 2009; Engels et al., 2008; Hättestrand and Robertsson, 2010). The researchers managed to identify periodically repeated, rather sharp climatic fluctuations from cold stadials to moderate interstadials, which were followed by a gradual return to a stadial. These climatic stages are known as the Dansgaard–Oeschger events identified for Greenland ice cores (Dansgaard et al., 1993, NGRIP members, 2004). The existence of Dansgaard–Oeschger events was indicated in the terrestrial record of warming and cooling intervals determined by different proxy-indicators (Spötl et al., 2006; Wohlfarth et al., 2008; Wohlfarth, 2010). At present, in addition to MIS, event-related climatostratigraphy is being applied to determine chronological sequence and to correlate the late Neopleistocene climatic changes and related variations in other landscape components in the North Atlantic and the adjacent areas. It was also established in Greenland ice cores and represented by the numbered sequence of the so-called Greenland interstadials (GI) and Greenland stadials (GS) (Rasmussen et al., 2014). Here GI and GS (which tend to reflect the phases of warm and cold climate in the North Atlantic Basin, respectively) are represented by the specific events of Dansgaard–Oeschger cycles. Representing the Middle Valdai interstadial in terms of event climatostratigraphy, for the most general approximation it will begin with GI-16 and finish with GS-4.

STUDY AREA: LOCATION AND STATE OF KNOWLEDGE

Northeastern Europe is the area comprising the contemporary Republic of Komi, Arkhangelsk Region, Republic of Karelia and Murmansk Region that commonly corresponds to the Arctic Ocean basin territory in the north of European Russia. The investigations were mainly concentrated on the catchment area of the Severnaya Dvina River falling into the White Sea (Fig. 1). The sections under study are located in the valley of the Vychegda River being the largest right tributary of the Severnaya Dvina; in the valley of the Kuloi River—a tributary of the Vaga River (the left largest tributary of the Severnaya Dvina River); and in the valley of the Severnaya Dvina River downstream from its confluence with the Vychegda River. Furthermore, we accounted for data from two sections of marine sediments from the Kamenka and the Bol'shaya Kumzhevaya river valleys on Terskii Coast of the White Sea, and from previously studied sections (Armand, 1969; Evzerov and Koshechkin, 1980; Evzerov et al., 1980) with continental sediments supposedly of the Middle Valdai age in the area of the Kovdor Massif and adjacent depressions of the Kovdor Lake and the Kovdor River in the southwest of the Murmansk Region (Fig. 1).

The territory of the Severnaya Dvina River basin represents a gently undulating plain with elevations from 60–100 to 200–250 m (Lavrov and Potapenko, 2005). The altitudes of the Terskii Coast do not exceed 120 m a.s.l. and of the Kovdor Massif—300–450 m a.s.l.

K.A. Vollosovich (1900) and M.A. Lavrova (1937) were the first to describe the regional Quaternary history and the "binary" till in the river valleys of the Severnaya Dvina ba-

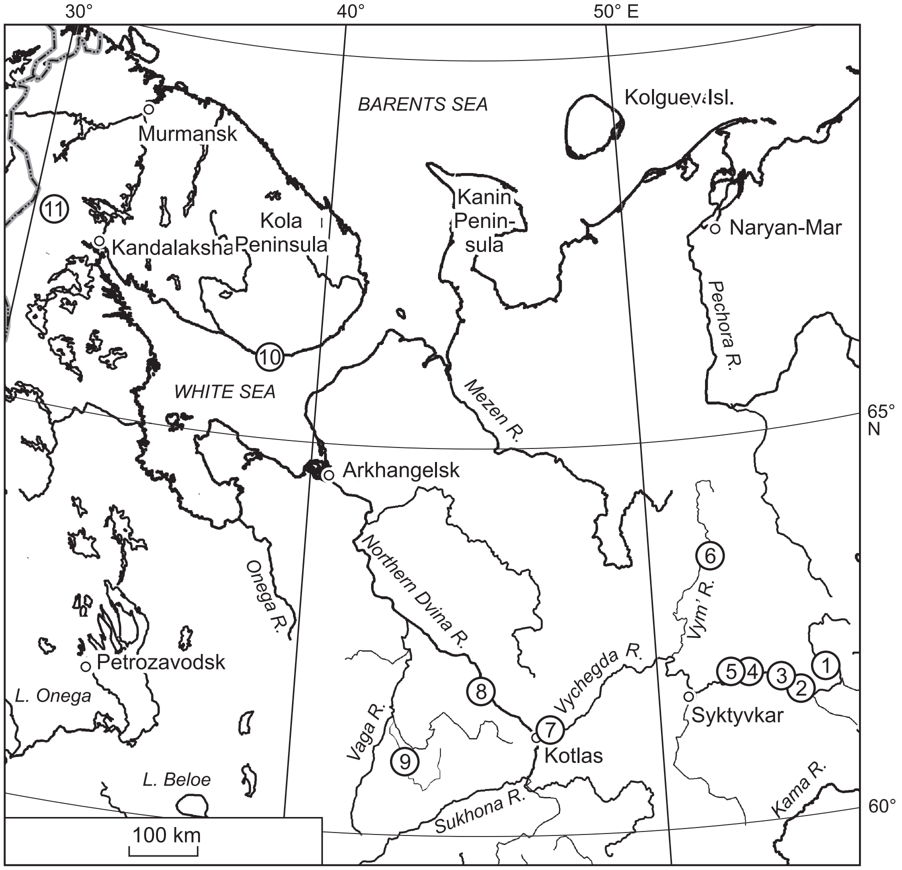

Fig. 1. Location of the studied sections in the northeast of Europe. The section numbers correspond to the numbers in the text, Table 1 and Figs. 2 and 3.

sin, which is currently divided into Moscow and Valdai Horizons. I.I. Krasnov (1948) developed the concept of the old age of the Severnaya Dvina and Vychegda Rivers valleys. E.I. Devyatova (1982), A.S. Lavrov and L.M. Potapenko also investigated the Severnaya Dvina River and constructed the map of the Quaternary formations for the entire northeastern Europe (Lavrov and Potapenko, 2005).

The studies of the Severnaya Dvina basin sections including the Middle Valdai deposits were conducted in 1970–1980 by B.I. Guslitser, A.S. Lavrov and L.M. Potapenko (Lavrova, 1937; Guslitser and Duryagina, 1983; Lavrov and Potapenko, 2005). Two parts were clearly distinguished in the general sequence section of the Severnaya Dvina basin: the lower part was predominantly composed of channel sands and oxbow alluvial deposits, while the upper part was formed by lacustrine sands, silts, and clays (Arslanov et al., 1980, 1981; Lavrov and Potapenko, 2005). Regarding the Middle Valdai Horizon, ^{14}C 20 dates were obtained from the wood and peat samples taken mainly from the sections of the Pechora Lowland in northeastern Europe. They fitted the time interval of 48–33 ka and allowed determining the palynozones sequence, which reflects climatic fluctuation stages and variations of the vegetation. Finally, in relation to the 48–33 ka interval, a ^{14}C chronostratigraphic division was performed for the Middle Valdai time interval with the allocation of nine climatic episodes: five warming and four cooling (Lavrov and Potapenko, 2005).

During that time A.D. Armand (1969), V.Ya. Evzerov (Evzerov and Koshechkin, 1980; Evzerov et al., 1980) were involved in the study of the Middle Valdai sections in the Kola Region. Unfortunately, age determinations for organogenic and lacustrine–alluvial deposits between two glacial Horizons of the Kovdor MPP ore mine pits appear to be out of the ^{14}C limit: >31,000 (GIN-484) and >53,000 (Tln-305) (Kind, 1973; Evzerov and Koshechkin, 1980; Evzerov et al., 1980). The age of deposits was mainly determined by lithostratigraphic, spore–pollen and diatoms data.

Extensive investigations at the turn of Millennium as part of the PECHORA and QUEEN projects (Svendsen et al., 2004; Larsen et al., 2006; and others) clarified the history and configuration of Pleistocene glaciations in the region, practically without acknowledgment of paleogeographic settings corresponding to MIS 3. As a result, it was proposed that the Kara or Barents Sea–Kara glaciation predated the Middle Valdai in northeastern Europe and that the glaciation maximum fell within 60 ka BP (Svendsen et al., 2004) or 55–45 ka BP (Demidov, 2010). According to (Svendsen et al., 2004), the Kara glacier overlapped only the White Sea Gorlo Strait without preventing Severnaya Dvina River outflow to the northwest. According to other reconstructions (Larsen et al., 2006; Lyså et al., 2011, 2014), at the beginning of the Middle Valdai (within time interval of 67–62 ka BP) the glacier covered all the White Sea basin and the lower reaches of the Severnaya Dvina River, forming the proglacial Belomorian (White Sea) Lake (Lyså et al., 2014).

Hence, the questions addressed to the Middle Valdai paleoenvironmental settings in the Severnaya Dvina and White Sea basins are still controversial. In particular, the contradictions are known to exist with regard to the Severnaya Dvina basin and domination of glacial (Lyså et al., 2011, 2014) or ice-free (Svendsen et al., 2004), or periglacial freshwater (Lyså et al., 2011; Lavrov and Potapenko, 2005; Andreicheva, 2011; Andreicheva et al., 2015), or fluvial (Sidorchuk et al., 2001) settings in this area. Ice-free settings (Kjellström et al., 2010) and a periglacial freshwater lake supposedly existed in the White Sea basin in the Middle Valdai time; and the lake was being saturated with salt as the glacier degraded (Larsen et al., 2006; Lyså et al., 2011). Besides that, the hiatus of 15 ka (might be within the interval of 35–20 ka BP) is found in the deposits lithostratigraphy as a result of fluvial and glacial erosion indicated in the continuous record of the Middle Valdai interstadial; this is one of the research problems posed for the Vychegda–Severnaya Dvina Region.

METHODS

The sections comprising the Middle Valdai time deposits were studied in the basin of the Severnaya Dvina River and on the coast of the White Sea. Lithostratigraphic studies were conducted during fieldwork. The samples for radiocarbon, uranium–thorium, electron spin resonance (ESR), feldspar-based infrared optically stimulated luminescence (IR-OSL) dating were taken from the sections (Table 1). Radiocarbon dating was mainly carried out at the Laboratory of Isotope Geochemistry and Geochronology at the Geological Institute RAS according to the standard methodology (Zaretskaya et al., 2007, 2012). Dating was mainly done on peat, loamy peat, buried soil and wood (Table 1). All the dates were calibrated using the Calib 6.11 software (Reimer et al., 2009) for comparability of the results obtained by different researchers. The sum probability option was used to estimate the probability density of the dates on the time scale, supposing that the intervals with densely spaced data corresponded to the periods of climate warming, and the gaps indicated colder periods. For independent control of radiocarbon dates, uranium–thorium dating was carried out in parallel. The detailed description of the uranium–thorium (^{230}Th/U) dating method is given in (Maksimov et al., 2011, 2015). The methodologies of IR-OSL dating of mineral deposits and ESR dating of malacofauna remains are described in (Molodkov et al., 1998; Molodkov and Bitinas, 2006).

FACTUAL MATERIAL AND ITS INTERPRETATION

Severnaya Dvina River basin sections

All studied sections are outcropped in the river terraces.

The Kuryador section (No. 1, 61°41′8.60″ N, 54°53′ 18.88″ E) is located in the upper reaches of the Vychegda

Table 1. List of age determinations (radiocarbon dates, calibrated age, IR-OSL dates, ^{230}Th/U ages), obtained for the Middle Valdai (MIS 3) time from the sections in the Severnaya Dvina River basin and the White Sea coast (Figs. 2, 3)

No.	Section	Dating material, depth, m	Lab. index and number	^{14}C date	Calibrated age, 1σ	Other age determinations	References
1	Kuryador, No. 1	Clayey silt with organic, 5.5–5.6	GIN-14320	26,200 ± 400	30,579–31,137	–	(Maksimov et al., 2015)
2		Clayey silt with organic, 5.9–6.0	GIN-14569	30,800 ± 170	34,928–35,363	–	(Maksimov et al., 2015)
3		Peat, no data available	LU-577	31,080 ± 280	35,131–36,237	–	(Lavrov and Potapenko, 2005)
4		Humous loam, 25–6.35	GIN-14321	31,200 ± 230	35,243–36,255	–	(Maksimov et al., 2015)
5		Humous loam, 6.5–6.55	GIN-15075	35,560 ± 350	40,410–41,192	–	In the present paper
6		Humous loam, 6.6–6.65	GIN-14322	36,920 ± 330	41,559–42,080	^{230}Th/U age:	(Maksimov et al., 2015)
7		Humous loam	GIN-15076-1	37,500 ± 300	41,944–42,438	46.8–38.8—TSD model	In the present paper
8		Buried soil, 6.8–6.85	GIN-14323	39,170 ± 260	43,031–43,612	50.1–45.5—L/L model	(Maksimov et al., 2015)
9		Buried soil, 7.8–7.9	GIN-15076-2	39,610 ± 360	43,360–44,062	–	In the present paper
10		Loamy peat, 8.35–8.39	GIN-14324	41,700 ± 600	44,716–45,591	–	(Maksimov et al., 2015)
11	Nem	No data available	LU-1237	26,980 ± 590	30,907–1868	–	(Arslanov et al., 1987)
12	Don, No. 2	Sand, 3.55	RLQG 2361-085	–	–	IR-OSL 9.4 ± 0.7 ka	In the present paper
13		Sand, 5.6	RLQG 2362-085	–	–	IR-OSL 23.1 ± 2.0 ka	In the present paper
14	Ozyag III, No. 3	Plant detritus in loam, 7.5	GIN-15081	24,880 ± 80	29,488–29,884	–	In the present paper
15		Sandy peat, 6.0–6.05	GIN-15079	27,300 ± 200	31,293–31,578	–	In the present paper
16		Sandy peat, 6.35–6.4	GIN-15080	28,500 ± 260	32,439–33,301	–	In the present paper
17	Storozhevsk, No. 4	Plant detritus in loam, 6.5	GIN-14878	25,060 ± 130	29,720–30,185	–	In the present paper
18	Nebdino, No. 5	Clayey loam with scat. org., 6.7–6.8	GIN-14576	26,300 ± 500	30,550–31,221	–	In the present paper
19		Clayey loam with scat.org., 7.5	GIN-14346	35,750 ± 1200	39,488–41,816	–	In the present paper
20	Kyltovka, No. 6	Wood, 5	LU-588	39,170 ± 470	42,948–43,793	–	(Lavrov and Potapenko, 2005)
21		Peat, 6.7	GIN-606	42,000 ± 1700	43,980–46,913	–	(Lavrov and Potapenko, 2005)
22		Spruce log, 11.2–11.3	LU-566	47,520 ± 1000	–	–	(Lavrov and Potapenko, 2005)
23	Baika, No. 7	Buried peaty soil	GIN-14866	44,050 ± 1200	46,004–48,515	–	In the present paper
24	Tolokonka, No. 8	Plant detritus in loam, 29	GIN-14874	24,570 ± 140	29,275–29,558	–	In the present paper
25		Plant detritus, 25.15	GIN-14877	25,980 ± 200	30,563–30,957	–	In the present paper
26		Peat, 18.2	GIN-14173	33,270 ± 350	37,509–38,580	^{230}Th/U age:	(Maksimov et al., 2011)
27		Loamy peat, 18.3	GIN-14174	37,350 ± 450	41,770–42,430	39.1 ± 7.6/6.6 ka–L/L-model	(Maksimov et al., 2011)
28		Loamy peat, 18.35	GIN-14175	37,800 ± 600	41,971–42,809	42.5 ± 2.8/2.7 ka–TSD-model	(Maksimov et al., 2011)
29	Kuloi, No. 9	Plant detritus in loam, 15 m	GIN-15167	21,450 ± 110	25,459–25,927	–	In the present paper
30	Shenkursk	No data available	Vib-40	24,900 ± 470	29,345–30,293	–	(Ostanin et al., 1979)
31	Kamenka, No. 10	Mollusks shells in loam, 5.5–5.8 (AE 36.6–36.9 m. above sea level)	Tln 344-073	–	–	ESR 58.7 ± 4.4 ka	(Korsakova et al., 2004)
32		Mollusks shells in loam, 5.5–5.6	RLQG 416-119	–	–	ESR 52 ± 4.3 ka	(Astafyev et al., 2012б)
33	Bolshaya Kumzhevaya	Sand, 6.6–6.5 m (AE 22.5 m. above sea level)	Tln 1521-103	–	–	IR-OSL 44.4 ± 3.2	(Korsakova et al., 2004)
34	Kovdor 1, No. 11	Peat (cellulose and humus), 3.5–4.9 (246 m.above sea level)	GIN-484 and GIN-484d	>31,000	–	–	(Kind, 1973)
35	Kovdor 2, No. 11	Plant remains in sands, 12.0–14.0	Tln 305	> 53,000	–	–	(Evzerov et al., 1980)

Note. Section numbers correspond to the numbers in Fig. 1.

River. This is a 15-m outcrop on the right bank of the river (Fig. 1). It was studied by a number of researchers (Guslitser and Duryagina, 1983; Lavrov and Potapenko, 2005; Andreicheva, 2011; Lyså et al., 2011; Zaretskaya et al., 2012, 2013; Andreicheva et al., 2015; Maksimov et al., 2015). We visited this section three times in 2010, 2011 and 2013. The Middle Valdai deposits with thickness of ~ 4.5 m, overlie the middle Neopleistocene alluvium (Lyså et al., 2011) with erosion contact and consist of two units (Fig. 2). Represented by clayey loams interlayered with medium–fine-grained sands (0.6 m) and overlapped with light gray fine-grained sands with ripple marks (about 1 m in thickness, creek sands), the bottom unit is interpreted as bar alluvium and floodplain deposits. The lenses of loamy peat found here were carbon-dated at 41,700 ± 600 (GIN-14324; 45.6–44.7 cal. ka BP). According to included plant remains (95% hypnum moss and 5% sedge), the loamy peat was formed in a hypnum lowland bog. Cryoturbation and ice wedge casts were identified in the sands. A series of inversive OSL-dates showed that the formation of the bottom member ranges from 71 to 56 and from 63 to 44 ka BP (Lyså et al., 2011). The whole member likely accumulated under conditions of intermittent flooding of the back marsh and residual still ponds.

The alluvial sequence is overlaid by a 0.7 m member of clayey soil deposits saturated with organogenic material to different extent. The upper 55 centimeters are dry unclearly layered light loam and sandy loam with organic material. The lower 15 centimeters are comprised of dark-brown sediments, which look like overdried peat. Herbs and bushes dominate in the content of plants remains, but water or marsh plants have not been found; therefore, that points to the abundance of upland plants and subaerial accumulation. Coniferous and coniferous–small-leaved forests were determined to have grown alternating with tundra–steppe that time (Zaretskaya et al., 2013). The 15 cm lower part of the member could be composed of buried alluvial dark-humus gleyic soil (Maksimov et al., 2015), which might have formed in the central part of the flood plain on the riverside meadow. The bottom of the soil horizon is deformed and carries traces of end contraction in the shape of cusps because of gravitational displacements of sediments. The thickness of the organogenic member is not maintained alongside because of cryogenic deformations; its lower boundary is sometimes festoon-shaped, and in one case, the whole soil layer is completely “cut off” and tightened as a xenolith into the underlying sands.

The results of radiocarbon dating revealed that the upper organogenic member was continuously accumulated from ~39.5 to 26.2 ka BP or ~43.6–30.6 cal. ka BP. Parallel ^{230}Th/U dating of the buried soil (Table 1) demonstrated good agreement of the results (Maksimov et al., 2015).

The upper organogenic layer is continuously overlapped with loess-like silts referring to the LGM (Guslitser and Duryagina, 1983). Their lower brownish-gray part is 3 m thick and enriched in clay fraction and in organic at the bottom with clearly defined layering and of with iron oxide noddles. Two consecutive ^{14}C dates were obtained for the bottom of lower silts: 26,200 ± 400 (GIN-14320) and 30,800 ± 170 (GIN-14569); the botanic analysis of dated samples (90% shrubs and 10% herbs) confirmed the subaerial origin of these deposits. The upper compact yellowish-brownish part of silts is 4.5 m thick with unclearly defined postsediment lamination and OSL dates of 17–14 ka (Lyså et al., 2011).

According to the spore and pollen data obtained for the sediments at the depth of 9.00–2.95 m (Andreicheva et al., 2015), three warming periods were defined. That was the time of forest vegetation domination represented by dark coniferous spruce forests with admixed pine.

The Don section (No. 2, 61°33′1.99″ N, 53°48′2.06″ E) is located on the right bank of the Vychegda River in the Kadam expansion of the valley and exhibits the first terrace, which is 5 m high above the river line (Fig. 1, 2). The section shows cross- and horizontally bedded alluvial sands with the blue-gray clay interlayer in the middle of the sequence. Cryogenic deformations are well defined in the clay. Sands are overlapped with the Holocene peaty clayey soil changing into peat. The IR-OSL date of 9.4 ± 0.7 ka (RLQG 2361-085) was obtained for the upper part of the sandy sequence (Table 1). The sample of peaty clayey soil overlapping the sands was carbon-dated at 7920 ± 120 ka BP (GIN-15078), which is stratigraphically consistent with the IR-OSL date. The IR-OSL date of 23.1 ± 2.0 ka (RLQG 2362-085) (Table 1) was obtained from the sands of the lower part of the section under the clay layer; that, consequently, confirms alluvial accumulation at the beginning of the Late Valdai time.

The Nizhnii Ozyag section or Ozyag III (No. 3, 61°47′49.68″ N, 53°19′52.63″ E) is located in the middle reach of the Vychegda River (Fig. 1, sublatitudinal bed interval) nearby Ozyag I and II sections previously studied in (Lyså et al., 2014). Two outcrops are represented here; they cut the first terrace, which is 7 m in height above the river line (Fig. 2). In spite of the same altitude position, these two sections differ by age. The upstream section exhibits cross- and horizontally bedded alluvial sands of the channel facies with underlying peaty sand, that has a ^{14}C date of 28,500 ± 260 years (GIN-15080). The downstream section differs essentially by the structure. The upper and the lower parts of the sands alluvial sequence are represented by two members of interlayered fine-grained sands and clayey loams with cryogenic deformations, and ice wedges casts are found in the bottom sands of the section. The alluvial sequence is underlain with a thin layer of clayey loam with plant detritus, which was dated back to 25,880 ± 80 years (GIN-15081). The OSL dates (36.0 ± 3.0, 29.1 ± 1.9 and 31.0 ± 2.0 ka) were previously determined for the sand-loam deposits of the Ozyag II section, but they were considered as invalid by the authors (Lyså et al., 2014).

The Storozhevsk section (No. 4, 61°54′53.20″ N, 52°25′56.54″ E) exposes a 6-m terrace on the left bank of the

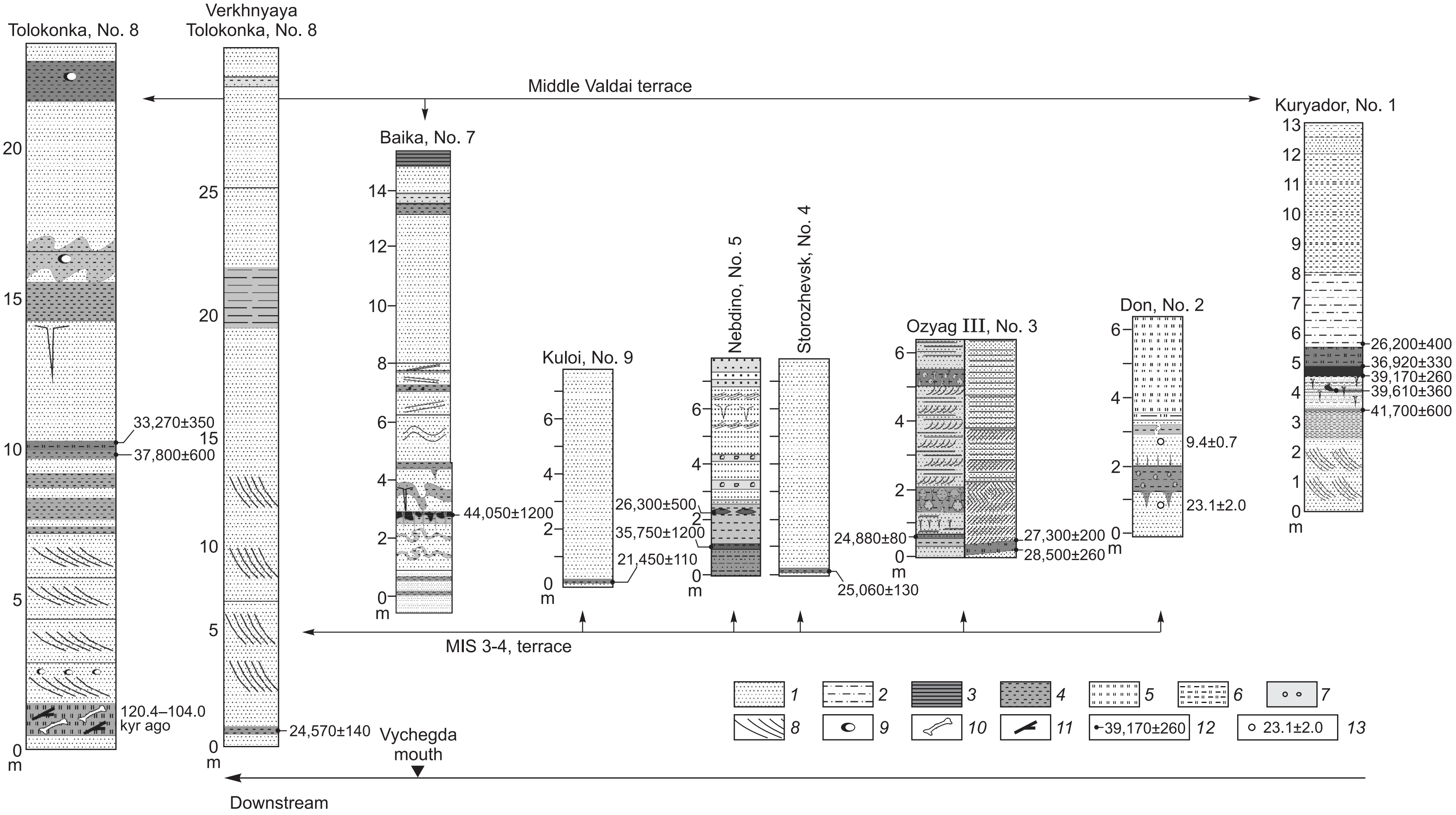

Fig. 2. Sections with dated deposits of the Byzovo Horizon in the Severnaya Dvina River basin. Location of corresponding sections is shown in Fig. 1. *1*, sand; *2*, silt (aleurite); *3*, clay; *4*, loam; *5*, peat; *6*, loamy peat; *7*, pebbles; *8*, cross-bedding; *9*, boulders; *10*, megafauna bones; *11,* wood; *12*, radiocarbon samples and dates; *13*, IR-OSL samples and dates.

Vychegda River in its middle reaches and opposite of its confluence with the Vishera River (Fig. 1). The terrace is composed of undisturbed alluvial sands of channel facies. The date of 25,060 ± 130 years (GIN-14878) was obtained from plant detritus contained in the sands of the section bottom.

The Niobdino section (No. 5, 61°55′18.71″ N, 52°9′11.37″ E) is on the right bank of the Vychegda River, 15 km lower than the Storozhevsk section (Fig. 1). The 6-m terrace has been exposed here. The deposits are represented with differently grained, cross- and horizontally bedded sands interlayered with small pebbles (Fig. 2). Two blue-gray clayey loam beds enriched in scattered plant organic are exposed in the middle and bottom parts of the section. Ice wedge casts are observed in cross-bedded sands, and cryogenic-type fractures are found in peaty clayey loams in the middle part of the section. The date of 26,300 ± 500 years (GIN-14576) was determined from the bulk samples of peaty loams, and the date of 35,750 ± 1200 (GIN-14346)—from plant detritus included in the loam interlayer at the bottom of the section.

The Kyltovka section (Fig. 1, No. 6) with a total thickness of 13 m is situated on the right bank of the Kyltovka River to be the inflowing stream of the Vym' River (the right tributary of the Vychegda River). It was previously described in (Lavrov and Potapenko, 2005). Three ^{14}C dates corresponding to the Middle Valdai were determined for the section (Table 1). The section exposes sands and loamy sands, which are poorly sorted, cross- or unclearly bedded, with pebble or gravel lenses. They are interbedded with compact gray unclearly layered silts containing lenses of peat and wood. The date of 47,520 ± 1000 years. (LU-566) was determined by the fir tree log sampled from the sand at the depth of 11.2 m; peat and wood were sampled from silts at the depth of 5 and 6.7 m and dated to 39,170 ± 470 (LU-588) and 42,100 ± 1700 years (GIN-606), respectively (Lavrov and Potapenko, 2005).

The Baika section (No. 7, 61°16′12.33″ N, 46°48′11.86″ E) in the 18-m high outcrop is located in the lower reaches on the right bank of the Vychegda River (Fig. 1) that was previously studied by a group of researchers (Sidorchuk et al., 2001). The 15-m terrace was exposed here in 2012. The upper part of the section is represented by sandy members. According to spore and pollen data, the sands were correlated with the LGM, and overlying cover loams with the Late Glacial (Sidorchuk et al., 2001). The Middle Valdai deposits are exposed at the lower part of the section and represented by loamy peat overlapped with horizontally bedded sands (Fig. 2). Various alluvial facies are likely to be represented here: from oxbow-lake buried peat in lenses to river bed facies composed of horizontally bedded sands. Furthermore, the organogenic horizon is exposed at a height of ~5 m from the river line. This layer is broken with ice wedges and appears to be buried soil dated to 44,050 ± 1200 years (GIN-14866).

The Tolokonka section (No. 8, 61°45′55.45″ N, 45°28′20.99″ E) is a more than 10 km long outcrop at the right bank of the Severnaya Dvina River and is located 100 km downstream from the Vychegda River mouth (Fig. 1). The section was studied by the team of the Norwegian Geological Survey together with researchers from the Institute of Limnology RAS (Lyså et al., 2014). We studied the outcrop in 2012. The section with a thickness of 28–30 m exhibits the terrace with the complex structure in its lower part (Fig. 2). The major outcrop (4 km long) consists of two parts. The lower one contains the record of the last 120 ka: loamy peat and peat of the MIS 5e age together with wood and megafauna bones (Zaretskaya et al., 2013) are exposed at the section bottom. The deposits referred to the Middle Valdai time are exposed in the middle of the section and represented by interlayered sands and silts with permafrost fractures. The loamy peat 20–80 cm thick at the top of this unit was sampled for parallel ^{14}C and ^{230}Th/U dating (Maksimov et al., 2011). The radiocarbon date obtained from the top of the layer is 33,270 ± 350 (GIN-14173) and from the bottom 37,800 ± 600 (GIN-14175) (Table 1). The calibrated age lies in the interval of 45.2 and 37.5 cal. ka BP and is consistent with the results of uranium–thorium dating (Maksimov et al., 2011). Underlying and overlaying sands are likely to be also of the Middle Valdai in age, although the OSL dating results are ambiguous (Lyså et al., 2014).

Sand and sandy-loam deposits of various alluvium facies (from the river bed facies to oxbow lake one) are exposed in the upstream part of the section. The lower section part is comprised of the Middle Valdai sediments, which are represented by sands with horizontal, cross and steep bedding, gravel interbeds and rare pebbles. The date of 27,830 ± 600 (GIN-14875) was determined from the wood sampled from the medium-grained sands at a distance of 5 m above the river line. The overlying loams with scattered plant detritus were dated by total carbon to 29,790 ± 800 years (GIN-14876).

Horizontally- and cross-bedded sands and small pebbles (probably of alluvial origin) are exposed upstream in the section of the same thickness, at a distance of 15 km (Fig. 2). A thin layer of loamy peat at the bottom of the section was dated to 24,570 ± 140 (GIN-14874). The member of varved clays in the middle part of the outcrop is traced at full length of the Tolokonka section (Fig. 2) and considered to be benchmark deposits of the proglacial lake associated with the LGM.

The radiocarbon date of 24,900 ± 470 (Vib-40) was obtained from deposits underlying the Late Valdai (LGM) till observed in the section in 10 km northwards from Shenkursk on the right bank of the Vaga River (Ostanin et al., 1979) (Table 1). The data were also obtained from the valley of the Kuloi River, which is the right tributary of the Vaga River (No. 9). The 18-m terrace outcrop exposing alluvium sands was studied on the left bank of the river (Fig. 2). Date 21,450±110 (GIN-14869) was obtained from the plant detritus included in the clayey loams at the bottom part of the section.

White Sea coast sections of the Kola Peninsula

The marine sediments of the Middle Valdai interstadial have been defined with a high percentage of certainty in the Kamenka section and a lower degree of probability in the Bol'shaya Kumzhevaya section.

The Kamenka section (No. 10, 66º05′41″ N, 38º17′10″ E) is located on the right bank of the Kamenka River, at a distance of 4700 m from its mouth (Fig. 1) and at the place, where the eastern extremity of the gently sloping hill with absolute height of 45 m above sea level is being washed out. The Middle Valdai interstadial deposits are represented by marine (Fig. 3, mIIIln) littoral and sublittoral sediments (from the bottom upwards):

– dark gray compact loam with rubble, fine pebble, cobblestones, and mollusk shell fragments (2 m thick);

– thin (~ 0.4 m) brown fine pebble-rubble-sandy sediments with inclusions of clay and silt, sand-and-gravel conglomerates, clay balls, highly weathered fine pebbles of the underlying gneisses;

– dark gray massive clayey loam and sandy loam with cloddy structure including sand, rubble and fine pebbles (1 m thick), which are separated by underlying fine pebble-rubble-sandy deposits with distinctly-defined grouting process and ferruginization (washout marker);

– brown-gray sandy loam with differently-grained sand, rubble, fine pebble, small balls, mollusk subfossils, sand lenses and interbeds with unclearly defined horizontal foliate lamination (~1.0 m thick).

Fragments and scallops of subfossil mollusk shells are represented by arctic and arctoboreal species, such as *Astarte crenata* Gray, *A. crenata* var. *crebricostata* Andr. et Forb., *Mya* sp. (*truncata?)*, *Chlamys islandicus* Müll (Grave et al., 1969). The occurrence of shell pieces of *Astarte crenata* at the bottom of the marine sequence let us suppose that their host deposits might have formed under conditions of the Mikulian interglacial period. On the one hand, the study of the diatom flora and its typical warm-water species did not reveal peculiar boreal transgression. On the other hand, singular shells were found in relation to the plenty of the Tertiary resediments and the Cretaceous diatom species (Grave et al., 1969), including *Silicoflagellata* and radiolarians. The diatom flora was determined to compose of *Isthmia nervosa* Ktz., Isthmia sp., *Rhabdonema* sp. (*arcuatum?*), *Melosira sulcat* (Her.) Ktz., and spiculae. V.S. Gunova identified two palynozones (PZ) in accord with palynomorph composition (Grave et al., 1969). The first PZ corresponds to the sequence bottom, from which the mollusk shell fragments were sampled for ESR dating: 58.7 ± 4.4 ka (Tln 344-073) and 52 ± 4.3 ka BP (RLQG 416-119) (Table 1). The PZ is distinguished by spores domination and small number of trees and herbaceous plant pollen. The second PZ corresponds to the rest larger portion of marine deposits. Spores continued dominating in this PZ though the number of trees and herbaceous plant pollen significantly increased. The palynomorph complex characterizes the phase of birch-pine open forests mixed with fir trees. Sediments having accumulated at the top of the sequence, continentality appeared to

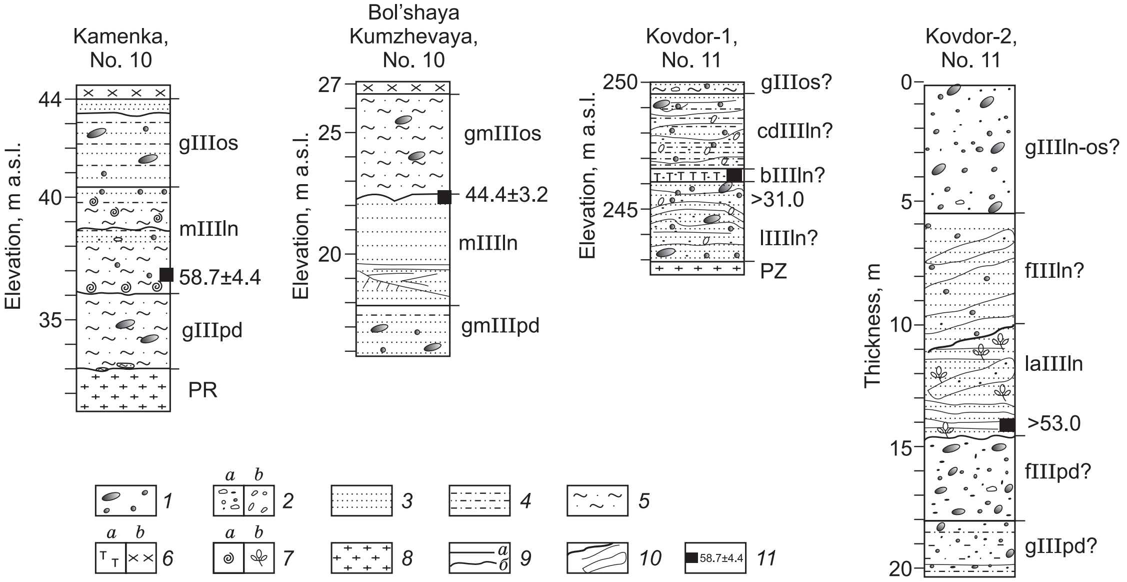

Fig. 3. Sections with dated marine and terrestrial deposits of the Leningrad horizon in the Kola Region. Kamenka and Bol'shaya Kumzhevaya sections were compiled according to (Korsakova et al., 2004), Kovdor-1 according to (Armand, 1969), and Kovdor-2 according to (Evzerov et al., 1980). Location of corresponding section is shown in Fig. 1. Indexes mark: Podporozhskii Horizon: gIIIpd, till; gmIIIpd, glaciomarine; fIIIpd, glacifluvial sediments; Leningrad Horizon: mIIIln, marine; laIIIln, lacustrine–alluvial; lIIIln, lacustrine; bIIIln, biogenic, cdIIIln, colluvial– diluvial; fIIIln, glacifluvial sediments; Ostashkovskii Horizon: gIIIos, till; gmIIIos, glaciomarine sediments; PR and PZ, Proterozoic and Paleozoic bedrock. *1*, boulders; *2*, gravel, pebble (*a*), breakstone, gruss (*b*); *3*, sand; *4*, sandy loam; *5*, loam; *6*, peat (*a*), soil (*b*); *7*, shelly detritus and mollusks shells (*a*), plants macrofossils (*b*); *8*, pre-Quaternary rocks; *9*, lithologic contacts (*a*), erosional surface (*b*); *10*, structures; *11*, geochronological samples and dates.

grow to some extent. Accordingly, this points to an increase in pollen of the dwarf arctic birch and wormwoods.

The interstadial character of the marine deposits from the Kamenka section was confirmed in the conclusion made by G.V. Stepanova. She managed to define a scanty complex of foraminifer, among which *Cibicides rotundatus* tended to dominate; *Islandiella helenae* and *Cassidulina subacuta* were also found in all the samples (Astaf'ev et al., 2012b).

The Middle Valdai marine deposits from the Kamenka section underlie on the brown clayey loam with pebbles, which is compact with unclear platy structures and well-defined upper boundary (Fig. 3, gIIIpd); they are supposedly referred to the glacial sediments of the Podporozhskii (Korsakova, 2009) or Moscow (Grave et al., 1969) Horizons. One more layer of glacial sediments is represented by brown drift sandy loam with abundant pebbles and gravels and referred to the Ostashkovskii glacial horizon (Fig. 3, gIIIos) when forming the section top.

Presence of the Middle Valdai marine sediments on the Kola Peninsula was confirmed by A.N. Molod'kov, who performed IR-OSL dating of sand deposits forming the accumulative marine terrace on the Tersky Coast and exposed in the **Bol'shaya Kumzhevaya section**. The sands from the river valley were dated in the section part close to the top of the marine sequence and overlapped with erosion glacial-marine deposits (Fig. 3). The determined age is 44.4 ± 3.2 ka (Table 1).

Terrestrial sections in the Kola Region

The Middle Valdai sequences were studied from four sections in the southeastern part of the Kola Region, in the vicinity of Kovdor. The sequences were exposed on the eastern wall of the iron-ore quarry belonging to the Zheleznyi mine (Armand, 1969; Evzerov and Koshechkin, 1980; Evzerov et al., 1980). Freshwater, freshwater-alluvial and bog formations of this area were found between glacial and water-glacial deposits at a height of ~250 m above sea level. Later, they were damaged as a result of the quarry expansion and exploitation. The radiocarbon dates were determined for deposits from two sections (Fig. 3, Kovdor-1 and Kovdor-2) in the middle of last century. They are just rough geochronological marks, which prevent from conducting correct correlation with other sections. According to the descriptions available (Armand, 1969), the Middle Valdai sequence from one of the sections (Kovdor-1) was represented by (from the bottom upwards) nonsorted and poorly sorted sandy-fine pebble, sandy loam-sand, peaty and sandy-loam deposits mixed with gravels and pebbles. The deposits with total thickness of 6.5 m were embedded under the 50 cm layer of glacial sediments. A lens of compact dark-brown peat was 30 cm thick and examined in the middle of this multilayered sequence. The peat ^{14}C age is >31,000 years (GIN-484, GIN 484d) (Kind, 1973). The spore and pollen analysis of the interstadial sequence sediments confirmed that they had accumulated in the settings of forest–tundra alternating with tundra. Diatoms are represented by freshwater psychrophilic arctalpine species.

The Middle Valdai sequence in another outcrop (Kovdor-2) from the same quarry (Evzerov and Koshechkin, 1980) was comprised of freshwater-alluvial deposits with the total thickness of 3.0–3.8 m. The deposits were represented by fine- and small-grained sand with abundant plant remains and lenses of coarse-grained sand and sand mixed with pebbles (Fig. 3, laIIIln). This sequence was embedded between the strata of fluvioglacial deposits composed of sands, gravels and pebbles. At that, the lower layer was underlain (Fig. 3, fIIIpd?), but the upper one was overlapped with glacial till. The ^{14}C age of sediments at the lower plane of the Middle Valdai sequence was determined as >53,000 years (Tln-305) (Table 1). Tundra and forest-tundra plants grew in the adjacent territory under conditions of freshwater-alluvial interstadial deposits formation (Evzerov et al., 1980).

Three other strata, admittedly composed of glacial deposits, were found in the sections (Kovdor-3 and Kovdor-4) of the same quarry and described by (Evzerov and Koshechkin, 1980). These strata were separated with lenses of fluvioglacial, round pebble and sand deposits with thickness from 0.1 to 7.0 m. The Middle Valdai subhorizontally laminated sandy loams and loams (up to 0.4 m thick) were supposed to lie occasionally in one of the sections, under the middle layer of glacial till on the compact diamicton of the lower glacial horizon. A locally deformed and torn peat interlayer (from 1–2 to 7 cm thick) was also observed in the section along the full length of 15–16 m. Its separate fragments were found at the lower plain of the middle layer of the overlying glacial deposits. The composition of pollen in subhorizontally laminated sandy loams and loams is rather scanty and gives evidence in favor of tundra plants growth in the adjacent territory, but peat accumulation resulted in forest–tundra. A date without reference of 43.5 ka was determined as a result of thermoluminescent analysis for the fluvioglacial deposits presented in the study (Astaf'ev et al., 2012a).

DISCUSSION

The presented data enable us to offer a scenario of the Severnaya Dvina and the White Sea basin development covering a long period from 59 to 24 ka BP.

An understanding of the environmental conditions in the Middle Valdai time (MIS 3) is impossible without the geologic setting of the precedent glacial epoch (MIS 4). The results of the QUEEN investigation (Svendsen et al., 2004) have shown that the glaciation preceding the Middle Valdai time occupied the territories of Fennoscandia, the Barents and Kara seas and partially the White Sea. The Severnaya Dvina River basin and the internal part (Basin) of the White Sea were ice-free, and the south glaciation limit ran along the Kola Peninsula coast and crossed the White Sea Gorlo Straight southeastward. The NGS group hold another opinion (Lyså et al., 2011). According to their interpretation of the Kuryador section, a member of light-gray sands in the middle of the section (Fig. 2) was accumulated in the settings of ice-blocked proglacial White Sea Lake, whose age was estimated to be 65–57 ka (Lyså et al., 2011). However, there is no other evidence in favor of such a basin to exist. In our interpretation, these sands appear to be of alluvial origin (overbank facies).

The glaciation preceding the Middle Valdai time was likely to cover the Kola Peninsula occupying the east of its White Sea coast. The data obtained from the continental sections in the vicinity of the town of Kovdor and from the section in the Kamenka River valley give evidence in favor of glacier advance in the Kola Region and in the White Sea depression at MIS 4 and at the beginning of MIS 3 (GS-16 and -15), and their deglaciation at early MIS 3 (GI-13, GI-14). The data on the Kovdor section confirm the occurrence of two warming and two cooling periods judging by the growth of forest-tundra and tundra plants. The first climatic warming, that followed the territory deglaciation, was the most expressed and characterized by the accumulation of lacustrine-alluvial sediments in the Kovdor-2 section, which were carbon-dated to >53,000 cal. BP (Fig. 3). At that time, there was a cold-water sea basin in the White Sea depression that is consistent with the data (Korsakova et al., 2004) and the ESR dates (Table 1) obtained for the Kamenka section (Korsakova et al., 2004; Astaf'ev et al., 2012b). Judging by the Kovdor sections, we come to the conclusion that the second climatic warming of MIS 3 in the west of the Kola Region followed the surge of the Scandinavian glacier, whose borders ran across Eastern Finland at early MIS 3 (GI-14) (Helmens et al., 2009). At that time, the marine paleoenvironment still existed in the White Sea basin, which agrees with the data on the Bol'shaya Kumzhevaya section (Fig. 3). The second warming caused the formation of peat deposits in the Kovdor-1 section (Fig. 3), and boulder-pebble and sand deposits overlying second till layer in the Kovdor-3 and Kovdor-4 sections, and dated as 43.5 ka BP (Table 1). Moreover, the data based on climate modeling (Kjellström et al., 2010) give evidence of ice-free conditions in Eastern Fennoscandia not only during GI-14, but also later, starting from GI-12, i.e., 44 ka BP. It was established that GI-12 was characterized by colder climate compared with the present time, but it was much warmer in comparison with the time of the LGM (Bond et al., 1993; Johnsen et al., 2001; Henriksen et al., 2007).

Therefore, the Severnaya Dvina River and its tributaries continued to flow northwards into the White Sea basin during cold MIS 4 and at the beginning of MIS 3 (GI-16–13). That resulted in accumulation of alluvial sands, which are exposed at the lower part of the Tolokonka section overlying the interglacial MIS 5e peats and loamy peats with fauna and wood remains (Fig. 2), and sands exposed in the sections of the third terrace in the lower reach of the Vychegda River. The further history of the Middle Valdai time in the Severnaya Dvina basin has been supported by geochronometrical data. The representative set of radiocarbon dates (over 30 determinations) has been stored; the data are confirmed by uranium-thorium dating and consistent with the results of the OSL dating of mineral sediments (Table 1). The obtained graph of the calibrated dates distribution (Fig. 4) could be compared with other chronological records including the NGRIP oxygen-isotope ratio curve (NGRIP members, 2004) and a climatostratigraphic record (Rasmussen et al., 2014).

The obtained data allowed us to propose that the sections of the Severnaya Dvina River basin demonstrate alluvial sedimentation under conditions of unstable base level and constant climatic variations. The sections can be divided into two groups. The first group comprises the sections of the so-called 2nd Middle Valdai terrace. The heights of these terraces above the current river line lie in the interval

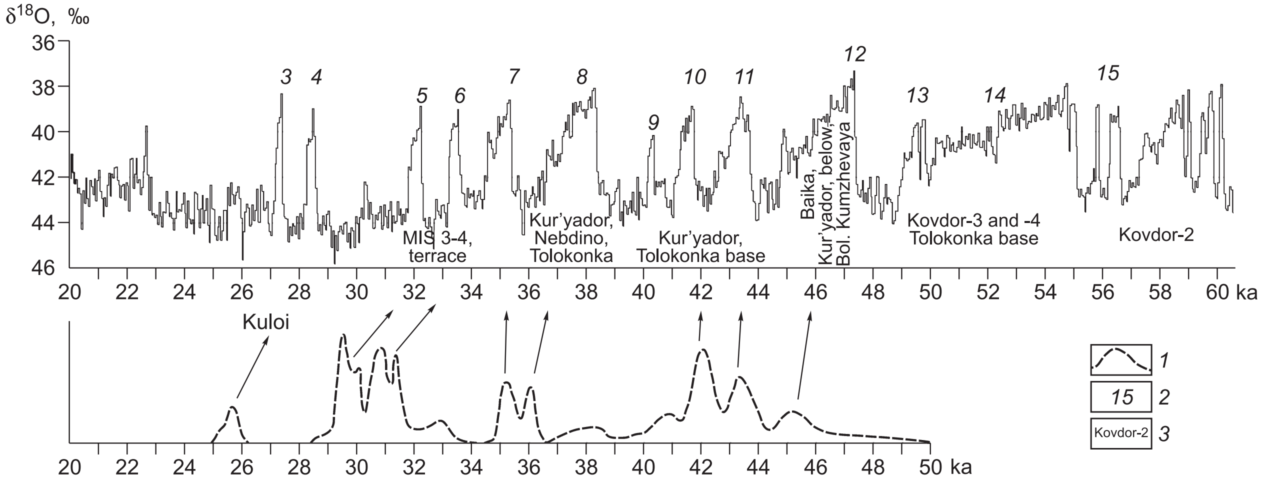

Fig. 4. Correlation of warming periods recorded in the Severnaya Dvina River basin with the Greenland interstadials (GI) (Rasmussen et al., 2014). *1*, graph of the distribution of radiocarbon calibrated dates; *2*, Greenland interstadials; *3*, sections for which the corresponding dates were obtained.

from 15 to 28–30 m, and they host the deposits of almost all the Middle Valdai time (MIS 3). Most of the sections expose the 1st terrace, which was formed at the end of the Middle Valdai (Fig. 2, MIS 3–4 terrace). The terrace height does not usually exceed the height of the Holocene flood plain, i.e., 5–7 m above the current river line. The terrace is comprised of cross- and horizontally-bedded sands of the channel alluvium sometimes with syncryogenic deformations. Thin layers of buried organogenic material are found at the bottom (often nearly the river line); they are represented by peat, loamy peat and plant detritus. The ^{14}C age of these organogenic layers determined by radiocarbon dating is 28–24 ka.

Buried soil in the Baika section with the date of 44,050 ± 1200 (GIN-14866) and the loamy peat in the Kuryador section dated to 41,700 ± 600 (GIN-14324) (Table 1, Fig. 2, Nos. 1, 7) in the basin of the Severnaya Dvina River could be synchronous with the long climatic warming corresponding to GI-12 (~47–44.5 cal. ka BP). It is GI-12, which could be the first from two "optima" of the Middle Valdai time for the basin of the Severnaya Dvina River. Nevertheless, due to the data obtained by Greenland cores and the data collected for Finland and Sweden, GI-14 was the most expressed and the longest climatic warming of MIS 3 (Huber et al., 2006; Wohlfarth, 2010). The subsequent cryogenic soil deformation recorded in the Baika section can reflect climatic cooling (GS-12) shown on the NGRIP curve (Fig. 4). The cryogenic deformations in the light alluvial sands of the Kuryador section (Fig. 2, No. 1) were likely to have formed at the same time. The marine sands (44 ka BP) from the Bol'shaya Kumzhevaya section give evidence in favor of a marine reservoir that existed in the White Sea at that time (Korsakova et al., 2004).

Next climatic warming (~44–42 cal. ka BP) is shown on the graph as two density peaks corresponding to GI-11 and 10; and climatic cooling (GS-11) is presented between these peaks. Organogenic horizons of the Kuryador (including buried soil) and the Tolokonka sections (buried loamy peat) were accumulating during the warming period, which lasted ~ 2 ka (Fig. 2, Nos. 1, 8). The subsequent cooling (GS-10 and GS-9) recorded both on the Pechora Lowland and in the sections of the Severnaya Dvina River basin was characterized by accumulation of river bed sand sequences, except the Kuryador section and its surroundings, where subaerial sedimentation conditions dominated. The cooling might have been long and intensive because the layer of buried soil and underlying sands (Fig. 2, No. 1) of the Kuryador section were severely cryoturbated.

Next climatic warming recorded in the sections and on the graph (age ~36.3–35 ka BP) is correlated with GI-8c, GS-8 and all phases of GI-7. The upper horizons of the organogenic sequence of the Kuryador section, the lower organogenic horizon of the Niobdino section, and the organogenic horizons of the Tolokonka section correspond to this climatic warming (Fig. 2, Nos. 1, 5, 8). Alluvial sands tended to accumulate in the time of the next climatic cooling.

Long-lasting climatic warming is traced at the bottoms of almost all the sections of the 1-st terrace at MIS 3–4 (Nem, Ozyag III, Storozhevsk, Niobdino, Verkhnyaya Tolokonka) and correlates with GI-5.1, GS-5.1 and GI-6. It is divided into two phases (31.9–30.3 and 30.2–29.2 cal. ka BP) in the basin of the Severnaya Dvina River. It seems to be the second from the two optima of the Middle Valdai time in northeastern Europe. The layers overlapping organogenic deposits preserve the traces of intensive syncryogenic (?) cryoturbation and permafrost fracturing (including organogenic horizons) in all studied terraces sections. It probably marks the beginning of the longstanding Late Valdai climatic cooling and consecutive glaciation. The incision of the Severnaya Dvina and Vychegda Rivers might have preceded the terrace formation, at whose bottom organogenic horizons (Fig. 2) dating this climatic warming are exposed. Unfortunately, confirming data are insufficient.

Despite the start of climatic cooling, short-time events of organogenic sedimentation still took place in the upper reaches of the rivers in the Severnaya Dvina basin. The horizon of buried loamy peat of the Kuloi section (the left bank of the Kuloi River–the right bank tributary of the Vaga River) with the date of ~26 cal. ka BP is likely to mark the episode of the short-time warming.

MIS 3 might have been warmer in the basin of the Severnaya Dvina River compared with the adjacent Pechora basin. This supposition is confirmed by numerous remains of mammoth fauna observed in the sections of the 2nd river terrace in the Pechora basin: forestless, periglacial landscape seemed to be favorable not only for the mammoth fauna proliferation, but also for the paleolithic man migration, whose traces were found on Byzovaya and Mamontovaya Kurya archaeological sites (Astakhov and Svensen, 2011). Coniferous and coniferous-small-leaved forests alternating with tundra-steppe were reconstructed during MIS 3 warmings in the basin of the Severnaya Dvina River, and in two sections (Kuryador and Baika) the development of organic-rich buried soils was determined, though bone fragments of megafauna (including artifacts) were not found in the Middle Valdai deposits.

CONCLUSIONS

In conclusion, the Middle Valdai time was a period of repeatable multiple abrupt climate changes in the areas of northeastern Europe. Such variations were "mirrored" in the reaction of the natural system, which left the traces that could be "read" in the studied sections. According to the available data, we can identify 12 episodes of climatic warming and cooling. The graph of probability density distribution demonstrates the "shifts" in date density peaks in relation to climatic warming peaks on the NGRIP curve towards rejuvenation. It reflects the lag in response of fluvial and marine systems to climatic events.

The main conclusions follow from the available data. The salt-water basin in the White Sea existed during the entire Middle Valdai time corresponding to MIS 3. The Severnaya Dvina River continuously flowed into this reservoir, and alluvial sedimentation occurred in the river basin under conditions of the unstable base level and constant climatic variations. In this setting, two terraces were consequently forming with probable alternation of the incision stages; their sediments were exposed by the studied sections.

In northeastern Europe, the warmest stages (which could be referred to as optimal) lay in the time interval of 47–43 and 31.3–29.2 cal. ka BP. The earliest Middle Valdai climatic warming (corresponding to GI 16–13) has not still been determined by the available dates from the studied sections in the Severnaya Dvina River basin.

The main part of the research was supported by RFBR (grant 17-05-00706), within the State assignment of GIN RAS (no. 0135-2019-0059), IG RAS (no. 0127-2019-0008), and GI KSC RAS (no. 0231-2015-0010); the studies of the lower reach of Vychegda were supported by the RSF (project 17-17-01289).

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Editorial responsibility: I.S. Novikov