ИЗВЕСТИЯ РАН. СЕРИЯ ГЕОГРАФИЧЕСКАЯ, 2025, том 89, № 4, с. 578–603

ЭВОЛЮЦИЯ
ПРИРОДНЫХ СИСТЕМ

УДК 551.89+551.312.48+551.435.4:5+551.4.075

PALEOARCHIVE OF LATE PLEISTOCENE SEDIMENTARY ENVIRONMENTS ON THE BORISOGLEBSKAYA UPLAND

© 2025 г. E. V. Garankina[1, 2, *], V. S. Posazhennikova[1, 2], and I. G. Shorkunov[1]

[1]*Institute of Geography RAS, Moscow, Russia*
[2]*Lomonosov Moscow State University, Moscow, Russia*

**e-mail: evgarankina@gmail.com*

Поступила в редакцию 23.12.2024 г.
После доработки 13.04.2025 г.
Принята к публикации 03.06.2025 г.

Landscapes of Central European Russia were sculpted by the last Middle Pleistocene glaciation that constrained most of the following sedimentation in successive interglacial and periglacial settings to various depressions of the glacial paleolandscape. However, corresponding continuous postglacial sequences are extremely rare in the region due to the dramatic fluctuations of the regional base level and significant fluvial activity in most large depressions. Therefore, the fullest available core covering the entire last glacial-interglacial cycle from a kettle hole infill on the northeastern macroslope of the Borisoglebskaya Upland was chosen to reconstruct the local sedimentary environments and to correlate the recorded paleoenvironmental response with the major Late Pleistocene climatic changes. A thorough macro- and mesomorphological investigation of the mechanized press-auger core was complemented by the selective radiocarbon dating of organic-rich sediments. A 20 m thickness of clastic and organic-clastic deposits reflects a pronounced shift from a subaqueous rhythmic lacustrine and eutrophic palustrine accumulation of the Last Interglacial and Early–Middle Pleniglacial to sub- and superaqueous colluvial deposition during the Late Pleniglacial, followed by the final turn to the predominance of subaerial slopewash input during the Late Glacial. Based on the ^{14}C age determinations, immanent hiatuses and sand lenses found in the sequence were correlated with the Early and Middle Pleniglacial fluvial activity, although the lacustrine sedimentation during those stages still prevailed, providing the major part of the entire sedimentary thickness.

Keywords: paleolimnology, lacustrine deposits, peat, glacial landscapes, facies analysis, colluvial input, kettle holes, periglacial conditions

DOI: 10.7868/S2658697525040069

INTRODUCTION

Lacustrine sedimentary sequences are one of the major sources of paleogeographic data in regions affected by the Quaternary glaciations [e.g., (Dearing, 1991)]. They are used for paleoenvironmental reconstructions and chronostratigraphical correlations in periglacial areas. The most prolonged uninterrupted lacustrine paleoarchives are often confined to specific settings such as maar depressions in paleovolcanic provinces of the Circum-Mediterranean region [e.g. (Britzius and Sirocko, 2022; Kattel and Sirocko, 2011; Veres et al., 2009; Wulf et al., 2004)] or linear tectonic depressions of the glaciated mountainous regions (Haflidason et al., 2022). However, in rather more stable and flat areas of the Great European plains, they are quite hard to be found (Lüthgens et al., 2011).

In Central and Eastern Europe, lately kettle hole infills are widely used to recover morpholithogenic features of specific landscapes and local environmental conditions [e.g., (Börner et al., 2018; Daumantas et al., 2022; Fajer et al., 2012; Hein et al., 2021; Hosek et al., 2019; Hrynowiecka et al., 2021; Kupryjanowicz et al., 2015, 2021; Majecka et al., 2022; Mirosław-Grabowska et al., 2021; Niska, 2016; Roman et al., 2021; Rychel, 2021; Rychel et al., 2022; Satkūnas et al., 2003; Satkūnas and Grigienė, 2012; Sokołowski et al., 2024; Woronko et al., 2018, 2022)]. Yet, in Central European Russia, most of the canonic reference sections [e.g., (Bazilevskaya et al., 1984; Chebotareva and Makarycheva, 1974; Moskvitin, 1967, 1976; Novskij, 1975; Problemy ..., 2001; Razrezy ..., 1977; Rusakov and Sedov, 2012; Rusakov et al., 2015, 2019; Sudakova et al., 1984)] were bound to occasional gully incisions or river bank exposures. Thus, those widely utilized paleoarchives were offset by a handful of geomorphic processes providing rather contingent and disrupted records (Sheremetskaya et al., 2022; Shishkina et al., 2019).

Landscapes of Central European Russia (Fig. 1a) were sculpted by the last Middle Pleistocene (MIS6) glaciation (Astakhov et al., 2016; Velichko et al., 2004) that constrained most of the following sedimentation to various depressions of the glacial paleolandscape. Continuous sequences of the last glacial-interglacial cycle are extremely rare in the region. The chronicles of the Galich (Borisova, 2018; Velichko et al., 2001) and Nero (Gunova, 1975) lake basins cover the last 50 and 120 ka, respectively. Yet significant gaps are related to the increased MIS4 — MIS3 erosion followed by the uneven solid runoff under the progressively arid climate of MIS2 (Alyoshinskaya and Gunova, 1997; Borisova et al., 2022). Furthermore, the Nero Lake paleoarchive is biased by the dramatic fluctuations of its water level during the Late Glacial (Alexandrovskiy, 2011; Gunova and Leflat, 1997; Samus et al., 2023; Wohlfarth et al., 2006) caused both by regional base level shifts and eventual damming of the lake by an alluvial fan (Konstantinov et al., 2022; Ukraintsev et al., 2020). The large catchment areas of both lakes [1220 and 872 km^2, respectively (Resources ..., 1972)] have provided a rather averaged regional paleogeographic record, which yet could simultaneously hamper the interpretations of local paleolandscape dynamics and significantly offset the actual paleoclimatic signal. Thus, some local-scale controls of interfluve paleoenvironments are required for better understanding and accurate interpretation of such regional paleoarchives.

In general, much of paleogeographic research has long been focused on the interglacial organic-rich intervals of lacustrine and palustrine records [e.g., (Grichuk et al., 1973; Mamakowa, 1989; Novenko, 2016)]. Particularly, numerous outcrops of MIS5e deposits were thoroughly investigated by paleofloristic studies (Borisova, 2005; Borisova et al., 2007; Gorlova, 1968a, b; Gubonina et al., 1973; Velichko et al., 2005, etc.). Although predominantly clastic sedimentary sequences of the Last Glacial remained much less accounted for or even obscurely attributed to the so-called mantle loams (Semenov et al., 1972), regardless of their extended thickness and even distinct footprints of subaquatic sedimentation. Some data even suggest that most local sinks of the Moscow paleolandscape were completely filled by the Early Pleniglacial (Borisova et al., 2022), completely lacking the rest of the record and thus commonly unsuitable for reconstructions of the Valdai paleoenvironments.

However, several extended kettle hole infills have been lately found at the Borisoglebskaya Upland, exposing almost uninterrupted MIS2 — MIS1 sedimentation (Rudinskaya et al., 2022; Zakharov et al., 2021, 2024) or even prolonged annals of the entire last glacial-interglacial cycle of MIS6 — MIS1 (Garankina et al., 2019; Shishkina et al., 2019). Hence, we chose the fullest available core covering the entire last glacial-interglacial cycle for a thorough chronolithostratigraphic investigation. We attempted to reconstruct the local sedimentary environments and to correlate the recorded paleolandscape response with the major Late Pleistocene environmental shifts at the eastern face of the Borisoglebskaya Upland.

MATERIALS AND METHODS

Solovey Depression is a kettle hole at the NE Borisoglebskaya Upland about 190 km northeast of Moscow and only 10 km WSW of the town of Rostov Veliky (Yaroslavl oblast) (see Fig. 1a). The region was last glaciated during the MIS6, then experiencing alternations of interglacial (MIS5e, MIS1) and periglacial (MIS5d — MIS2) conditions [e.g., (Astakhov et al., 2016; Velichko et al., 2004)]. The glacial topography of the area is dominated by low-amplitude hilly plains alternating with pronounced flat-topped hills and shallow flat-bottomed depressions. The latter are mostly kettle holes considerably filled with sediments reflected as very gently concave lows of the modern landscape, ranging from 0.5 to 4 km in diameter (Garankina et al., 2019, 2023).

Solovey depression belongs to the Puzhbol Gully catchment (Belyaev et al., 2020) lying beyond the upper reaches of its upper right tributary — Western Cheremoshnik Gully (Fig. 1b). From the north and west, the semi-round depression is canvassed by two large hills elevated 25–50 m, while smaller knobs 5–7 m high are spread along its southern and eastern margins. The hills have a rather complex inner structure, being composed of highly contrasting laminated glaciolacustrine sands and loams alternating with glacial diamicts and glacially dislocated blocks (Garankina, 2023). In-between the hills, there are gentle troughs that, however, do not currently drain the basin, except for an artificial drainage channel at the NE. The catchment area of the depression totals up to about 2 km^2. The dry, flat, slightly concave floor of the depression (1.0 km × 0.7 km) has semi-separated S and NE hollows, while at the NW it is slightly elevated and has a specific hummocky pattern of 1–1.5 m height amplitudes. The southern part is only slightly waterlogged, yet until the land reclamation and construction of an artificial drainage system in 1984, a distinct shallow waterbody persisted there.

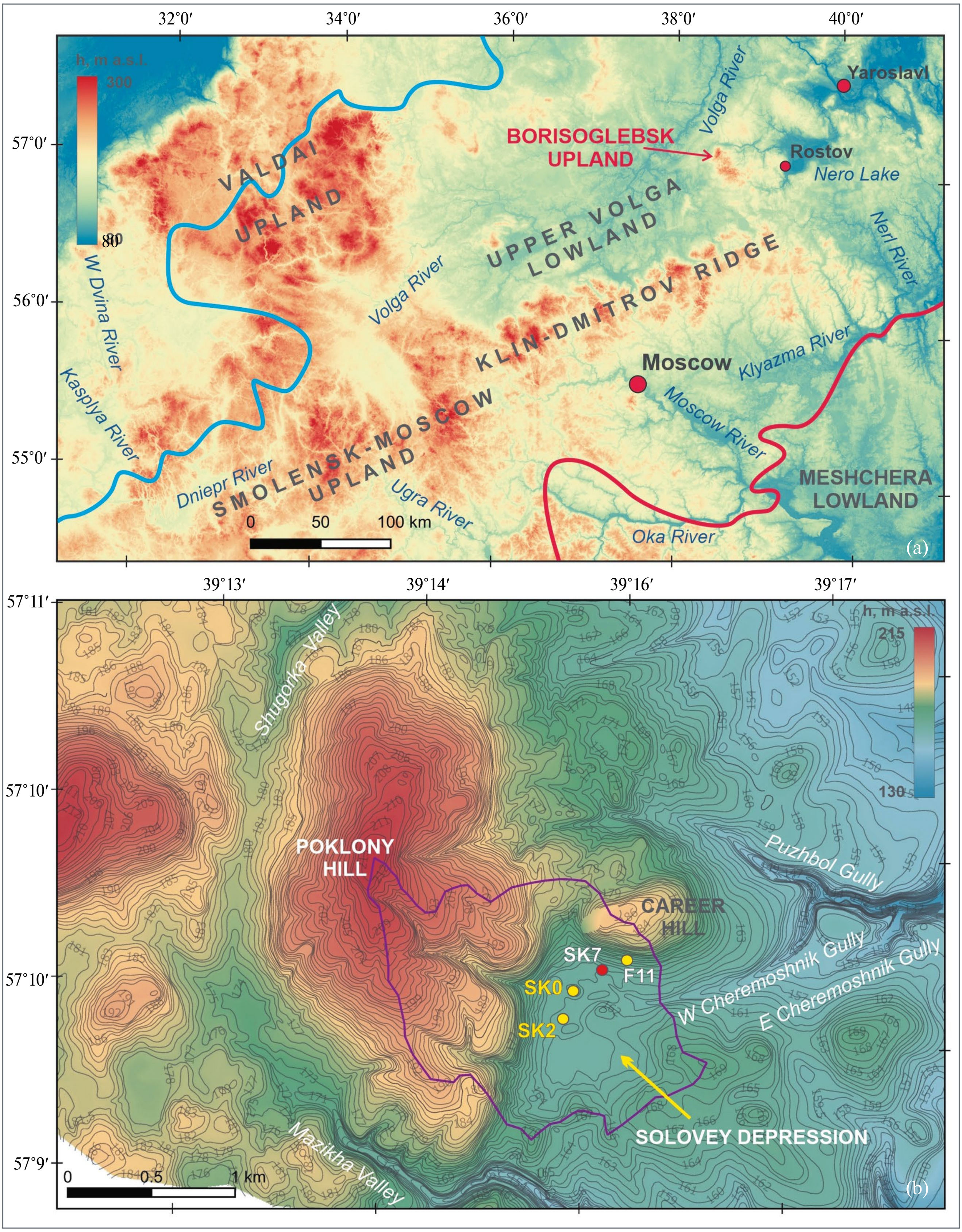

Fig. 1. (a) Location of the Borisoglebskaya Upland at the center of the Russian Plain (background — DEM SRTM). Red and blue lines show the maximum distribution of the Moscow and Late Valdai glacial covers [after (Astakhov et al., 2016)], the yellow star signifies the study area position; (b) Topography of the study area at the NE Borisoglebskaya Upland with the position of the key core SK7 and other geological exposures mentioned in the text. The purple outline shows the catchment area of the Solovey Depression (DEM derived from digitized contours of the land-planning map).

Against the predominance of *Glossic Luvisols* on the watershed (Matinyan et al., 1996; Rusakov and Sedov, 2012; Shorkunov and Rusakov, 2023), the depression bottom and toeslopes of its sides are covered with *Gleyic Luvisols* plowed throughout the 20th century while being deforested by the end of the 18th century.

Recent geophysical reconnaissance of the Solovey depression (Garankina et al., 2023, 2024) has revealed an overdeepening of the glacial base by 20–25 m below its modern surface. That suggests a profound Late Pleistocene accumulation advocated by the MIS3 ^{14}C age of the organic-rich deposit at the 5.5 m depth in a 9 m deep core (Garankina et al., 2019). Thus, extensive coring (12 cores in total) of the depression (Garankina et al., 2023) using a mechanized press-auger (Posazhennikova et al., 2024) was accomplished.

This study focuses on a comprehensive macro- and mesomorphological analyses of lithological features in the thickest (21.5 m) available core SK7 at the northern toeslope of the Solovey depression (see Fig. 1b), complemented by the selective radiocarbon dating of organic-rich sediments. In the field, the surfaces of each auger core 1–1.5 m high were cleared with sharp knives to expose their inner structure. Each auger was shot in reflected light as a whole and in overlapping 10–30 cm intervals. Thorough field morphological and textural description (Garankina and Shorkunov, 2024; Schnurrenberger et al., 2003) was accompanied by further analysis of acquired macrophotos emphasizing the shifts in color, lamination patterns, sedimentary macro and microstructures, the character of lithological boundaries, fabric, inclusions, and pedogenic features (Table 1). CorelDRAW 2023 graphic design software was used to produce the lithostratigraphic visualization of the column.

Revealed distribution patterns of sedimentary attributes and post-sedimentary alterations throughout the core provided a reliable basis for determining both the composition and genetic types of the sediment and facies interpretation. Thus, local sedimentary environments were classified into subaerial, superaqueous, and subaqueous types. The latter were further differentiated in terms of relative water depth changes of the paleobasin, its trophic state, genetic type, and dynamic mode, while deposition and post-deposition agents were distinguished for the former. Major shifts in the relative organic content were used as a rough proxy of regional thermal conditions, allowing a general correlation of the identified lithological units with the global climatic signal of the last glacial-interglacial cycle. ^{14}C AMS dating was carried out at the Laboratory of Radiocarbon Dating and Electronic Microscopy, Institute of Geography, RAS and Center for Applied Isotope Studies, University of Georgia, USA. Calibration of ^{14}C ages was performed with CALIB REV 8.2 using the IntCal20 curve (Reimer et al., 2020). Thus, numerical age determination, coupled with thorough mesomorphological analysis of deposits, allowed more robust correspondence of the identified lithological units with the general chronostratigraphy of the area.

RESULTS

Lithofacial characteristics of sediments. At the northern toeslope of the Solovey depression (Fig. 1c), the SK7 core has reached massive glacial diamicts at a depth of 20.55 m, recovering yet the longest postglacial sedimentary sequence of the NE Borisoglebskaya Upland. A thick stratified loamy stratum with sand, peat, and gyttja beds was distinguished into 15 lithological units (see Table 1, Fig. 2) composed of varying sedimentary facies.

Above the glacial base (U16), the lower 2.8 m of the column (U15–U14) reflect multi-order rhythmically laminated lacustrine silts with contrasting thicker sand interlayers, microfaults, and angular disconformities. Exclusively clastic unit 15 accommodates lenses of massive sandy diamict that resemble the underlying glacial deposit (U16) yet have angular disconform contacts and probably are a product of underwater slumping. In unit 14, fine organic matter and plant remains, including large wood fragments, commence to appear against the general decrease in sand fraction and overall textural contrast of lamination. Above, a 2.5 m thickness of stratified carbonate sapropels (U13) and dense rough peats (U12) stands out due to the increased organic content reflecting the shift from lacustrine to palustrine origin of the deposit. On the eroded top of peats, a rather more homogenous 4-m lacustrine thickness of less organic content rests. Dark patchy fine-sandy silt loams (U11) with lenses of allochthonous plant detritus at the base and gravel inclusions upwards are gradually substituted by stratified sandy gyttja (U10) with loamy and peaty lenses against the progressive increase in organic matter content upwards.

Above, with another erosional boundary, a lithologically contrasting sequence up to almost 7 m thick reflects texturally-laminated lacustrine clay to sandy-silt loams with highly varying organic content (U8 and U6), disrupted by pronounced fine-sand beds (U9 and U7) and several thinner interlayers in U6. Except for the brownish-gray U9, the sands are of a contrasting reddish-yellow hue. Erosional lower contacts of those units and coarse grain size suggest an alluvial origin of the load.

Above 2.5 m depth, clayey silt loams (U5–U4) show no clear lamination or preserved macroscopic inclusions of organic matter. The color of unit 5

Table 1. Lithology of the Solovey depression, SK7 core

Unit	Depth, cm		Color	Lithology	Structure	Lower contact
U1	47–61	0–47	grayish-brown	silt loam	low-contrast lenticular lamination (h ~ 5–20 mm) with large patches intercalated with whitish silt	clear wavy (A ~ 2 mm, P ~ 3 mm)
		47–61	light-brown-light-gray to light-yellow ↓	fine-sandy silt	multiphase irregular contrast large patches & low-contrast fine patches	clear tonguic (A ~ 7 cm)
U2	61–123	61–75	red-brown	silt loam	wavy lamination with large patches intercalated with a dense network of plane pores filled with whitish silt	noticeable
		75–90	reddish-light-brown	loam	multiphase wavy lamination, angular disconformities with underlying layering	noticeable
		90–123	dull yellowish-light-brown		large, often subvertical, multiphase patches & numerous soft dark brown concretions	gradual
U3	123–196		grayish-yellow to yellow-light-gray ↓	clayey silt loam	lenticular lamination of bright red-yellow phase, vertical deformation of lamination	clear on decrease in red-yellow phase
U4	196–320		light-gray to whitish with dull reddish-yellow	clayey silt loam	multiphase wavy lamination (A ~ 5–10 mm) with bright red-yellow lenses & soft dark brown concretions	gradual on increase in viscosity & decrease in red-yellow phase
U5	320–445	320–425	light-gray & brownish-light-gray with red-yellow	clayey silt loam ↓410 cm — denser	non-contrast wavy lamination (A < 4 mm), dull red-yellow lenses & patches, red-yellow aggregated lenses with soft dark-brown core	gradual
		425–445	gray	slightly sandy silt loam	non-contrast textural lamination, large bright red-yellow hard concretions with dark-brown core	sharp oblique
U6	445–610	445–455	gray with reddish-brown-gray	slightly sandy organic-rich silt loam	low-contrast lamination of dark-gray & reddish-brown to dark-gray phases	sharp oblique
		455–460	brownish-yellow	fine sand	*not preserved*, *core was stretched during extraction*	sharp wavy (A ~ 1 cm, P ~ 1–3 cm) oblique
		460–470	dark-gray & bluish-light-gray	slightly sandy silt loam with organic-rich layers	contrast oblique lamination of dark reddish brown interlayers (h<10 mm) ↓isometric sand lenses with angular disconformities	sharp contrast irregularly wavy to tonguic (A to 5 cm, P ~ 1–5 cm) oblique
		470–490	brownish-light-gray	fine sand	*not preserved*, *core was stretched during extraction*	sharp wavy (A < 5 mm, P ~ 1–2 cm) oblique

Table 1. Continued

Unit	Depth, cm		Color	Lithology	Structure	Lower contact
		490–510	dark-gray & brownish-gray with reddish-light-brown	alternation of loam, clay loam with organic-rich fine-sandy loam	texturally contrast wavy lamination (h ~ 0.2–1 cm) of gray & reddish-light-brown phases	sharp oblique
		510–520	dark dark-brown to reddish-brown	fine-sandy gyttja with peat lens	irregular lamination	clear tonguic (A ~ 7 cm, P ~ 10 cm)
		520–530	dark-gray & reddish-brown	slightly sandy silt loam	non-contrast lamination of dark gray & reddish-brown to dark-gray phases	clear wavy (A ~ 3 mm, P ~ 1 cm)
		530–550	bluish-gray & grayish-brown	clay loam	contrast wavy lamination (h ~ 2–4 mm, A < 1 cm) of bluish-gray & brownish-gray phases	noticeable on thicker lamination
		550–610	bluish-gray & grayish-brown with brown-light-gray	clay loam	contrast irregular lenticular lamination (h ~ 1–2 mm to 1–3 cm) with rare large brown-gray lenses ↓wavy lamination (A ~ 1–3 cm)	sharp wavy (A ~ 5–8 mm, P ~ 5–20 mm)
U7	610–708		yellowish-red	fine sand ↓690 cm — silty fine sand	*not preserved*, *core was stretched during extraction*	noticeable
U8	708–809	708–750	gray & brownish-gray	clay loam with irregular sandy interlayers	non-contrast lamination (h ~ 2–3 mm) occasionally highlighted by soft dark-brown concretions, with rare contrast sandy interlayers (h ~ 2–25 mm)	sharp horizontal
		750–792	gray & brownish-gray	clay loam with organic-rich interlayers	texturally contrast fine lamination (h ~ 0.5–2 mm) as in overlying subunit enriched with organic matter	noticeable on increase in organic matter & lamination
		789–809	light-brownish-gray	clay loam with sandy interlayers	texturally non-contrast fine lamination	noticeable wavy (A < 5 mm, P ~ 15–20 mm)
U9	809–1124	809–820	brownish-gray	organic-rich silty fine & very fine sand with sandy-loam interlayers	irregular non-contrast lamination (h ~ 10 mm)	sharp oblique
		820–890	brownish-gray	fine & very fine sand with coarse-sand lenses	texturally non-contrast lamination (*core was stretched during extraction*, h ~ 5–15 mm)	*not clear*, *high water saturation*
		890–1100	brown-gray to gray↓	very fine sand with organic-rich silty patches	large dark-brown lenses & interlayers, occasionally disconform with host material	clear wavy (A < 10–15 mm, P ~ 3–4 cm)
		1100–1124	brownish-gray	fine-sandy loam	textural lamination (h ~ 1 mm) with superimposed contrasting interlayers of well-sorted sand (h 2 mm)	sharp oblique

Table 1. Continued

Unit	Depth, cm		Color	Lithology	Structure	Lower contact
U10	1124–1305	1124–1160	reddish-brown	organic-rich sandy loam	massive with lenses of dark-brown to black phase	noticeable oblique
		1160–1245	brownish-gray	sandy gyttja with small clasts of loam	non-contrast lamination	noticeable on increase in organic matter & lamination
		1245–1305	brownish-gray	alternation of loam & fine-sandy loam with organic-rich interlayers ↓1275 cm — silty loam	irregular textural lamination (h ~ 1–2 mm to 1–2 cm)	clear wavy
U11	1305 – 1523	1305–1465	greenish-gray & brownish-gray	fine-sandy silt loam ↓1420 cm — large gravel	contrast greenish-gray & brownish-gray patches ↓1415 cm — less contrast patchiness	clear on increase in organic matter
		1465–1523	gray with dark-brown	dense loam with detritus	contrast lenticular to patchy with large organic-rich lenses & interlayers	sharp wavy (A ~ 1–2 cm)
U12	1523–1670		reddish-brown to yellow-dark-brown	weakly humified peat with remains of mosses, shrub & tree leaves ↓increasing peat density & humification	fine lenticular lamination (h < 1 mm) with organic-rich interlayers, fragments of wood trunks and branches	sharp wavy (A ~ 3 cm, P > 6 cm)
U13	1670–1775	1670–1674	brownish-gray to yellow	carbonate sandy sapropel with detritus	fine patchy	sharp horizontal
		1674–1700	reddish-brown to reddish-dark-brown	carbonate sandy sapropel with organic-rich lenses	fine lenticular lamination	sharp oblique
		1700–1754	brownish-gray to brown↓	carbonate sandy sapropel ↓increasing density & organic matter	fine lenticular lamination with rare sandy interlayers	sharp horizontal
		1754–1775	greenish-brown to grayish-dark-brown	carbonate fine-sandy loam with lenses of sandy silt & detritus	fine textural lamination (h ~ 1–2 mm to ↓2–5 mm) ↓1755 cm — organic-rich lenses, folded deformation	clear oblique
U14	1775–1925	1775–1784	bluish-gray & dark-gray	carbonate fine-sandy loam to gyttja with small shell detritus	fine lamination (h < 1 mm) with plastic deformations ↓ ↓1785 cm — wavy (A ~ 4 cm) sandy layers h~2–6 mm	sharp wavy (A ~ 1.5 cm, P ~ 2 cm)
		1784–1787	grayish-dark-brown	peaty gyttja with varying sand content	coarse lenticular oblique lamination	sharp oblique disconform

Table 1. Ending

Unit	Depth, cm		Color	Lithology	Structure	Lower contact
		1787–1798	dark-brown with bluish-dark-gray & brownish-gray	clay loam with gyttja interlayers	oblique fine textural lamination (h ~ 0.1–0.3 mm, inclination gradually flattens out from 15° to 4–5°)	sharp zip-like with angular disconformity (A ~ 1 cm, P ~ 1.5 cm)
		1798–1804	dark-bluish-gray & dark-gray	clay loam	multiphase fine lamination (h ~ 0.1 mm) with microfaults & angular disconformities	sharp angular folded (A < 1 cm, P > 1 cm)
		1804–1877	bluish-gray to dark-gray with dark-brown	clay loam to loam with sand interlayers and occasional detritus 1830–1845 cm — rare sand interlayers 1850 cm — wood fragment ↓1867 cm — organic-rich interlayers	irregular fine textural lamination (h ~ 0.3–0.5 to 1–2 mm) with plastic deformations & rare wavy interlayers (A~5–10 mm)	sharp angular (A ~ 1 cm, P ~ 2 cm), with microfaults & angular disconformities
		1877–1889	bluish-gray to gray with brownish-gray	clay loam to loam with organic matter	multiphase lenticular lamination ↓1884 cm — sandy lenses with plastic deformations	sharp oblique
U15	1889–2055	1889–1912	gray to grayish-light-brown	clay loam to loam with sand interlayers	texturally contrast lamination (h ~ 1–2 mm) ↑plastic deformations	clear horizontal
		1912–1925	gray to yellowish-gray	clay loam to loam	texturally non-contrast fine lamination (h~μm)	sharp wavy
		1925–1950	brownish-gray	sand loam with coarse sand, small gravel & rare large gravel	massive	sharp oblique
		1950–2004	brownish-gray	clay loam to loam, 1979–1984 cm — angular lens of sand loam	multi-order rhythmic lamination with microfaults alternation of sandy & loamy interlayers	sharp oblique
		2004–2040	grayish-brown to light-brownish-gray	clay loam to loam with sand interlayers	texturally contrast lamination (h ~ 0.1–2 mm) ↓2030 cm — large reddish-brown patches	sharp wavy
		2040–2055	gray	clayey sand	laminated	gradual
U16	2055–2150 (...)		gray to reddish-gray ↓	sandy silt loam with gravel ↓2095 cm — small angular pebbles	massive	*not exposed*

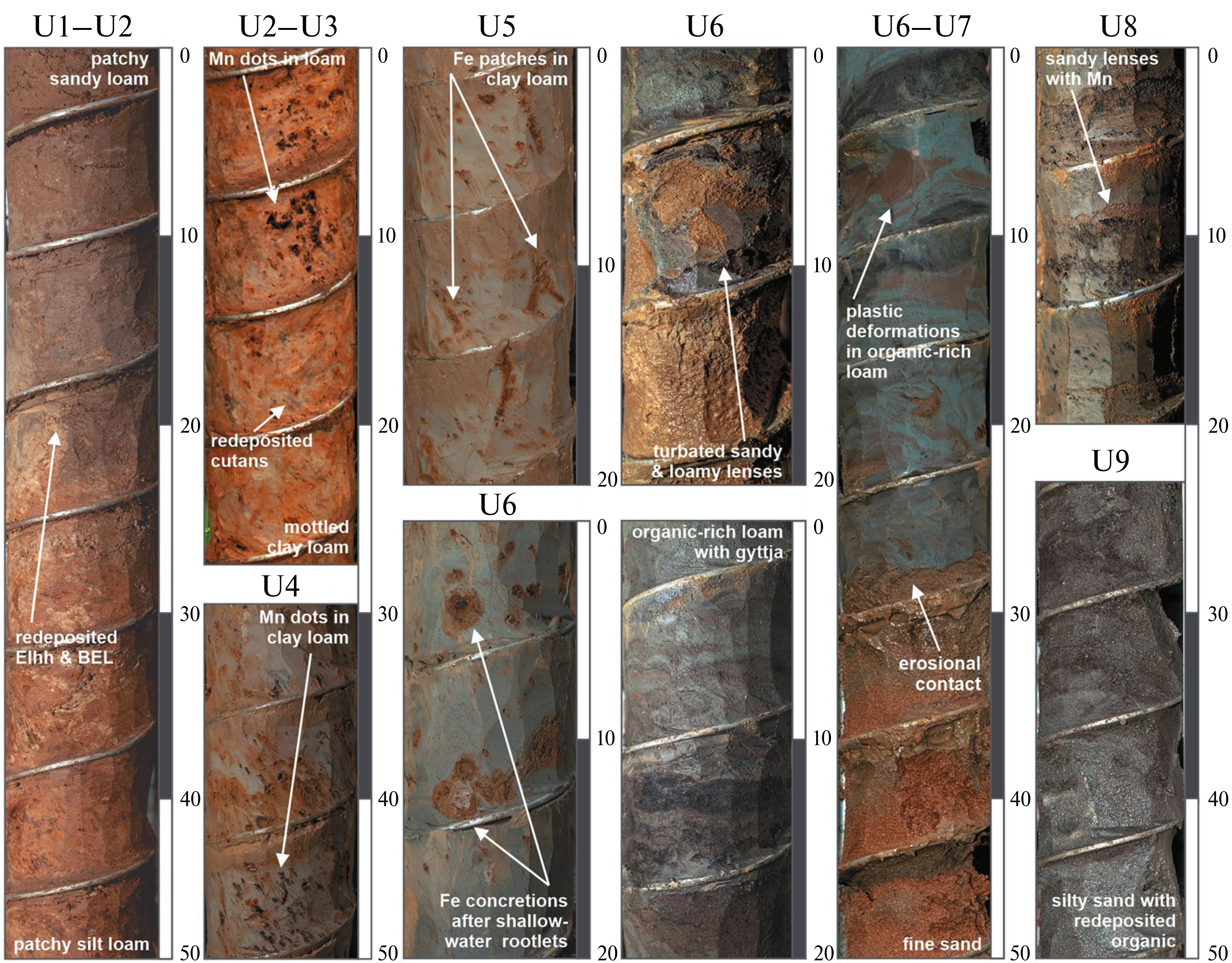

Fig. 2. Details of the lithological structure of the SK7 reference core. Photos show specific structures of different units, allowing genetic interpretations.

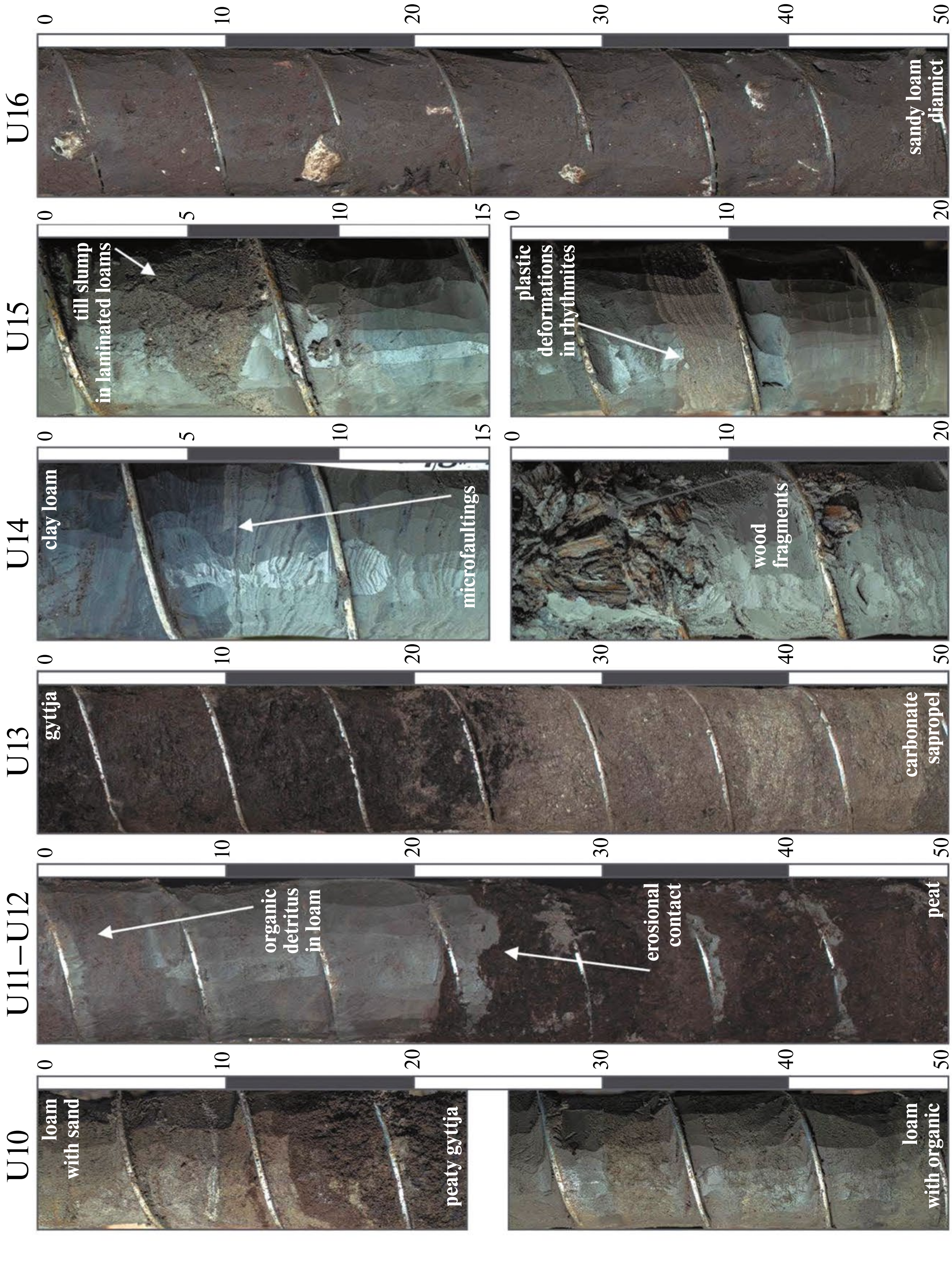
U16
sandy loam diamict
U15
till slump in laminated loams
plastic deformations in rhythmites
U14
clay loam
microfaultings
wood fragments
U13
gyttja
carbonate sapropel
U11–U12
organic detritus in loam
erosional contact
peat
U10
loam with sand
peaty gyttja
loam with organic
0
5
10
15
20
30
40
50

Fig. 2. Ending.

gradually changes from gray to lighter pale gray, forfeiting its bluish hue to mottled yellow-light-gray in unit 4. Characteristic bright red-yellow ferruginous concretions with dense brown interiors at the base of U5 are substituted upwards by less contrasting reddish-yellow and reddish-brown vertical patches and completely mottled impregnations in U4. Both units reflect a certain amount of colluvial input, yet the lower one still shows some obscure rhythmic lamination of water-lain origin, while the lenticular mottled structure of the upper one is more likely a result of slope redeposition of its material by solifluction and creep.

The uppermost 2 m of the loamy stratum starts up where the reddish-light-brown phase tends to overrun the light-gray one (U3). Irregular reddish-bright-yellow wavy lenses highlight the low-contrast lamination in the clay loams of creep nature. On the almost complete dissipation of the light-gray and reddish-yellow phases against a noticeable rise in dark reddish-brown impregnations, a series of rather thin loamy beds of more reddish hue and lighter composition (U2) follows upward. The upper part of U2 turns to reddish-brown silt loams with a reticulate network of pale light-yellow silt. The topmost grayish-brown fine-sandy loams (U1) are marked by a low-contrast lenticular lamination with large irregular silt patches. At the lower contact of U1, a pocket of pale reddish-light-gray silt reflects the redeposited ELhh and BEL horizons of a paleosol. Variegated lenticular structure, dull reddish hue, and coarser composition with a noticeable intercalation of fine sand in the stratified thickness (U2–U1) represent the signs of slopewash redeposition. Each bed is penetrated by a specific network of pedogenic pore planes filled with either brownish-gray cutans or pale light-yellow siltans.

Age determination. Four ^{14}C age determinations of organic-rich deposits were accomplished for the SK7 core (Table 2), complementing the previously published dates from the neighboring core SK2 and pits SK0 and F11 (Belyaev et al., 2020; Garankina et al., 2019; Shorkunov and Rusakov, 2023). In both cores, the second half of the middle Valdai interval has been identified, being presented by predominantly grayish loamy thicknesses yet with apparent darker lenses of gyttja enriched with peat (Figs. 3a, b). The lowest sample (SK7a–104) occurred to be out of the ^{14}C dating range; however, as it was taken from a rather disturbed sand unit 9 regarded as a footprint of pronounced alluvial input, some degree of older organic matter redeposition rests possible (see Fig. 2, U9). The next sample (SK7a–83) from the top of the same unit received an age of around 36.8–38.1 ka, which is in good alignment with the 35.2–36.3 ka age from the peat lens in the SK2 core. There are no age inversions, though upwards, for a quite extended interval (1.3 m) of loamy sedimentation, two samples (SK7–2 and SK7–4) yielded very close dates falling in-between 31.6 and 31.1 ka (see Fig. 3a). The lower one was obtained for a small lens of dispersed organic matter in characteristic bluish loams (U6) above the distinct sand layer (U7). The upper date marks the termination of alluvial input shortly followed by the transition to a very shallow pond-like type of accumulation (Fig. 3c). Such a negligible difference in age either calls for rather high rates of sedimentation mounting up to 1 mm/year or some organic matter redeposition causing the absence of the age gap. Two younger dates obtained for the thin gyttja layers from the neighboring exposures are well-coordinated, albeit they correspond to the Middle Holocene (~5.7–6.7 ka). The youngest date obtained for the burned buried birch roots on the footslope of the depression (F11) points to 1 ka AD as an onset of the cut-and-burn practices at the key site (Belyaev et al., 2020).

DISCUSSION

Local sedimentary environments. The pronounced depression within the Moscow (MIS6) glacial sedimentary complex was filled with more than 20 m of the postglacial loamy stratum, reflecting several dramatic shifts in textural composition, organic matter content, and structures (see Table 1, Figs. 2, 3a, b). The major part of the sequence (U15–U5) reflects rhythmic clastic and organic-clastic sedimentation in a subaqueous environment (see Fig. 3c) manifested in multi-order textural horizontal lamination. Lacustrine sedimentation was dominant, although the repeated peat accumulation (U12, top of U10) indicates at least periodic cessations of the waterbody, causing the shifts to a superaqueous mode of deposition. Erosional contacts both atop those peats and at the base of coarse-grained layers (U9, U7, and sand lenses in U6) suggest several hiatuses caused by erosion episodes both in subaqueous and superaqueous environments.

The lower part of the lacustrine sequence, characterized by fine rhythmic textural lamination (U15–U14), corresponds to the most dynamically contrasting sedimentary environments. Encompassed lenses of massive glacial diamicts witness the rapid slumping along the steep, unstable sides of paleodepression as their sharp angular edges signify the dislocation of diamict blocks in a frozen state. Microfaulting also indicates uneven settling of the laminated thickness, likely due to melting of the buried glacier ice under the warming effect of a relatively deep-water basin, as evidenced by the (sub)millimeter textural lamination. At the latest stages of deglaciation, an ice-walled lake also could not be excluded as a possible explanation. However, the upward increase in organic content and its dispersion in the predominantly clastic deposit

Table 2. Radiocarbon dates of the Solovey depression

№	Field Code	Lab Code	H abs, m	Depth, cm	Lithology / Dated fraction	14C yrs BP ± 1 σ	cal yrs BP, 2 σ range
1	F11	$IGAN_{AMS}$–7632	167	080–092	loamy colluvium / charcoal of *Betula albae*	1060 ± 20	925–976
2	SK2–13–12	Ki–19676	160.8	096–102	gyttja in loam / TOC*	5190 ± 60	5753–6179
3	SK0	IGAN–2535	163	65	gyttja / HA**	5600 ± 140	6009–6731
4	SK2–44	Ki–19671	156.3	550–555	peat lens in loam / TOC	31 440 ± 300	35234–36346
5	SK7–2	$IGAN_{AMS}$–10760	158.1	455–460	loam / TOC	27255 ± 110	31099–31551
6	SK7–4	$IGAN_{AMS}$–10761	156.8	582–594	organic-rich loam / TOC	27390 ± 110	31155–31625
7	SK7a–83	$IGAN_{AMS}$–10762	154.5	820–830	fine organic-rich sand / TOC	32945 ± 150	36883–38105
8	SK7a–104	$IGAN_{AMS}$–10763	152.4	1030–1040	reworked organic matter in sand / TOC	>50000	out of range

Note: *Total organic carbon; **humic acid.

suggest progressively improving climatic conditions (Fig. 3d) against the reducing energy of the depositional environment while indirectly pointing to the stabilization of the adjacent interfluves.

That tendency flourishes in the overlying carbonate sapropels (U13), reflecting rather mild conditions of a low-energy shallow-water eutrophic basin, yet in a climate with rather contrasting seasons. Gradual substitution by the superaqueous phytogenic accumulation of peats (U12) marks the transition to a superaqueous environment and warmer settings (see Fig. 3d). Low humification of plant tissues and even incorporation of tree branches and trunks point to a rather rapid deposition at a eutrophic forested bog.

No signs of subaerial reworking of peat, its sharp upper contact, and redeposition of detritus in the overlying laminated loams (U11) (see Fig. 2) suggest that the recovery of subaqueous conditions in the basin shortly followed the peat deposition. Likely, it caused a simultaneous erosion atop the peat, yet rather locally constrained. Thus, a position relatively close to the lakeshore against periodic landscape destabilization on adjacent interfluves could be argued. Predominant clastic sedimentation in an oligotrophic lake of the period denotes some deterioration of climate conditions, while textural patchiness of the sediment signifies some perturbation that could be attributed to either cryogenic or biogenic activity, both pointing at a rather shallow-water setting.

A gradual substitution by gyttja (U10) topped with a thin peat layer signifies another increase in bioproductivity of a shallower eutrophic lake, related probably to the next regional climate warming. There is no certainty whether that peaty lens indicates yet another drop of the water level and recurrence of superaqueous conditions, as the plant remains are rather well-humified and could reflect input of redeposited detritus from the shore.

Upwards, a lithologically contrasting sequence (U9–U6) reflects a fairly dynamic sedimentary environment of variable energy. Against the preservation of the lacustrine setting of an average depth the amount and rates of terrigenous input shifted profoundly with its peaks highlighted by fine sandy units (U9, U7, lenses in U6) of differentiated sorting (see Fig. 2). Stratified fine sands (U9) with disrupted lenses of allochthonous organic matter likely indicate increased transport capacity at the catchment both through linear and slope erosion causing certain reworking of the underlying organic-rich unit (U10). Progressive incorporation of clastic fines up to the transition to laminated loams (U8) indicates the gradually reducing energy of the sedimentary environment against its yet pronounced alternations highlighted by contrasting detritus and sand interlayers. A new phase of even more intense erosion of the catchment and alluvial input into the lake is highlighted by a sharp boundary with the coarser unit (U10, see Fig. 2). Lithological variability and lack of rhythmicity in the thick pack of sands suggest a rather high-energy sedimentary environment. Simultaneously, a very short-distance transport and fast burial are implied as sands preserved their vibrant red hue that could only have been inherited from the glacial tills eroded on the adjacent interfluve. Plastic deformations of sand and loam lenses in U6 and U7 allow assuming they were affected by cryoturbation, which endorses a shallow-water setting with periodic freezing of the lake floor. Yet it seems that both the slight erosion

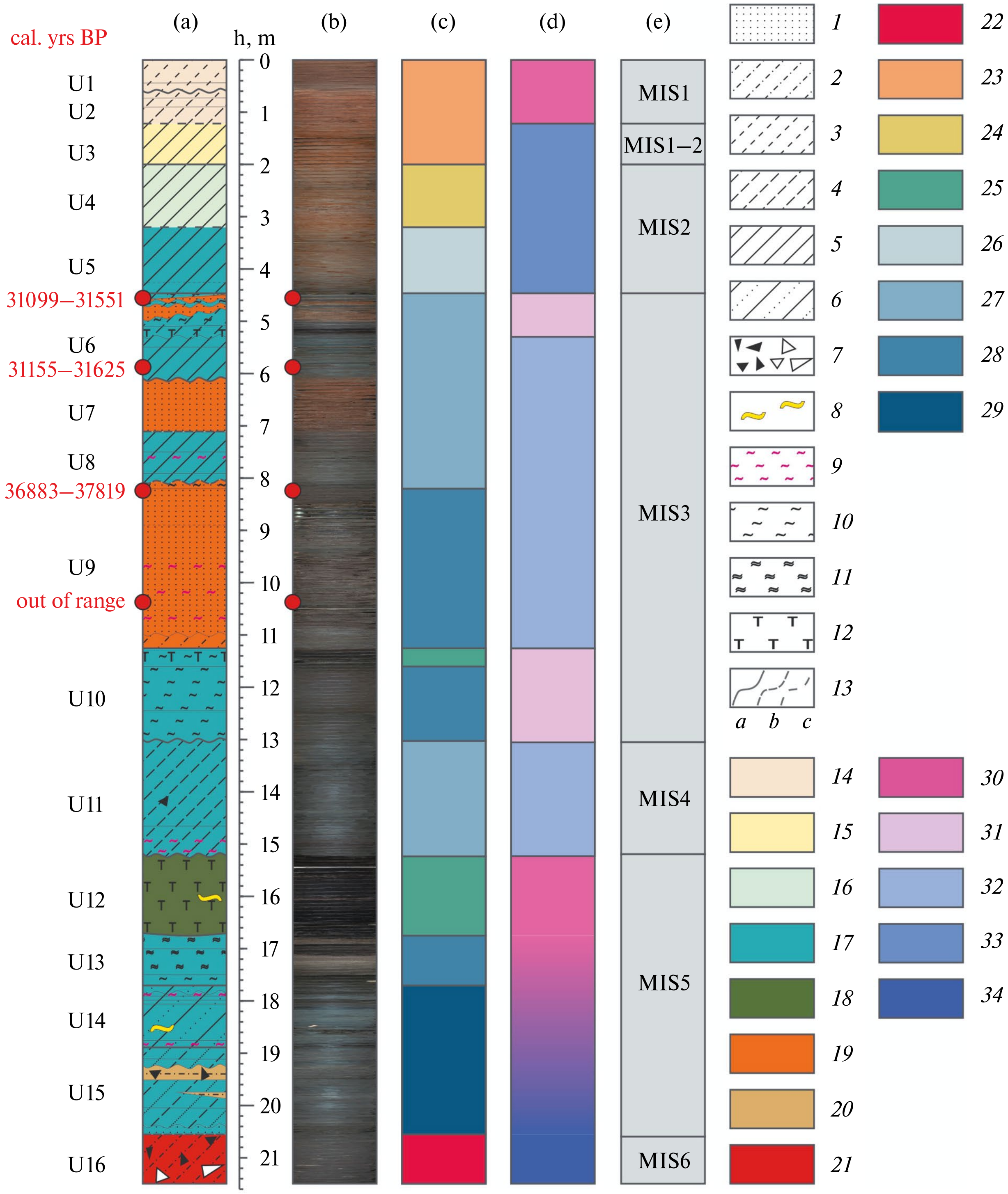

Fig. 3. Interpretation of the key lithological column SK7: (a) lithology and facies, (b) natural color changes, (c) local sedimentary environments, (d) relative changes in regional climatic conditions, (e) correlation with marine isotope stages. *Lithology* (*column a*): *1* — very fine & fine sand, *2* — sandy loam, *3* — silt loam, *4* — loam, *5* — clay loam, *6* — loam laminated with sand, *7* — gravel and pebble, *8* — wood fragments, *9* — plant detritus, *10* — gyttja, *11* — sapropel, *12* — peat, *13* — contacts: a — sharp, b — noticeable, c — gradual. *Facies* (*column a*): *14* — slopewash, *15* — creep, *16* — solifluction and creep; *17* — lacustrine, *18* — palustrine, *19* — alluvial, *20* — underwater slump, *21* — glacial. *Local sedimentary environments* (*column c*): *subaerial*: *22* — glacial, *23* — slope; *superaqueous*: *24* — slope, *25* — waterlogged bog; *subaqueous*: *26* — very shallow water body (pond up to 1–2 m deep) with distinct colluvial input, *27* — shallow water body (2–5 m) with weak water grading, *28* — water body of medium depth (5–10 m) with multi-order water grading; *29* — relatively deep water body (> 10–15 m) with multi-order contrast textural grading. *Relative changes in regional climatic conditions* (*column d*): *30* — warm (interglacials), *31* — warmer (periglacial interstadials), *32* — milder (periglacial stadials and interstadials), *33* — colder (periglacial stadials), *34* — cold (glacials).

of underlying loams and the deposition of each sandy layer occurred in a subaqueous environment. Thus, the latter can be interpreted as a gully bedload repeatedly deposited at an underwater alluvial fan. The total thickness of sands amounts to almost 3.5 m, which is a sign of quite prominent erosion on the rather limited adjacent interfluve.

The gradual lightening of the sediment color upwards, backed by the general decline in organic matter in U5, signifies progressive shallowing of the water basin. Iron segregation in anoxic conditions was concentrated along the hydrophyte rootlets. That is reflected in hard ferruginous concretions at the base of U5, extending upwards as vertically oriented aggregated reddish-yellow lenses with darker interiors in pale gray clayey silt loams. It is worth acknowledging that no signs of eutrophication associated with an articulate decrease in the water depth have been found throughout the area (Garankina et al., 2019, 2022; Sheremetskaya et al., 2022). Thus, rather severe climatic conditions can be suggested for the period as preventing the vegetative overgrowth of the shallowing lake, coupled yet against a very low-energy sedimentation environment as suggested by the fine grain size and overall textural homogeneity of loams. A specific pond-like type of accumulation can be argued to have prevailed during that time not only in deeper inherited glacial depressions but in smaller lows such as thermokarst throughs (Garankina et al., 2019, 2022).

Upwards an increase in reddish-yellow impregnations (U4) accompanied by distinct signs of slope redeposition indicate the general transition to superaqueous settings. Certain periodic waterlogging had persisted as reflected both by traces of bluish hue and fragments of characteristic cm–mm lenticular layering highlighted by ferruginous and manganese segregations. However, the major deposition agent shifted to slope processes, among which solifluction and creep are most expected.

A transition to the predominantly subaerial deposition is associated with a series of thin loam and silt loam beds (U3–U1) presenting distinct signs of repeated slope reworking with a change of the primary agent from creep (in U3) to slopewash (in U2–U1). Also, the pack is significantly altered by certain episodes of pedogenesis imprinted in the separate pore planes networks filled with either cutans (running both in U3 and U2) or siltans (only in the upper part of U2). The erosional base of U1 with pockets of redeposited ELhh and BEL material marks the end of a certain surface stabilization stage that resulted in a texturally-differentiated soil formation on the adjacent watershed area. On the contrary, unit 1 itself seems almost unaffected by modern soil formation, which points to its rather young age of deposition. It shows typical signs of agrogenically-triggered redeposition reflected in a rather more homogenous lenticular to patchy structure, against no signs of textural differentiation. The onset of cut-and-burn cultivation led to erosion intensification on previously forested slopes, which triggered the agrogenic colluvium (U1) accumulation on the adjacent footslopes and in local depressions.

Correlation with regional chronolithostratigraphy and general environmental changes. Recent studies (Baranov, 2022; Baranov et al., 2022; Borisova et al., 2022) convincingly argued against the existence of large proglacial lake basins in Central European Russia during the Valdai epoch [as suggested by (Kvasov, 1975; Rusakov and Sedov, 2012; etc.)]. Thus, local yet quite frequent findings of rather pronounced postglacial sedimentary thicknesses up to 10 m on local interfluves (Markov et al., 1969; Moskvitin, 1976; Novskij, 1975; Razrezy ..., 1977; Semenov et al., 1972; Sudakova et al., 1984; etc.) are attributed to spatially-constrained semi-closed depressions of glacial paleolandscapes such as kettle holes [e.g., (Antonov, 1998; Garankina et al., 2019; Sheremetskaya et al., 2012; Zakharov et al., 2024)] or glaciofluvial incisions [e.g., (Eremenko and Panin, 2010; Eremenko et al., 2011; Kuzmina et al., 2022; Shishkina et al., 2019)].

As shown by the electrotomographic profiling (Garankina et al., 2023, 2024), the studied Solovey depression embodies several merged kettle holes, which are almost undetectable in the modern landscape (see Fig. 1b). Thus, while the sedimentary sequence of SK7 core most fully represents the general lithostratigraphy of the Solovey paleobasin, it also bears specific erosion signals not recorded in some neighboring cores due to the paleolandscape variability. Hence, we attempted to correlate tendencies in the reconstructed sequence of local sedimentary environments with the regional chronostratigraphic scheme, keeping in mind that the climatic signal could be offset by the locally triggered gully erosion and slope processes.

The grayish, loamy, lacustrine stratum is interrupted by several drastically contrasting layers of coarser sands or darker organic-rich matter. Received ^{14}C ages coupled with the facies interpretation and general stratigraphic position above the Moscow tills allow making some rather robust assumptions about the chronology of deposition in the Solovey depression. The middle Valdai stratum (31–38 ka and older) covers a significant part of the column in its middle.

Below, a characteristic peat unit (U12) overlays a stratified lacustrine sequence of loams (U15–14) and sapropells (U13). In the region, thick dense peat and gyttja lenses are characteristic of the Mikulino interglacial (MIS5e) (Bazilevskaya et al., 1984; Chizhikov, 1956; Gorlova, 1968b; Markov et al., 1969; Problemy ..., 2001, etc.), thus, they could be used as one of the tentative markers for correlation. A series of similar outcrops has long been known in the vicinity of the studied kettle, the closest being the compressed yet alike sedimentary sequences in the Cheremoshnik and Puzhbol gullies 1.7–1.9 km eastwards. Thoroughly palinologically studied (Borisova, 2005; Gorlova, 1968a; Gubonina et al., 1973; Markov et al., 1969; Novenko et al., 2005; Rusakov et al., 2015; Sheremetskaya et al., 2022; Sukachev and Nedoseeva, 1954; Tyuremnov and Vinogradova, 1952; etc.), they are well-known references for the first half of the Mikulino interval. On top of the Moscow till, the onset of organogenic accumulation is marked by thin lenses of well-decayed peats ^{230}U–Th dated to 122–144 ka (Rusakov et al., 2015, 2019), followed by varved clay sedimentation shortly substituted by gyttjas and peats of 114–115 ka ^{230}U–Th age. Thus, the deposition ages encompassing the entire MIS5e are consistent with the Mikulino palynological interpretation (Gorlova, 1968a, b; Markov et al., 1969; Novenko et al., 2005; Problemy ..., 2001; Rusakov et al., 2015, 2019; Sheremetskaya et al., 2022; Sudakova et al., 1984), allowing them to be correlated with the investigated units 13 and 12. Thus, contrastingly laminated units 15 and 14, which line up the glacially-laden floor of the Solovey paleodepression and show imprints of initially rather cold but progressively warming conditions, can be aligned with the transition from late glacial conditions of the Late Moscow (MIS6) deglaciation to interglacial settings of the early MIS5e (Figs. 3d, e). An emerging kettle hole started to simultaneously fill in with contrasting clastic material against yet unfinished buried ice thawing and sediment settling.

Peats of U12 are truncated with some traces of their redeposition in the overlying loams (U11). Such hiatuses atop the Mikulino peats have been reported in the Puzhbol and Cheremoshnik exposures covering the entire interglacial optimum and even the majority of the MIS5d — MIS4 (Novenko et al., 2005; Rusakov et al., 2015, 2019; Sheremetskaya et al., 2022). A significant lowering of the water table has long been argued for the area (Gunova, 1975), however, two major questions remain open. The first one concerns the cause of such a water level drop: whether it was a drying response to the regional amelioration of the climate in the second half of the Mikulino Interglacial (Alyoshinskaya and Gunova, 1997; Gunova, 1975; Markov et al., 1969) or additional drainage of such depressions triggered by the widespread linear erosion (Shishkina et al., 2019). The other issue concerns what could have caused the following recovery of water bodies that was majorly out of character for the region, as lately argued by Borisova et al. (2022). As general answers to both questions lie quite beyond the scope of this study, there is yet no evidence suggesting that the particular depression had experienced any significant drainage during that time. That indirectly supports the climatic forcing of the water level drop and deposition break, followed by only slight local erosion of the banks. Thus, it also eliminates the need to look for an additional cause for the damming of the depression, which could have been simply refilled with water during the wetter stages.

The timing of that lake recovery remains quite obscure, referring to a prolonged interval from the early stages of cooling in MIS5d–a or MIS4 to the first half of MIS3 (prior to the radiocarbon age determination limit). It is quite confident to say that lacustrine conditions persisted at least until the transition to or the beginning of MIS2, showing tendencies to terrigenous slope and alluvial input since ca. 38 ka (U9–U6), followed by the progressive shallowing and depletion in organic matter since ca. 31 ka (U5–U4). It could be tentatively correlated with the analog climatic signal in SK2 core (Garankina et al., 2019) where several organic-rich lenses with close ^{14}C dates (37.5–35 cal ka BP) also refer to rather warmer stages of the Middle Valday (MIS3) interstadial with a quite sharp shift to less favorable, cooler and dryer, conditions (probably of MIS2). The major difference in those cores appears to be no signs of alluvial load in the SK2 core as opposed to the pronounced sand units [e.g., U9, U7) in the SK7 core. That reveals the local signal recorded in the latter core, probably due to its close position to the eroded sides of the depression.

Upwards, no precise age control is available for the SK7 core, yet the correlation with neighboring exposures in the vicinity of the key site and general climatic trends reconstructed for the Upper Volga Region (Borisova, 2021) made it possible to propose some chronostratigraphic frames. A drop in the organic content against the pronounced increase in the "loess" (coarse silt) fraction was reported (Garankina et al., 2019) in sediments correlative with U5 and further upwards. Footprints of cryogenic slope reworking found in U4 can be quite confidently corresponded to distinct signs of cryoturbation, solifluction, and small cryogenic cracks in the SK2 core, pointing to a significant deterioration of the climate. Those units can generally be correlated with the MIS2 pleniglacial conditions, yet an attribution of U5 to the LGM and U4 to the Late Glacial remains only tentative. Unit 3 still bearing some evidence of a predominant creep mechanism of movement against yet low organic content can be preliminarily attributed to the end of the Late Glacial or transition to the Holocene, as it is also penetrated by clay cutans of interglacial soil.

The upper 1.25 m of colluvial accumulation is quite surely correlated with the Holocene stages of landscape destabilization. However, if the lower unit (U2) consisted of several thin beds with erosional contacts reflects some regional climatic shifts, then the accumulation of the upper one (U1) was probably stimulated by the beginning of agricultural development of the Upper Volga Region. The onset of cut-and-burn cultivation led to erosion intensification on previously forested fields, which triggered the agrogenic colluvium (U1) accumulation on the adjacent footslopes and in local depressions commencing 0.6–1.3 cal ka BP (Belyaev et al., 2020). At the key site, the timing can be more precisely constrained by the pyrogenic event dated to the turn of the 10th and 11th centuries in the F11 exposure.

Evidence of the Middle Holocene land surface stabilization indicated throughout the area by either buried *in situ* texturally-differentiated soil profiles or products of its redeposition caused by the following extensive erosion around 5–6 ka BP (Belyaev et al., 2020; Garankina et al., 2019, 2023) remains obscure in the key core. However, in the neighboring exposures (SK0, SK2), a period (~5.7–6.7 ka) of temporary waterlogging of the lower parts of the depression bottom is recorded by gyttja deposition. Those gyttjas are buried by another series of thin colluvial beds, which could be tentatively correlated with U2. Simultaneously, no signs of analogue water-lain deposits in the key core SK7 are probably due to its higher position on the toeslope.

It can be resumed that throughout its existence, the water basin in the Solovey Depression shifted in depth from more than 15–20 m at the early stages of the kettle hole formation during MIS6 deglaciation and initial infill at the onset of the Mikulino interglacial (U14–15) to shallower settings ever since, with some periods of almost complete drying (as U12). Garankina et al. (2019) showed that multi-order rhythmic lamination of lacustrine sediments has been preserved during the Early and Middle Valdai epochs, at least in the central part of the depression (core SK2). Thus, at the key core (SK7) position, the water depth can be estimated as deeper than 4–5 m, which prevented the disruption of the initial lamination, at least until the pronounced sand accumulation of U9 around 37 ka. It can be suggested that then the lake depth gradually decreased up to 2–3 m (U6), followed by a stage of very shallow (1–2 m) pond-like waterbody reflected in the deposits of U5, which almost completely ceased to exist by the end of the Late Pleniglacial. The presented reconstruction contradicts the thesis proposed earlier by Borisova et al. (2022) that in the Upper Volga Region, all of the local depressions were almost completely filled with sediments by the end of Valdai Early Glacial (MIS5 a) or even before. However, our reconstruction is supported by a series of the Middle Valdai AMS ^{14}C dates acquired for the pronounced laminated lacustrine infills of the adjacent depressions (Garankina et al., 2019, 2023; Shishkina et al., 2019), suggesting some specific conditions of the Borisoglebskaya Upland, which allowed that deviation from the standard scenario (Borisova et al., 2022). Here, we can only speculate that the anomalous thickness of both the dead ice blocks and the associated Late Moscow glaciofluvial and limnoglacial accumulation were the precursors of the highly amplitudinal glacial topography of the study area, which provided the opportunity for the recovery of lacustrine environments after the Last Interglacial.

CONCLUSIONS

We delivered a thorough macromorphological lithological investigation of the 20 m deep core in the eastern part of the Borisoglebskaya Upland. Considerable hiatuses are found in the sequence, yet it presents the fullest available Late Pleistocene paleoarchive on the interfluves of the Borisoglebskaya Upland. It allowed major sedimentation agents and local sedimentary environments to be reconstructed and correlated with the regional climatic trends.

Initially emerging as a kettle hole of about 20 m deep during the degradation of the Late Moscow glaciation, the Solovey Depression became an arena of the Late Pleistocene clastic and organic-clastic rhythmic sedimentation. The major part of the studied sequence reflects rather calm and cold water environments 5 to 10 m deep of the Middle and Late Valdai stages. Thus, the presented reconstruction shows specific conditions of the Borisoglebskaya Upland, which allowed the recurrence of lacustrine sedimentation during most of the Pleniglacial, in contrast to the regional trend of a complete infill of the local glacial depressions by the end of the Early Glacial.

Multi-order stratification of lake sediments refers to their sensitivity to both regional environmental cyclicity (from seasonal and annual to decadal, centennial, and millennial) and irregular episodic shifts on a catchment scale (e.g., local fluvial incision events).

Following the LGM, a shift from subaqueous to superaqueous and later (during the Late Glacial) to subaerial sedimentary environments dominated by colluvial input coincided with the regional trend of climatic deterioration during the MIS2.

FUNDING

This research has been supported by the Russian Science Foundation, project no. 23-77-10063.

ACKNOWLEDGMENTS

We are grateful to the drilling master A.Yu. Kachalov for his field experience and to

Yu.V. Shishkina and N.V. Mokievsky for their assistance in the field core sampling.

ФИНАНСИРОВАНИЕ

Исследование выполнено при поддержке Российского научного фонда, проект № 23-77-10063.

БЛАГОДАРНОСТИ

Авторы благодарны буровому мастеру А.Ю. Качалову за его непревзойденный полевой опыт и Ю.В. Шишкиной и Н.В. Мокиевскому за помощь в полевом отборе бурового керна.

REFERENCES

Aleshinskaya Z.V., Gunova V.S. Recent deposits and paleogeography of Lake Nero. *Vestn. Mosk. Univ., Ser. 5: Geogr.*, 1997, no. 1, pp. 49–52. (In Russ.).

Alexandrovskiy A.L. Soil evolution on the low terraces of Lake Nero. *Eurasian Soil Sci.*, 2011, vol. 44, pp. 1055–1067.
https://doi.org/10.1134/S1064229311100024

Antonov S.I. Pleistocene lacustrine lithomorphogenesis at the southeastern Moscow region limits. In *Istoriya pleistotsenovykh ozer Vostochno-Evropeiskoi ravniny* [History of Pleistocene Lakes of the East-European Plain]. S.-Petersburg: Nauka Publ., 1998, pp. 282–290. (In Russ.).

Astakhov V., Shkatova V., Zastrozhnov A., Chuyko M. Glaciomorphological map of the Russian Federation. *Quat. Int.*, 2016, vol. 420, pp. 4–14.
https://doi.org/10.1016/j.quaint.2015.09.024

Baranov D.V. Geomorphology of the upper Volga River valley: Study history and state of the problem (paper 2. The Upper Volga Lowland). *Geomorfolog.*, 2022, vol. 53, no. 1, pp. 35–48. (In Russ.).
https://doi.org/10.31857/S0435428122010047

Baranov D.V., Utkina A.O., Panin A.V. Tver proglacial lake (Tver region, Russia): Myth or reality. *Limnol. Freshwater Biol.*, 2022, no. 4, pp. 1383–1384.
https://doi.org/10.31951/2658-3518-2022-A-4-1383

Bazilevskaya L.I., Bol'shakov V.A., Velichkevich F.Yu., Nemtsova G.M., Pisareva V.V., Sudakova N.G. Results of a complex study of Quaternary sediments in the Rostov area, Yaroslavl region. In *Geologiya, poleznye iskopaemye i inzhenerno-geologicheskie issledovaniya Tsentral'nykh raionov evropeiskoi chasti SSSR* [Geology, Mineral Deposits and Geotechnical Investigations of the Central Regions of the European Part of the USSR]. Moscow: MinGeo Publ., 1984, pp. 56–71. (In Russ.).

Belyaev V.R., Garankina E.V., Shorkunov I.G., Konstantinov E.A., Rusakov A.V., Shishkina Y.V., Andreev P.V., Verlova T.A. Holocene erosion and deposition within a small catchment of the NE Borisoglebsk Upland (Central European Russia). *IOP Conf. Ser.: Earth Environ. Sci.*, 2020, no. 438, art. 012002.
https://doi.org/10.1088/1755-1315/438/1/012002

Borisova O.K. Vegetation and climate changes at the Eemian/Weichselian transition: New palynological data from Central Russian Plain. *Polish Geol. Inst. Spec. Pap.*, 2005, vol. 16, pp. 9–17.

Borisova O.K. Lake Galich during the late Valdai (Weichselian) glaciation. In *Paleolimnology of Northern Eurasia: Experience, Methodology, Current Status and Young Scientists School in Microscopy Skills in Paleolimnology*. Kazan: Kazan Univ. Publ., 2018, pp. 25–27.

Borisova O.K. Landscape and climatic conditions in the Central East European Plain in the last 22 thousand years: Reconstruction based on paleobotanical data. *Water Resour.*, 2021, vol. 48, pp. 886–896.
https://doi.org/10.1134/S0097807821060038

Borisova O., Konstantinov E., Utkina A., Baranov D., Panin A. On the existence of a large proglacial lake in the Rostov-Kostroma lowland, north-central European Russia. *J. Quat. Sci.*, 2022, vol. 37, no. 8, pp. 1442–1459.
https://doi.org/10.1002/jqs.3454

Borisova O.K., Novenko E.Y., Velichko A.A., Kremenetski K.V., Junge F.W., Boettger T. Vegetation and climate changes during the Eemian and Early Weichselian in the Upper Volga region (Russia). *Quat. Sci. Rev.*, 2007, vol. 26, no. 19–21, pp. 2574–2585.
https://doi.org/10.1016/j.quascirev.2007.07.001

Börner A., Hrynowiecka A., Stachowicz-Rybka R., Niska M., Moskal-del Hoyo M., Kuznetsov V., Maksimov F., Petrov A. Palaeoecological investigations and ^{230}Th/U dating of the Eemian Interglacial peat sequence from Neubrandenburg-Hinterste Mühle (Mecklenburg-Western Pomerania, NE Germany). *Quat. Int.*, 2018, vol. 467, part A, pp. 62–78.
https://doi.org/10.1016/j.quaint.2017.04.003

Britzius S., Sirocko F. Subfossil Coleoptera from Eifel maar sediments as indicators of the environmental evolution in Central Europe over the last 60,000 years. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2022, vol. 596, art. 110981.
https://doi.org/10.1016/j.palaeo.2022.110981

Chebotareva N.S., Makarycheva I.A. *Poslednee oledenenie Evropy i ego geokhronologiya* [The Last Glaciation of Europe and Its Geochronology]. Moscow: Nauka Publ., 1974. 216 p.

Chizhikov N.V. Geomorphology and soils of the Nero Lake basin and Ustje-Kotorosl' rivers. In *Trudy laboratorii sapropelevykh otlozhenii. Tom 6* [Works of the Sapropel Deposits Laboratory. Vol. 6]. Moscow: Izd-vo AN SSSR, 1956, pp. 130–144. (In Russ.).

Daumantas L., Šinkūnas P., Rudnickaitė E., Dobrotin N., Kisielienė D., Spiridonov A. Late Pleistocene to Middle Holocene record of sedimentation and carbonate content in the Zervynos paleolake-dune complex, Lithuania. *Estonian J. Earth Sci.*, 2022, vol. 71, no. 4, pp. 214–229. https://doi.org/10.3176/earth.2022.15

Dearing J.A. Lake sediment records of erosional processes. *Hydrobiologia*, 1991, vol. 214, pp. 99–106. https://doi.org/10.1007/978-94-011-3592-4_13

Eremenko E.A., Panin A.V. Genesis of linear depressions network in the central and southern regions of the East-European Plain. *Vestn. Mosk. Univ., Ser. 5: Geogr.*, 2011, no. 3, pp. 59–66. (In Russ.).

Eremenko E.A., Karevskaya I.A., Panin A.V. Postglacial transformation of glacio-fluvial channels in the marginal zone of the Moscow (OIS 6) glaciation. *Izv. Akad. Nauk, Ser. Geogr.*, 2010, no. 2, pp. 56–70. (In Russ.).

Fajer M., Waga J.M., Rzetala M., Szymczyk, A., Nita M., Machowski R., Rzetala M., Ruma M. The Late Vistulian and Holocene evolution of Jezioro Lake: A record of environmental change in southern Poland found in deposits and landforms. *J. Paleolimnol.*, 2012, vol. 48, pp. 651–667. https://doi.org/10.1007/s10933-012-9634-1

Garankina E. Stop 2. Glacial inheritance vs postglacial metamorphoses of the Borisoglebsk Upland interfluves. 2a. Glacial deposits and associated topography. In *Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023.* Moscow: Inst. Geogr. RAN, 2023, pp. 37–46. https://doi.org/10.15356/periglacial978-5-89658-071-3

Garankina E.V., Shorkunov I.G. The silence of the sections: Methodological approach to geological exposures in regard to paleogeographic goals. In *Materialy I Belorusskogo geograficheskogo kongressa. Tom 6* [Materials of the 1st Geographical Congress. Vol. 6]. Minsk: BGU Publ., 2024, pp. 46–52. (In Russ.).

Garankina E.V., Belyaev V.R., Shorkunov I.G., Shishkina Yu.V., Andreev P.V., Sheremetskaya E.D. Lake sedimentation as an agent of postglacial transformation of interfluves and fluvial landscapes of the Borisoglebsk Upland, Central European Russia. *Proc. Int. Assoc. Hydrol. Sci.*, 2019, vol. 381, pp. 13–20. https://doi.org/10.5194/piahs-381-13-2019

Garankina E.V., Lobkov V.A., Shorkunov I.G., Belyaev V.R. Identifying relict periglacial features in watershed landscape and deposits of Borisoglebsk Upland, Central European Russia. *J. Geol. Soc.*, 2022, vol. 179, no. 5, art. jgs2021–135. https://doi.org/10.1144/jgs2021-135

Garankina E., Posazhennikova V., Lobkov V., Shorkunov I. Stop 2. Glacial inheritance vs postglacial metamorphoses of the Borisoglebsk Upland interfluves. Stop 2b. Postglacial lacustrine sedimentation. In *Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023.* Moscow: Inst. Geogr. RAN, 2023, pp. 46–63. https://doi.org/10.15356/periglacial978-5-89658-071-3

Garankina E.V., Shorkunov I.G., Yurchenko A.P., Posazhennikova V.S., Lobkov V.A. Transformation of local kettle holes based on geological and geophysical evidence, Borisoglebsk Upland, Central European Russia. *Limnol. Freshwater Biol.*, 2024, no. 4, pp. 310–317. https://doi.org/10.31951/2658-3518-2024-A-4-310

Gorlova R.N. Change of vegetation in the Mikulino interglacial according to studies of peatlands of the Yaroslavl region. In *Istoriya razvitiya rastitel'nogo pokrova tsentral'nykh oblastei evropeiskoi chasti SSSR v antropogene* [History of Vegetation Cover of the Central Regions of the European Part of the USSR in Anthropogene]. Moscow: Nauka Publ., 1968a, pp. 45–91. (In Russ.).

Gorlova R.N. *Smena rastitel'nosti kak komponenta biogeotsenoza v predposlednee mezhlednikov'e* [Change of Vegetation as Component of Biogeocenosis in the Penultimate Interglacial]. Moscow: Nauka Publ., 1968b. 72 p. (In Russ.).

Grichuk V.P., Gubonina Z.P., Zelikson E.M., Monoszon M.Kh. Interglacial deposits of the Rostov (Yaroslavskiy) region. In *Palinologiya pleistotsena i pliotsena* [Palynology of Pleistocene and Pliocene]. Moscow: Nauka Publ., 1973, pp. 188–203. (In Russ.).

Gubonina Z.P., Zelinkson E.M., Monoszon M. Kh. Floristic and phytoceneologic analyses of paleobotanical materials on interglacial deposits in the Cheremoshnik area. In *Palinologiya pleistotsena i pliotsena* [Palynology of Pleistocene and Pliocene]. Moscow: Nauka Publ., 1973, pp. 53–59. (In Russ.).

Gunova V.S. History of Lake Nero according to paleobotanical data. *Extended Abstract of Cand. Sci. (Geogr.) Dissertation.* Moscow: Moscow State Univ., 1975. 21 p. (In Russ.).

Gunova V.S., Leflat O.N. Holocene and current state of the ecosystem of Lake Nero. *Vestn. Mosk. Univ., Ser. 5: Geogr.*, 1997, no. 4, pp. 42–45. (In Russ.).

Haflidason H., Brendryen J., Eldegard R.F., Mangerud J., Ólafsdóttir S., Regnéll C., Svendsen J.I. High-resolution chronology of 24 000-year long cores from two lakes in the Polar Urals, Russia, correlated with palaeomagnetic inclination records with a distinct event about 20 000 years ago. *J. Quat. Sci.*, 2022, vol. 37, no 5, pp. 778–789. https://doi.org/10.1002/jqs.3391

Hein M., Urban B., Tanner D.C., Buness A.H., Tucci M., Hoelzmann P., Dietel S., Kaniecki M., Schultz J., Kasper T., von Suchodoletz H., Schwalb A., Weiss M., Lauer T. Eemian landscape response to climatic shifts and evidence for northerly Neanderthal occupation at a palaeolake margin in northern Germany. *Earth Surf. Process. Landf.*, 2021, vol. 46, no. 14, pp. 2884–2901. https://doi.org/10.1002/esp.5219

Hosek J., Prach J., Krızek M., Sıda P., Moska P., Pokorny P. Weichselian thermokarst landscape discovered in the Czech Republic, central Europe. *Boreas*, 2019, vol. 48, pp. 988–1005. https://doi.org/10.1111/bor.12404

Hrynowiecka A., Stachowicz-Rybka R., Niska M., Moskal-del Hoyo M., Börner A., Rother H. Eemian (MIS5e) climate oscillations based on palaeobotanical analysis from the Beckentin profile (NE Germany). *Quat. Int.*, 2021, vol. 605–606, pp. 38–54. https://doi.org/10.1016/j.quaint.2021.01.025

Kattel G., Sirocko F. Palaeocladocerans as indicators of environmental, cultural and archaeological developments in Eifel maar lakes region (West Germany) during the Lateglacial and Holocene periods. *Hydrobiologia*, 2011, vol. 676, pp. 203–221. https://doi.org/10.1007/s10750-011-0872-4

Konstantinov E.A., Karpukhina N.V., Zakharov A.L., Bricheva S.S., Ukraintsev V.Yu., Lazukova L.I., Rudinskaya A.I. Fluctuations of Nero Lake in the Holocene. *Dokl. Earth Sci.*, 2022, vol. 506, Suppl. 1, pp. 48–54. https://doi.org/10.1134/S1028334X22700258

Kupryjanowicz M., Drzymulska D., Fiłoc M. Eemian and early Weichselian Lobelia lakes in northeastern Poland. *Rev. Palaeobot. Palynol.*, 2015, vol. 219, pp. 28–38. https://doi.org/10.1016/j.revpalbo.2015.03.006

Kupryjanowicz M., Fiłoc M., Woronko B., Karasiewicz T.M., Rychel J., Adamczyk A., Jarosz J. Eemian and early Weichselian environmental changes at the Jałówka site, NE Poland, and their correlation with marine and ice records. *Quat. Res.*, 2021, vol. 104, pp. 69–88. https://doi.org/10.1017/qua.2021.8

Kuzmina S.A., Sycheva S.A., Ershova E.K., Zyuganova I.S., Zakharov A.L., Gorbatov E.S., Kolesnikov S.F., Panin P.G. Ivantsevo section of the buried Middle and Late Pleistocene lake-bog deposits near the town Dmitrov, Moscow Region. *Geomorfolog.*, 2022, vol. 53, no. 3, pp. 7–18. https://doi.org/10.31857/S0435428122030087

Kvasov D.D. *Pozdnechetvertichnaya istoriya krupnykh ozer i vnutrennikh morei Vostochnoi Evropy* [Late Quaternary History of Eastern Europe's Large Lakes and Inland Seas]. Leningrad: Nauka Publ., 1975. 278 p. (In Russ.).

Lüthgens C., Böse M., Lauer T., Krbetschek M., Strahl J., Wenske D. Timing of the last interglacial in Northern Europe derived from Optically Stimulated Luminescence (OSL) dating of a terrestrial Saalian-Eemian-Weichselian sedimentary sequence in NE-Germany. *Quat. Int.*, 2011, vol. 241, no. 1–2, pp. 79–96. https://doi.org/10.1016/j.quaint.2010.06.026

Majecka A., Wachecka-Kotkowska L., Krzyszkowski D., Malkiewicz M., Miroslaw-Grabowska J., Niska M., Rzodkiewicz M., Myoekow E., Tomaszewska K., Wieczorek D., Raczyk J. Environmental changes during the MIS6a — MIS5e transition. The Parchliny 2016 profile, central Poland. *Geol. Quarterly*, 2022, vol. 66, no. 4, pp. 1–27. https://doi.org/10.7306/gq.1663

Mamakowa K. Late Middle Polish Glaciation, Eemian and Early Vistulian vegetation at Imbramowice near Wroclaw and the pollen stratigraphy of this part of the Pleistocene in Poland. *Acta Palaeobotanica*, 1989, vol. 29, no. 1, pp. 11–176.

Markov K.K., Velichko A.A., Sudakova N.G., Breslav S.L., Berdnikov V.V. *Putevoditel' ekskursii Moskva — Verkhnyaya Volga. Simpozium "Paleogeografiya i periglyatsial'nye yavleniya pleistotsena"* [Guidebook for Field Excursions Moscow — Upper Volga. Symp. on Paleogeography and Pleistocene Periglacial Phenomena]. Moscow: Nauka Publ., 1969. 72 p.

Matinyan N.N., Rusakov A.V., Kerzum P.P. General patterns of soil cover structure of the Yaroslavl Volga region. *Vestn. S.-Petersb. Univ. Ser. 3: Biol.*, 1996, vol. 1, no. 3, pp. 74–86. (In Russ.).

Mirosław-Grabowska J., Borówka R.K., Radzikowska M., Sławińska J., Hrynowiecka A., Sobczyk A., Stachowicz-Rybka R., Stefaniak K. Environmental changes recorded in the sequence of lake-peat bogs in the Eemian Interglacial and Vistulian on the basis of multi-proxy data. *Quat. Int.*, 2021, vol. 632, pp. 51–64. https://doi.org/10.1016/j.quaint.2021.11.023

Moskvitin A.I. *Trudy geologicheskogo instituta AN SSSR. Tom 156. Stratigrafiya pleistotsena Evropeiskoi chasti SSSR* [Works of the Geol. Inst., Acad. of Sci., USSR. Vol. 156. Pleistocene stratigraphy of the European part of the USSR]. Moscow: Nauka Publ., 1967.

Moskvitin A.I. *Opornye razrezy pleistotsena Russkoi ravniny* [Pleistocene Reference Sections of the Russian Plain]. Moscow: Nauka Publ., 1976.

Niska M.M. The Eemian/Early Vistulian development of the Solniki paleolake (north-eastern Poland) as shown by subfossil Cladocera. *Adv. Oceanogr. Limnol.*, 2016, vol. 7, no. 2, pp. 206–219. https://doi.org/10.4081/aiol.2016.6217

Novenko E.Y. *Izmeneniya rastitel'nosti i klimata Tsentral'noi i Vostochnoi Evropy v pozdnem pleistotsene i golotsene v mezhlednikovye i perekhodnye etapy klimaticheskikh makrotsiklov* [Changes in Vegetation and Climate of Central and Eastern Europe in the Late Pleistocene and Holocene during Interglacial and Transitional Stages of Climatic Macrocycles]. Moscow: GEOS Publ., 2016.

Novenko E.Y., Velichko A.A., Zuganova E.S., Junge F.W., Boettger T. Dynamics of vegetation at the Late Pleistocene Glacial/Interglacial transition (new data from the center of the East European Plain). *Polish Geol. Inst. Spec. Pap.*, 2005, no. 16, pp. 77–82.

Novskii V.A. *Pleistotsen Yaroslavskogo Povolzh'ya* [Pleistocene of the Yaroslavl Volga Region]. Moscow: Nauka Publ., 1975.

Posazhennikova V.S., Garankina E.V., Shorkunov I.G., Konstantinov E.A., Kachalov A.Yu. Cores of paleolake sediments: How to obtain and how to process. In *Materialy I Belorusskogo geograficheskogo kongressa. Tom 6* [Materials of the 1st Geographical Congress. Vol. 6]. Minsk: BGU Publ., 2024, pp. 150–155. (In Russ.).

Problemy stratigrafii chetvertichnykh otlozhenii i paleogeografii Yaroslavskogo Povolzh'ya. Materialy simpoziuma [Problems in Stratigraphy of Quaternary Deposits and Paleogeography of the Yaroslavl Volga Region. Proc. of the Int. Symp.]. Lavrushin Yu.A., Chistyakova I.A., Eds. Moscow: GEOS-Press Publ., 2001. (In Russ.).

Razrezy otlozhenii lednikovykh raionov tsentra Russkoi ravniny [Sections of Sediments of Glaciated Areas of Russian Plain Center]. Markov K.K., Ed. Moscow: Izd-vo MGU, 1977. 198 p.

Reimer P., Austin W., Bard E., et al. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, vol. 62, no. 4, pp. 725–757.
https://doi.org/10.1017/RDC.2020.41

Resursy poverkhnostnykh vod SSSR. T. 10. Verkhne-Volzhskii raion. Opisanie otdel'nykh rek i ozer [Surface Water Resources of the USSR. Vol. 10. Upper Volga Region. Description of Individual Rivers and Lakes]. Yablokov Yu.E., Ed. Leningrad: Gidrometeoizdat, 1972.

Roman M., Mirosław-Grabowska J., Niska M. The Eemian Lakeland of the central Polish Plain: Environmental changes and palaeogeography. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2021, vol. 561, art. 110087.
https://doi.org/10.1016/j.palaeo.2020.110087

Rudinskaya A.I., Zakharov A.L., Konstantinov E.A., Shorkunov I.G., Garankina E.V., Zaretskaya N.E. Conditions of sedimentation in the Sarskoye Swamp (Yaroslavl region, Russia) in the Late Glacial and Holocene. *Limnol. Freshwater Biol.*, 2022, no. 4, pp. 1553–1555.
https://doi.org/10.31951/2658-3518-2022-A-4-1553

Rusakov A., Sedov S. Late Quaternary pedogenesis in periglacial zone of NE Europe near ice margins since MIS3: Timing, processes, and linkages to landscape evolution. *Quat. Int.*, 2012, vol. 265, pp. 126–141.
https://doi.org/10.1016/j.quaint.2012.03.002

Rusakov A., Nikonov A., Savelieva L., Simakova A., Sedov S., Maksimov F., Kuznetsov V., Savenko V., Starikova A., Korkka M., Titova D. Landscape evolution in the periglacial zone of Eastern Europe since MIS5: Proxies from palaeosols and sediments of the Cheremoshnik key site (Upper Volga, Russia). *Quat. Int.*, 2015, vol. 365, pp. 26–41.
https://doi.org/10.1016/j.quaint.2014.09.029

Rusakov A., Sedov S., Sheinkman V., Dobrynin D., Zinovyev E., Trofimova S., Maximov F., Kuznetsov V., Korkka M., Levchenko S. Late Pleistocene palaeosols in the extra-glacial regions of NW Eurasia: Pedogenesis, post-pedogenic transformation, palaeoenvironmental inferences. *Quat. Int.*, 2019, vol. 501, pp. 174–192.
https://doi.org/10.1016/j.quaint.2018.03.020

Rychel J. Palaeogeographic reconstruction of the North Podlasie region in the Sokółka area during the Late Pleistocene (NE Poland). *Geol. Quarterly*, 2021, vol. 65, no. 1, pp. 65–12.
https://doi.org/10.7306/gq.1585

Rychel J., Sokołowski R.J., Sieradz D., Hrynowiecka A., Mirosław-Grabowska J., Sienkiewicz E., Niska M., Szymanek M., Zbucki Ł., Ciołko U., Rogóż-Matyszczak A. Late Pleniglacial–Late Glacial climate oscillations detected in the organic lacustrine succession at the Lipowo site, north-eastern Poland. *J. Quat. Sci.*, 2022, vol. 38, no. 2, pp. 186–207.
https://doi.org/10.1002/jqs.3477

Samus A.V., Konstantinov E.A., Borisova O.K., Lazukova L.I. Transformation of plant communities at the turn of the Pleistocene and Holocene in the Rostov Lowland (Yaroslavl Region). *Geomorfol. Paleogeogr.*, 2023, vol. 54, no. 4, pp. 163–178. (In Russ.).
https://doi.org/10.31857/S2949178923040114

Satkūnas J., Grigienė A. Eemian-Weichselian palaeoenvironmental record from the Mickūnai glacial depression (Eastern Lithuania). *Geologija*, 2012, vol. 54, no. 2, pp. 35–51.
https://doi.org/10.6001/geologija.v54i2.2482

Satkūnas J., Grigienė A., Velichkevich F., Robertsson A.M., Sandgren P. Upper Pleistocene stratigraphy at the Medininkai site, eastern Lithuania: A continuous record of the Eemian-Weichselian sequence. *Boreas*, 2003, vol. 32, no. 4, pp. 627–641.
https://doi.org/10.1111/j.1502-3885.2003.tb01240.x

Schnurrenberger D., Russell J., Kelts K. Classification of lacustrine sediments based on sedimentary components. *J. Paleolimnol.*, 2003, vol. 29, pp. 141–154.
https://doi.org/10.1023/A:1023270324800

Semenov A.A, Tsukurova A.M., Kvyatkovskaya G.N., Kuznetsov V.K. *Poyasnitel'naya zapiska k geologicheskim i gidrogeologicheskim kartam SSSR masshtaba 1:200000. Ser. Moskovskaya. O–37–XXVIII* [State Geological Map of USSR, Scale 1:200000, Moscow Ser. Explanatory Note. O–37–XXVIII]. Moscow: VSEGEI Publ., 1972.

Sheremetskaya E.D., Borisova O.K., Panin A.V. Planation of Moscow glaciation periglacial zone during postglacial epoch. *Geomorfolog.*, 2012, no. 1, pp. 92–106. (In Russ.).
https://doi.org/10.15356/0435-4281-2012-1-92-106

Sheremetskaya E.D., Karevskaya I.A., Samus A.V., Garankina E.V., Shorkunov I.G. New data on stratigraphic importance of the Cheremoshnik section (Yaroslavl oblast). *Vestn. Mosk. Univ., Ser. 5: Geogr.*, 2022, no. 4, pp. 88–100. (In Russ.).

Shishkina Y., Garankina E., Belyaev V., Shorkunov I., Andreev P., Bondar A., Potapova V., Verlova T. Postglacial incision-infill cycles at the Borisoglebsk Upland: Correlations between interfluve headwaters and fluvial network. *Int. Soil Water Conserv. Res.*, 2019, vol. 7, pp. 184–195.
https://doi.org/10.1016/j.iswcr.2019.02.001

Shorkunov I., Rusakov A. Stop 3. Mantle loams and postglacial pedogenesis of the Borisoglebsk Upland interfluves. Poklony hilltop. Pi-pedone & Pi5p key sites. In *Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023*. Moscow: Inst. Geogr. RAN, 2023, pp. 64–72.
https://doi.org/10.15356/periglacial978-5-89658-071-3

Sokołowski R.J., Hrynowiecka A., Niska M., Mirosław-Grabowska J. The northernmost Polish Eemian palaeolake near Łęczyce — Stratigraphic and palaeoecological implications for a MIS6a — MIS5d sediment record. *Catena*, 2024, vol. 245, art. 108314.
https://doi.org/10.1016/j.catena.2024.108314

Sudakova N.G., Dashevskiy V.V., Pisareva V.V., Chebotareva N.S., Shik S.M. *Putevoditel' ekskursii 27-go MGK. Chetvertichnye otlozheniya okrestnostei g. Rostova-Yaroslavskogo* [Quaternary Deposits near the Town of Rostov-Yaroslavsky. Excursion 10–B Guidebook. 27th Int. Geol. Congr.]. Moscow: Nauka Publ., 1984.

Sukachev V.N., Nedoseeva A.V. Vegetation changes during the Riss-Wurm interglacial. *Dokl. AN SSSR*, 1954, vol. 94, no. 6, pp. 1171–1174. (In Russ.).

Tyuremnov S.N., Vinogradova E.A. Interglacial deposits near Rostov-Yaroslavsky. *Uchen. Zapis. Yaroslav. Pedogog. Inst.*, 1952, vol. 14, no. 24, pp. 229–254. (In Russ.).

Velichko A.A., Kremenetskii K.V., Negendank J., Mingram J., Borisova O.K., Gribchenko Yu.N., Zelikson E.M., Klimanov V.A., Novenko E.Yu., Pirumova L.G., Pisareva V.V., Razumovskii L.V., Timireva S.N. Late Quaternary paleogeography of the northeastern Europe (based on Galich lake multi-proxy study). *Izv. Akad. Nauk*, *Ser. Geogr.*, 2001, no. 3, pp. 42–54. (In Russ.).

Velichko A.A., Faustova M.A., Gribchenko Yu.N., Pisareva V.V., Sudakova N.G. Glaciations of the East European Plain — distribution and chronology. In *Developments in Quaternary Sciences. Vol. 2*, *part 1*. Amsterdam: Elsevier Publ., 2004, pp. 337–354.
https://doi.org/10.1016/S1571-0866(04)80083-6

Velichko A.A., Novenko E.Y., Pisareva V.V., Zelinkson E.M., Boettger T., Junge F.W. Vegetation and climate changes during the Eemian interglacial in Central and Eastern Europe: Comparative analysis of pollen data. *Boreas*, 2005, vol. 34, no. 2, pp. 207–219.
https://doi.org/10.1111/j.1502-3885.2005.tb01016.x

Veres D., Lallier-vergès E., Wohlfarth B., Lacourse T., Keravis D., Bjorck S., Preusser F., Andrieu-Ponel V., Ampel L. Climate-driven changes in lake conditions during late MIS3 and MIS2: A high-resolution geochemical record from Les Echets, France. *Boreas*, 2009, vol. 38, no. 2, pp. 230–243.
https://doi.org/10.1111/j.1502-3885.2008.00066.x

Ukraintsev V.Y., Konstantinov E.A., Zakharov A.L. Drainage changes in the Nero Lake basin, Central European Russia. *Limnol. Freshwater Biol.*, 2020, vol. 4, pp. 476–477.
https://doi.org/10.31951/2658-3518-2020-A-4-476

Wohlfarth B., Tarasov P., Bennike O., Lacourse T., Subetto D., Torssander P., Romanenko F. Late glacial and Holocene palaeoenvironmental changes in the Rostov-Yaroslavl' area, West Central Russia. *J. Paleolimnol.*, 2006, vol. 35, pp. 543–569.
https://doi.org/10.1007/s10933-005-3240-4

Woronko B., Rychel J., Karasiewicz T.M., Kupryjanowicz M., Adamczyk A., Fiłoc M., Marks L., Krzywicki T., Pochocka-Szwarc K. Post-Saalian transformation of dry valleys in eastern Europe: An example from NE Poland. *Quat. Int.*, 2018, vol. 467, pp. 161–177.
https://doi.org/10.1016/j.quaint.2016.09.054

Woronko B., Karasiewicz T.M., Rychel J., Kupryjanowicz M., Fiłoc M., Moska P., Adamczyk A., Demitroff M.N. A palaeoenvironmental record of MIS3 climate change in NE Poland — Sedimentary and geochemical evidence. *Quat. Int.*, 2022, vol. 617, pp. 80–100.
https://doi.org/10.1016/j.quaint.2021.08.012

Wulf S., Kraml M., Brauer A., Keller J., Negendank J.F. Tephrochronology of the 100 ka lacustrine sediment record of Lago Grande di Monticchio (southern Italy). *Quat. Int.*, 2004, vol. 122, no. 1, pp. 7–30.
https://doi.org/10.1016/j.quaint.2004.01.028

Zakharov A.L., Garankina E.V., Zaretskaya N.E., Karpukhina N.V., Konstantinov E.A., Lugovoy N.N., Rudinskaya A.I., Shorkunov I.G., Ukraintsev V.Yu. Sarskoe swamp — a Late Pleistocene and Holocene paleoarchive of the Moscow glaciation margin zone. In *Puti evolyutsionnoi geografii — 2021. Tom 2* [Pathways of the Evolutionary Geography — 2021. Vol. 2]. Moscow: Inst. Geogr. RAN, 2021, pp. 786–789. (In Russ.).

Zakharov A.L., Garankina E.V., Konstantinov E.A., Rudinskaya A.I., Shorkunov I.G., Yurchenko A.P., Shukhvostov R.S. Prospects for studying the paleo archive of lake sediment from the Sarskoe Bog. *Limnol. Freshwater Biol.*, 2024, no. 4, pp. 733–736.
https://doi.org/10.31951/2658-3518-2024-A-4-733

Палеоархив позднеплейстоценовых обстановок осадконакопления на Борисоглебской возвышенности

Е. В. Гаранкина[a, b, *], В. С. Посаженникова[a, b], И. Г. Шоркунов[a]

[a] *Институт географии РАН, Москва, Россия*
[b] *Московский государственный университет имени М.В. Ломоносова, Москва, Россия*

**e-mail*: *evgarankina@gmail.com*

Ландшафты центра Европейской России были сформированы последним среднеплейстоценовым оледенением, что сосредоточило значительную часть последующего осадконакопления межледниковых и перигляциальных обстановок в депрессиях ледникового палеорельефа. Однако соответствующие непрерывные постледниковые седиментационные архивы крайне редки в регионе из-за резких колебаний регионального базиса эрозии и значительной эрозионной активности во многих крупных депрессиях. Поэтому для реконструкции локальных обстановок осадконакопления и корреляции зафиксированного палеоэкологического сигнала с основными климатическими изменениями позднего плейстоцена был выбран наиболее полный имеющийся керн из котловины на северо-восточном макросклоне Борисоглебской возвышенности, который охватывает весь последний ледниково-межледниковый цикл. Тщательное макро- и мезоморфологическое исследование кернов механизированного свайно-шнекового бурения было дополнено селективным радиоуглеродным датированием богатых органикой отложений. Толща минеральных и органоминеральных осадков мощностью более 20 м отражает направленный переход от ритмичной субаквальной озерной седиментации и эвтрофно-болотной аккумуляции во время последнего межледниковья, раннего и среднего пленигляциала к суб- и супераквальному накоплению продуктов преимущественно склонового сноса во время позднего пленигляциала. На заключительных этапах позднего плейстоцена, в позднеледниковье, произошла окончательная смена к преобладанию субаэрального склонового смыва. На основании определений радиоуглеродного возраста были выявлены перерывы в осадочной записи. В купе с обнаруженными линзами аллювиальных песков они были соотнесены с флювиальной активностью времени раннего и среднего пленигляциала, хотя обстановки озерного осадконакопления на этих этапах продолжали превалировать, обеспечив большую часть мощности всей толщи выполнения котловины.

Ключевые слова: палеолимнология, озерные отложения, торф, ледниковый рельеф, фациальный анализ, склоновый снос, котловины вытаивания мертвого льда, перигляциальные условия

СПИСОК ЛИТЕРАТУРЫ

Алешинская З.В., Гунова В.С. Новейшие отложения и палеогеография озера Неро // Вестн. Моск. ун-та. Серия 5. География. 1997. № 1. С. 49–52.

Антонов С.И. Плейстоценовый озерный литоморфогенез в пределах юго-западного Подмосковья // История плейстоценовых озер Восточно-Европейской равнины. СПб.: Наука, 1998. С. 282–290.

Базилевская Л.И., Большаков В.А., Величкевич Ф.Ю., Немцова Г.М., Писарева В.В., Судакова Н.Г. Результаты комплексного изучения четвертичных отложений г. Ростова Ярославской области // Геология, полезные ископаемые и инженерно-геологические условия центральных районов Европейской части СССР. М.: Изд-во МинГео, 1984. С. 56–71.

Баранов Д.В. Геоморфология долины верхней Волги: история изучения и состояние проблемы (ст. 2. Верхневолжская низина) // Геоморфология. 2022. Вып. 53. № 1. С. 35–48. https://doi.org/10.31857/S0435428122010047

Величко А.А., Кременецкий К.В., Негенданк Й., Минграм Й., Борисова О.К., Грибченко Ю.Н., Зеликсон Э.М., Климанов В.А., Новенко Е.Ю., Пирумова Л.Г., Писарева В.В., Разумовский Л.В., Тимирева С.Н. Позднечетвертичная палеогеография северо-востока Европы (по данным комплексного изучения осадков Галичского озера) // Изв. РАН. Сер. геогр. 2001. № 3. С. 42–54.

Гаранкина Е.В., Шоркунов И.Г. О чем молчат разрезы: методические аспекты работы с грунтовыми выработками в палеогеографических целях: матер. I Белорусского геогр. конгресса, Минск, 8–13 апреля 2024 г. Т. 6. Минск: БГУ, 2024. С. 46–52.

Гаранкина Е.В., Шоркунов И.Г., Юрченко А.П., Посаженникова В.С., Лобков В.А. Трансформация локальных ледниковых депрессий по геологическим и геофизическим данным, Борисоглебская возвышенность, центр Европейской части России // Limnol. and Freshwater Biol. 2024. № 4. P. 310–317. https://doi.org/10.31951/2658-3518-2024-A-4-310

Горлова Р.Н. Смена растительного покрова в микулинское межледниковье по исследованиям торфяников Ярославской области // История развития растительного покрова центральных областей Европейской части СССР в антропогене / под ред. Н.И. Пьявченко. М.: Наука, 1968а. С. 45–91.

Горлова Р.Н. Смена растительности как компонента биогеоценозов в предпоследнее межледниковье. М.: Наука, 1968б. 72 с.

Гричук В.П., Губонина З.П., Зеликсон Э.М., Моносзон М.Х. Межледниковые отложения района г. Ростова (Ярославского) // Палинология плиоцена и плейстоцена. М.: Наука, 1973. С. 188–203.

Губонина З.П., Зелинксон Э.М., Моносзон М.Х. Флористический и фитоценологический анализ палеоботанических материалов по межледниковым отложениям в районе д. Черемошник // Палинология плейстоцена и плиоцена. М.: Наука, 1973. С. 53–59.

Гунова В.С. История озера Неро по палеоботаническим данным. Автореф. дис. ... канд. геогр. наук. М.: МГУ, 1975. 21 с.

Гунова В.С., Лефлат О.Н. Голоценовое и современное состояние экосистемы озера Неро // Вестн. Моск. ун-та. Серия 5. География. 1997. № 4. С. 42–45.

Еременко Е.А., Каревская И.А., Панин А.В. Послеледниковая трансформация флювиогляциальных ложбин в краевой зоне московского оледенения // Изв. РАН. Сер. геогр. 2010. № 2. С. 56–70.

Еременко Е.А., Панин А.В. Происхождение ложбинной сети в центральных и южных районах Восточно-Европейской равнины // Вестн. Моск. ун-та. Серия 5. География. 2011. № 3. С. 59–66.

Захаров А.Л., Гаранкина Е.В., Константинов Е.А., Рудинская А.И., Шоркунов И.Г., Юрченко А.П., Шухвостов Р.С. Перспективы изучения палеоархива озерных отложений Сарского болота // Limnol. and Freshwater Biol. 2024. № 4. С. 733–736. https://doi.org/10.31951/2658-3518-2024-A-4-733

Захаров А.Л., Гаранкина Е.В., Зарецкая Н.Е., Карпухина Н.В., Константинов Е.А., Луговой Н.Н., Рудинская А.И., Шоркунов И.Г., Украинцев В.Ю. Сарское болото — палеоархив позднего плейстоцена и голоцена краевой зоны московского оледенения // Пути эволюционной географии. М.: ИГ РАН, 2021. Вып. 2. С. 786–789.

Квасов Д.Д. Позднечетвертичная история крупных озер и внутренних морей Восточной Европы. Л.: Наука, 1975. 278 с.

Марков К.К., Величко А.А., Судакова Н.Г., Бреслав С.Л., Бердников В.В. Путеводитель экскурсий Москва–Верхняя Волга. Симпозиум "Палеогеография и перигляциальные явления плейстоцена". М.: Наука, 1969. 72 с.

Матинян Н.Н., Русаков А.В., Керзум П.П. Основные черты строения почвенного покрова Ярославского Поволжья // Вестн. Санкт-Петербург. ун-та. Сер. 3. Биология. 1996. Вып. 1. № 3. С. 74–86.

Москвитин А.И. Стратиграфия плейстоцена Европейской части СССР // Тр. ГИН АН СССР. М.: Наука, 1967. Т. 156. 238 с.

Москвитин А.И. Опорные разрезы плейстоцена Русской равнины. М.: Наука, 1976. 203 с.

Новенко Е.Ю. Изменения растительности и климата Центральной и Восточной Европы в позднем плейстоцене и голоцене в межледниковые и переходные этапы климатических макроциклов. М.: ГЕОС, 2016. 228 с.

Новский В.А. Плейстоцен Ярославского Поволжья. М.: Наука, 1975. 236 с.

Посаженникова В.С., Гаранкина Е.В., Шоркунов И.Г., Константинов Е.А., Качалов А.Ю. Керны древних озерных отложений: особенности извлечения и обработки: матер. I Белорусского геогр. конгресса, Минск, 8–13 апреля 2024 г. Ч. 6. Минск: БГУ, 2024. С. 150–155.

Проблемы стратиграфии четвертичных отложений и палеогеография Ярославского Поволжья. Материалы симпозиума / под ред. Ю.А. Лаврушина, И.А. Чистяковой. М.: ГЕОС, 2001. 158 с.

Разрезы отложений ледниковых районов Центра Русской равнины / под ред. К.К. Маркова. М.: Изд-во МГУ, 1977. 198 с.

Ресурсы поверхностных вод СССР. Т. 10. Верхне-Волжский район. Описание отдельных рек и озер / под ред. Ю.Е. Яблокова. Л.: Гидрометиздат, 1972. 247 с.

Самусь А.В., Константинов Е.А., Борисова О.К., Лазукова Л.И. Трансформация растительных сообществ на рубеже плейстоцена и голоцена в ростовской низине (Ярославская область) // Геоморфология и палеогеография. 2023. Т. 54. № 4. С. 163–178. https://doi.org/10.31857/S2949178923040114

Семенов А.А., Цукурова А.М., Квятковская Г.Н., Кузнецов В.К. Пояснительная записка к геологическим и гидрогеологическим картам СССР масштаба 1 : 200 000. Серия московская. Л. О–37–XXVIII. М.: ВСЕГЕИ, 1972. 126 с.

Судакова Н.Г., Дашевский В.В., Писарева В.В., Чеботарёва Н.С., Шик С.М. Путеводитель экскурсии 27-го МГК. Экскурсия 10–Б. Четвертичные отложения окрестностей г. Ростова-Ярославского. М.: Наука, 1984. 26 с.

Сукачев В.Н., Недосеева А.В. О смене растительности в течение рисс-вюрмского межледниковья // Докл. АН СССР. 1954. Т. 94. № 6. С. 1171–1174.

Тюремнов С.Н., Виноградова Е.А. Межледниковые отложения близ г. Ростова-Ярославского // Уч. Зап. Ярославского пед. ин-та. 1952. Вып. 14. № 24. С. 229–254.

Чеботарева Н.С., Макарычева И.А. Последнее оледенение Европы и его геохронология. М.: Наука, 1974. 216 с.

Чижиков Н.В. Геоморфология и почвы бассейна озера Неро и реки Усть-Которосль // Тр. Лабор. сапропелевых отлож. М.: АН СССР, 1956. Вып. VI. С. 130–144.

Шеремецкая Е.Д., Борисова О.К., Панин А.В. Динамика послеледникового выравнивания рельефа междуречий в краевой зоне московского оледенения (на примере бассейна р. Протвы) // Геоморфология. 2012. № 1. С. 92–106. https://doi.org/10.15356/0435-4281-2012-1-92-106

Шеремецкая Е.Д., Каревская И.А., Самусь А.В., Гаранкина Е.В., Шоркунов И.Г. Новые данные о стратиграфической значимости разреза "Черемошник" (Ярославская область) // Вестн. Моск. ун-та. Серия 5. География. 2022. № 4. С. 88–100.

Alexandrovskiy A.L. Soil evolution on the low terraces of Lake Nero // Eurasian Soil Sci. 2011. Vol. 44. P. 1055–1067.
https://doi.org/10.1134/S1064229311100024

Astakhov V., *Shkatova V.*, *Zastrozhnov A.*, *Chuyko M.* Glaciomorphological map of the Russian Federation // Quat. Int. 2016. Vol. 420. P. 4–14.
https://doi.org/10.1016/j.quaint.2015.09.024

Baranov D.V., *Utkina A.O.*, *Panin A.V.* Tver proglacial lake (Tver region, Russia): Myth or reality // Limnol. and Freshwater Biol. 2022. № 4. P. 1383–1384.
https://doi.org/10.31951/2658-3518-2022-A-4-1383

Belyaev V.R., *Garankina E.V.*, *Shorkunov I.G.*, *Konstantinov E.A.*, *Rusakov A.V.*, *Shishkina Y.V.*, *Andreev P.V.*, *Verlova T.A.* Holocene erosion and deposition within a small catchment of the NE Borisoglebsk Upland (Central European Russia) // IOP Conf. Ser.: Earth and Environ. Sci. 2020. № 438. P. 012002.
https://doi.org/10.1088/1755-1315/438/1/012002

Borisova O.K. Vegetation and climate changes at the Eemian/Weichselian transition: New palynological data from Central Russian Plain // Polish Geol. Inst. Spec. Pap. 2005. Vol. 16. P. 9–17.

Borisova O.K. Lake Galich during the late Valdai (Weichselian) glaciation / Paleolimnology of Northern Eurasia: Experience, methodology, current status and young scientists school in microscopy skills in paleolimnology. Kazan: Kazan Univ. Publ., 2018. P. 25–27.

Borisova O.K. Landscape and climatic conditions in the Central East European Plain in the last 22 thousand years: Reconstruction based on paleobotanical data // Water Res. 2021. Vol. 48. P. 886–896.
https://doi.org/10.1134/S0097807821060038

Borisova O., *Konstantinov E.*, *Utkina A.*, *Baranov D.*, *Panin A.* On the existence of a large proglacial lake in the Rostov-Kostroma lowland, north-central European Russia // J. Quat. Sci. 2022. Vol. 37. № 8. P. 1442–1459.
https://doi.org/10.1002/jqs.3454

Borisova O.K., *Novenko E.Y.*, *Velichko A.A.*, *Kremenetski K.V.*, *Junge F.W.*, *Boettger T.* Vegetation and climate changes during the Eemian and Early Weichselian in the Upper Volga region (Russia) // Quat. Sci. Rev. 2007. Vol. 26. № 19–21. P. 2574–2585.
https://doi.org/10.1016/j.quascirev.2007.07.001

Börner A., *Hrynowiecka A.*, *Stachowicz-Rybka R.*, *Niska M.*, *Moskal-del Hoyo M.*, *Kuznetsov V.*, *Maksimov F.*, *Petrov A.* Palaeoecological investigations and $^{230}Th/U$ dating of the Eemian Interglacial peat sequence from Neubrandenburg-Hinterste Mühle (Mecklenburg-Western Pomerania, NE Germany) // Quat. Int. 2018. Vol. 467. Part A. P. 62–78.
https://doi.org/10.1016/j.quaint.2017.04.003

Britzius S., *Sirocko F.* Subfossil Coleoptera from Eifel maar sediments as indicators of the environmental evolution in Central Europe over the last 60.000 years // Palaeogeogr. Palaeoclimatol. Palaeoecol. 2022. Vol. 596. P. 110981.
https://doi.org/10.1016/j.palaeo.2022.110981

Daumantas L., *Šinkūnas P.*, *Rudnickaitė E.*, *Dobrotin N.*, *Kisielienė D.*, *Spiridonov A.* Late Pleistocene to Middle Holocene record of sedimentation and carbonate content in the Zervynos paleolake-dune complex, Lithuania // Estonian J. Earth Sci. 2022. Vol. 71. № 4. P. 214–229.
https://doi.org/10.3176/earth.2022.15

Dearing J.A. Lake sediment records of erosional processes // Hydrobiologia. 1991. Vol. 214. P. 99–106.
https://doi.org/10.1007/978-94-011-3592-4_13

Fajer M., *Waga J.M.*, *Rzetala M.*, *Szymczyk A.*, *Nita M.*, *Machowski R.*, *Rzetala M.*, *Ruma M.* The Late Vistulian and Holocene evolution of Jezioro Lake: A record of environmental change in southern Poland found in deposits and landforms // J. Paleolimnol. 2012. Vol. 48. P. 651–667.
https://doi.org/10.1007/s10933-012-9634-1

Garankina E. Stop 2. Glacial inheritance vs postglacial metamorphoses of the Borisoglebsk Upland interfluves. 2a. Glacial deposits and associated topography // Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023. M.: IG RAS Publ., 2023. P. 37–46.
https://doi.org/10.15356/periglacial978-5-89658-071-3

Garankina E.V., *Belyaev V.R.*, *Shorkunov I.G.*, *Shishkina Yu.V.*, *Andreev P.V.*, *Sheremetskaya E.D* Lake sedimentation as an agent of postglacial transformation of interfluves and fluvial landscapes of the Borisoglebsk Upland, Central European Russia // Proc. of the Int. Association of Hydrological Sciences. 2019. Vol. 381. P. 13–20.
https://doi.org/10.5194/piahs-381-13-2019

Garankina E.V., *Lobkov V.A.*, *Shorkunov I.G.*, *Belyaev V.R.* Identifying relict periglacial features in watershed landscape and deposits of Borisoglebsk Upland, Central European Russia // J. Geol. Soc. 2022. Vol. 179. № 5. P. jgs2021–135.
https://doi.org/10.1144/jgs2021-135

Garankina E., *Posazhennikova V.*, *Lobkov V.*, *Shorkunov I.* Stop 2. Glacial inheritance vs postglacial metamorphoses of the Borisoglebsk Upland interfluves. Stop 2b. Postglacial lacustrine sedimentation // Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023. M.: IG RAS Publ., 2023. P. 46–63.
https://doi.org/10.15356/periglacial978-5-89658-071-3

Haflidason H., *Brendryen J.*, *Eldegard R.F.*, *Mangerud J.*, *Ólafsdóttir S.*, *Regnéll C.*, *Svendsen J.I.* High-resolution chronology of 24 000-year long cores from two lakes in the Polar Urals, Russia, correlated with palaeomagnetic inclination records with a distinct event about 20 000 years ago // J. Quat. Sci. 2022. Vol. 37. № 5. P. 778–789.
https://doi.org/10.1002/jqs.3391

Hein M., *Urban B.*, *Tanner D.C.*, *Buness A.H.*, *Tucci M.*, *Hoelzmann P.*, *Dietel S.*, *Kaniecki M.*, *Schultz J.*, *Kasper T.*, *von Suchodoletz H.*, *Schwalb A.*, *Weiss M.*, *Lauer T.* Eemian landscape response to climatic shifts

and evidence for northerly Neanderthal occupation at a palaeolake margin in northern Germany // Earth Surf. Process. Landf. 2021. Vol. 46. № 14. P. 2884–2901.
https://doi.org/10.1002/esp.5219

Hosek J., Prach J., Krızek M., Sıda P., Moska P., Pokorny P. Weichselian thermokarst landscape discovered in the Czech Republic, central Europe // Boreas. 2019. Vol. 48. P. 988–1005.
https://doi.org/10.1111/bor.12404

Hrynowiecka A., Stachowicz-Rybka R., Niska M., Moskal-del Hoyo M., Börner A., Rother H. Eemian (MIS5e) climate oscillations based on palaeobotanical analysis from the Beckentin profile (NE Germany) // Quat. Int. 2021. Vol. 605–606. P. 38–54.
https://doi.org/10.1016/j.quaint.2021.01.025

Kattel G., Sirocko F. Palaeocladocerans as indicators of environmental, cultural and archaeological developments in Eifel maar lakes region (West Germany) during the Lateglacial and Holocene periods // Hydrobiologia. 2011. Vol. 676. P. 203–221.
https://doi.org/10.1007/s10750-011-0872-4

Konstantinov E.A., Karpukhina N.V., Zakharov A.L., Bricheva S.S., Ukraintsev V.Yu., Lazukova L.I., Rudinskaya A.I. Fluctuations of Nero Lake in the Holocene // Dokl. Earth Sci. 2022. Vol. 506. Suppl. 1. P. 48–54.
https://doi.org/10.1134/S1028334X22700258

Kupryjanowicz M., Drzymulska D., Fiłoc M. Eemian and early Weichselian Lobelia lakes in northeastern Poland // Rev. Palaeobot. Palynol. 2015. Vol. 219. P. 28–38.
https://doi.org/10.1016/j.revpalbo.2015.03.006

Kupryjanowicz M., Fiłoc M., Woronko B., Karasiewicz T.M., Rychel J., Adamczyk A., Jarosz J. Eemian and early Weichselian environmental changes at the Jałówka site, NE Poland, and their correlation with marine and ice records // Quat. Res. 2021. Vol. 104. P. 69–88.
https://doi.org/10.1017/qua.2021.8

Kuzmina S.A., Sycheva S.A., Ershova E.K., Zyuganova I.S., Zakharov A.L., Gorbatov E.S., Kolesnikov S.F., Panin P.G. Ivantsevo section of the buried Middle and Late Pleistocene lake-bog deposits near the town Dmitrov, Moscow Region // Geomorfologiya. 2022. Vol. 53. № 3. P. 7–18.
https://doi.org/10.31857/S0435428122030087

Lüthgens C., Böse M., Lauer T., Krbetschek M., Strahl J., Wenske D. Timing of the last interglacial in Northern Europe derived from Optically Stimulated Luminescence (OSL) dating of a terrestrial Saalian-Eemian-Weichselian sedimentary sequence in NE-Germany // Quat. Int. 2011. Vol. 241. № 1–2. P. 79–96.
https://doi.org/10.1016/j.quaint.2010.06.026

Majecka A., Wachecka-Kotkowska L., Krzyszkowski D., Malkiewicz M., Miroslaw-Grabowska J., Niska M., Rzodkiewicz M., Myoekow E., Tomaszewska K., Wieczorek D., Raczyk J. Environmental changes during the MIS6a — MIS5e transition. The Parchliny 2016 profile, central Poland // Geol. Quarterly. 2022. Vol. 66. № 4. P. 1–27.
https://doi.org/10.7306/gq.1663

Mamakowa K. Late Middle Polish Glaciation, Eemian and Early Vistulian vegetation at Imbramowice near Wroclaw and the pollen stratigraphy of this part of the Pleistocene in Poland // Acta Palaeobotanica. 1989. Vol. 29. № 1. P. 11–176.

Mirosław-Grabowska J., Borówka R.K., Radzikowska M., Sławińska J., Hrynowiecka A., Sobczyk A., Stachowicz-Rybka R., Stefaniak K. Environmental changes recorded in the sequence of lake-peat bogs in the Eemian Interglacial and Vistulian on the basis of multi-proxy data // Quat. Int. 2021. Vol. 632. P. 51–64.
https://doi.org/10.1016/j.quaint.2021.11.023

Niska M.M. The Eemian/Early Vistulian development of the Solniki paleolake (north-eastern Poland) as shown by subfossil Cladocera // Adv. Oceanogr. Limnol. 2016. Vol. 7. № 2. P. 206–219.
https://doi.org/10.4081/aiol.2016.6217

Novenko E.Y., Velichko A.A., Zuganova E.S., Junge F.W., Boettger T. Dynamics of vegetation at the Late Pleistocene Glacial/Interglacial transition (new data from the center of the East European Plain) // Polish Geol. Inst. Spec. Pap. 2005. № 16. P. 77–82.

Reimer P., Austin W., Bard E., et al. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP) // Radiocarbon. Vol. 62. № 4. P. 725–757.
https://doi.org/10.1017/RDC.2020.41

Roman M., Mirosław-Grabowska J., Niska M. The Eemian Lakeland of the central Polish Plain: Environmental changes and palaeogeography // Palaeogeogr. Palaeoclimatol. Palaeoecol. 2021. Vol. 561. P. 110087.
https://doi.org/10.1016/j.palaeo.2020.110087

Rudinskaya A.I., Zakharov A.L., Konstantinov E.A., Shorkunov I.G., Garankina E.V., Zaretskaya N.E. Conditions of sedimentation in the Sarskoye Swamp (Yaroslavl region, Russia) in the Late Glacial and Holocene // Limnol. and Freshwater Biol. 2022. № 4. P. 1553–1555.
https://doi.org/10.31951/2658-3518-2022-A-4-1553

Rusakov A., Nikonov A., Savelieva L., Simakova A., Sedov S., Maksimov F., Kuznetsov V., Savenko V., Starikova A., Korkka M., Titova D. Landscape evolution in the periglacial zone of Eastern Europe since MIS5: Proxies from palaeosols and sediments of the Cheremoshnik key site (Upper Volga, Russia) // Quat. Int. 2015. Vol. 365. P. 26–41.
https://doi.org/10.1016/j.quaint.2014.09.029

Rusakov A., Sedov S., Sheinkman V., Dobrynin D., Zinovyev E., Trofimova S., Maximov F., Kuznetsov V., Korkka M., Levchenko S. Late Pleistocene palaeosols in the extra-glacial regions of NW Eurasia: Pedogenesis, post-pedogenic transformation, palaeoenvironmental inferences // Quat. Int. 2019. Vol. 501. P. 174–192.
https://doi.org/10.1016/j.quaint.2018.03.020

Rusakov A., Sedov S. Late Quaternary pedogenesis in periglacial zone of NE Europe near ice margins since MIS3: Timing, processes, and linkages to landscape evolution // Quat. Int. 2012. Vol. 265. P. 126–141.
https://doi.org/10.1016/j.quaint.2012.03.002

Rychel J., Sokołowski R.J., Sieradz D., Hrynowiecka A., Mirosław-Grabowska J., Sienkiewicz E., Niska M., Szymanek M., Zbucki Ł., Ciołko U., Rogóż-Matyszczak A. Late Pleniglacial–Late Glacial climate oscillations detected in the organic lacustrine succession at the Lipowo site, north-eastern Poland // J. Quat. Sci. 2022. Vol. 38. № 2. P. 186–207.
https://doi.org/10.1002/jqs.3477

Rychel J. Palaeogeographic reconstruction of the North Podlasie region in the Sokółka area during the Late Pleistocene (NE Poland) // Geol. Quarterly. 2021. Vol. 65. № 1. P. 65–12.
https://doi.org/10.7306/gq.1585

Satkūnas J., Grigienė A., Velichkevich F., Robertsson A.M., Sandgren P. Upper Pleistocene stratigraphy at the Medininkai site, eastern Lithuania: A continuous record of the Eemian-Weichselian sequence // Boreas. 2003. Vol. 32. № 4. P. 627–641.
https://doi.org/10.1111/j.1502-3885.2003.tb01240.x

Satkūnas J., Grigienė A. Eemian-Weichselian palaeoenvironmental record from the Mickūnai glacial depression (Eastern Lithuania) // Geologija. 2012. Vol. 54. № 2. P. 35–51.
https://doi.org/10.6001/geologija.v54i2.2482

Schnurrenberger D., Russell J., Kelts K. Classification of lacustrine sediments based on sedimentary components // J. Paleolimnol. 2003. Vol. 29. P. 141–154.
https://doi.org/10.1023/A:1023270324800

Shishkina Y., Garankina E., Belyaev V., Shorkunov I., Andreev P., Bondar A., Potapova V., Verlova T. Postglacial incision-infill cycles at the Borisoglebsk Upland: Correlations between interfluve headwaters and fluvial network // Int. Soil and Water Conservation Res. 2019. Vol. 7. P. 184–195.
https://doi.org/10.1016/j.iswcr.2019.02.001

Shorkunov I., Rusakov A. Stop 3. Mantle loams and postglacial pedogenesis of the Borisoglebsk Upland interfluves. Poklony hilltop. Pi-pedone & Pi5p key sites. In Valdai Periglacial Field Symposium Guidebook, 27–30 August 2023. M.: IG RAS Publ., 2023. P. 64–72.
https://doi.org/10.15356/periglacial978-5-89658-071-3

Sokołowski R.J., Hrynowiecka A., Niska M., Mirosław-Grabowska J. The northernmost Polish Eemian palaeolake near Łęczyce — Stratigraphic and palaeoecological implications for a MIS6a — MIS5d sediment record // Catena. 2024. Vol. 245. P. 108314.
https://doi.org/10.1016/j.catena.2024.108314

Velichko A.A., Faustova M.A., Gribchenko Yu.N., Pisareva V.V., Sudakova N.G. Glaciations of the East European Plain — distribution and chronology // Developments in Quat. Sci. Amsterdam: Elsevier Publ., 2004. Vol. 2. Part 1. P. 337–354.
https://doi.org/10.1016/S1571-0866(04)80083-6

Velichko A.A., Novenko E.Y., Pisareva V.V., Zelinkson E.M., Boettger T., Junge F.W. Vegetation and climate changes during the Eemian interglacial in Central and Eastern Europe: comparative analysis of pollen data // Boreas. 2005. Vol. 34. № 2. P. 207–219.
https://doi.org/10.1111/j.1502-3885.2005.tb01016.x

Veres D., Lallier-vergès E., Wohlfarth B., Lacourse T., Keravis D., Bjorck S., Preusser F., Andrieu-Ponel V., Ampel L. Climate-driven changes in lake conditions during late MIS3 and MIS2: A high-resolution geochemical record from Les Echets, France // Boreas. 2009. Vol. 38. P. 230–243.

Ukraintsev V.Y., Konstantinov E.A., Zakharov A.L. Drainage changes in the Nero Lake basin, Central European Russia // Limnol. and Freshwater Biol. 2020. Vol. 4. P. 476–477.
https://doi.org/10.31951/2658-3518-2020-A-4-476

Wohlfarth B., Tarasov P., Bennike O., Lacourse T., Subetto D., Torssander P., Romanenko F. Late glacial and Holocene palaeoenvironmental changes in the Rostov-Yaroslavl' area, West Central Russia // J. Paleolimnol. 2006. Vol. 35. P. 543–569.
https://doi.org/10.1007/s10933-005-3240-4

Woronko B., Karasiewicz T.M., Rychel J., Kupryjanowicz M., Fiłoc M., Moska P., Adamczyk A., Demitroff M.N. A palaeoenvironmental record of MIS3 climate change in NE Poland — Sedimentary and geochemical evidence // Quat. Int. 2022. Vol. 617. P. 80–100.
https://doi.org/10.1016/j.quaint.2021.08.012

Woronko B., Rychel J., Karasiewicz T.M., Kupryjanowicz M., Adamczyk A., Fiłoc M., Marks L., Krzywicki T., Pochocka-Szwarc K. Post-Saalian transformation of dry valleys in eastern Europe: An example from NE Poland // Quat. Int. 2018. Vol. 467. P. 161–177.
https://doi.org/10.1016/j.quaint.2016.09.054

Wulf S., Kraml M., Brauer A., Keller J., Negendank J.F. Tephrochronology of the 100 ka lacustrine sediment record of Lago Grande di Monticchio (southern Italy) // Quat. Int. 2004. Vol. 122. № 1. P. 7–30.
https://doi.org/10.1016/j.quaint.2004.01.028