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Landscape evolution in the periglacial zone of Eastern Europe since MIS5: Proxies from paleosols and sediments of the Cheremoshnik key site (Upper Volga, Russia)

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ABSTRACT

A variety of studies of the re-examined (new exposure) Late Pleistocene key section Cheremoshnik (East European plain, middle of the Volga Basin of Yaroslavl) was conducted on a new methodological level using modern methods. For the first time, a series of paleosols (MIS5–MIS1) from the section offering significant information in regard to chronostratigraphy and landscape evolution have been studied in detail and dated. An excavation ~7 m deep reveals a soil-sediment stratum which formed over the course of ~115 ka in an accumulative beam-like terrace and consists of five lithological layers and six pedostratigraphical units.

The base of the section was determined to be an Early Mikulino peat-dark humus paleosol which marked incipient subaerial pedogenesis on the Moscow (Riss II) moraine and was covered with a thickness of gyttja with a peat horizon (Histosol) which had formed 114–115 ka and was reliably dated using uranium–thorium dating. The following paleosols were successfully identified within the series of weak stone gullied-channel sediments within the Valdai (Wűrm) thickness (from bottom to top): (1) Bryansk paleosol (MIS3) – Gleysol – with three pedogenesis rhythms; (2) Trubchevskaya paleosol – Gleyic Turbic Cryosol (MIS2) and (3) pedosediment formed at the end of the Bölling interstadial (MIS2). Terminal Pleistocene formations are marked with a gravelly stratum on the section's surface formed during the Preboreal period. Recent Regosol formed on loess-like loam deposits was identified at the top of the whole soil-sediment stratum. The ^{14}C age of the paleosol humus varied between 27,500 and 11,400 cal. BP. The paleosols represent the northernmost occurrence of MIS5–MIS2 fossil soil in Europe, dominated by features of gleyzation, cryogenic aggregation, cracking, and humus and peat formation.

Pollen analysis results allowed estimation of changes in vegetation cover, climatic conditions and the age of deposit sedimentation for the period from the Moskow Late Glacial to the Valdai Late Glacial and early Holocene times. Successive stages in the development of vegetation, high contents of alder and hazel pollen and the climax and distinct appearance of broadleaf trees relate the formation of biogenic sediments (LPAZ 2–6) in the Cheremoshnik section to the Mikulino Interglacial. Valdai (MIS4–MIS2) glacial sediment is absent within the investigated area.

1. Introduction

The reconstruction of paleoenvironments during the Late Quaternary and Holocene periods (MIS5–MIS1), including the last interglacial period (Eemian Stage in Europe, Mikulino Stage in Russia), an extensive phase of milder climatic conditions within the last glacial period (Valdai or Wűrm glaciation) and the coldest Late

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Valdai glacial maximum, is still a matter of intensive discussion. Paleosols, a reliable terrestrial paleoecological proxy with high spatial resolution (Targulian and Goryachkin, 2004, 2008), could contribute to understanding environmental changes.

The stratigraphic position of the paleosols within thick heterochronous soil-sediment strata of the Cheremoshnik key section and the character of their bedding are the most important elements of paleosol memory. The mere existence of paleosol bodies and horizons attests to stabilization of the surface, the development of vegetation and the attenuation of various slope processes. Paleosols mark ancient surfaces, and the character of their bedding in the section makes it possible to judge paleotopographic conditions.

Cheremoshnik is one of the most important key sections of Quaternary deposits in the center of European Russia, located within the Upper Volga Basin on the accumulative Borisoglebskaya Upland in the Lake Nero basin near the town Rostov-Velikiy (Fig. 1). The Lake Nero basin underwent subsidence at each stage of its evolution. A moraine with detached fragments of Mesozoic rocks and a series of fluvio-glacial deposits left after ice melting. The Nero ice-tongue east of this zone caused significant widening of the lake's basin, leaving push-accumulative ridges and hills at the periphery. During Late Moscow Time (MIS6), some vast periglacial lakes occupied the Rostov lowlands (Sudakova et al., 1984). Shallow lakes were formed among moraine hills. During Mikulino and Valdai times (MIS5–MIS2), they were turned into swamps. Thus, one of these ancient shallow lakes was intersected by the Cheremoshnik ravine. The Lake Nero basin was an area of intensive sedimentation in the Mikulino and Valdai times.

The sections of the Cheremoshnik ravine consisting of interglacial and periglacial deposits have been under investigation for a very long time, since 1938. Previous investigations have been conducted by geologists and specialists in related disciplines, including palynologists, paleogeographers, and paleobotanists, in the Cheremoshnik area (Tjuremnov and Vinogradova, 1952; Sukachev, 1954; Sukachev and Nedoseeva, 1954; Chebotareva, 1959; Serebryannyi and Chebotareva, 1963; Moskvitin, 1967; Novskiy, 1968, 1971, 1975; Gorlova, 1972; Grichuk et al., 1973; Sudakova, 1974; Markov, 1977; Lavrushin and Chistyakova, 2001; Novenko et al., 2005).

After more than 70 years of research of the Cheremoshnik key section, discussions regarding its proper interpretation continue. They focus on: (1) the autochthonic condition of the Mikulian deposits at the base of the section in the absence of numerical dating; (2) the genesis and numerical age of the detrital sediments over the Mikulian deposits. Sufficient attention has not been paid to the soil-sediment stratum in the middle and top parts of the section, which also have not been dated. Finally (3), the paleosol units formed within the MIS5–MIS1 interval have not been studied in detail or dated.

Based on a detailed study of the recently reopened (2008–2013) exposure of the key section Cheremoshnik, as well as neighbouring sections, we have managed to answer these questions using a range of modern methods and approaches. The main goal of this work is to examine the complexly organized heterochronous key section Cheremoshnik containing MIS5–MIS1 paleosols/pedosediments and deposits in order to identify the soil record of the evolution of the Late Pleistocene and Holocene landscapes. The intent is to identify all pedogenetic and sedimentary processes, trace their temporal relations and, when possible, date them using modern methods. Furthermore, linkage of pedogenesis to climate, changes in vegetation (MIS5–MIS1) and geomorphological evolution is considered. The aim of this paper is to highlight the interaction of the different blocks of "soil memory" in the resulting complex soil body.

2. Methods

The morphological description of the paleosols was developed using standard international methods (FAO, 2006). The classification of the paleosols was constructed using the World Reference Base for Soil Resources (IUSS Working Group WRB, 2006). The classification of paleosols is somewhat challenging because many pedogenetic features could be erased by subsequent diagenetic processes, and thus only stable features may be used for classifying paleosols (Mack et al., 1993). Thus, several schemes for paleosol classification have been developed using only the stable properties of soils, based both on the USDA Soil Taxonomy (Nettleton et al., 2000) and the WRB (Krasilnikov and García Calderón, 2006). However, these classifications are seldom used by

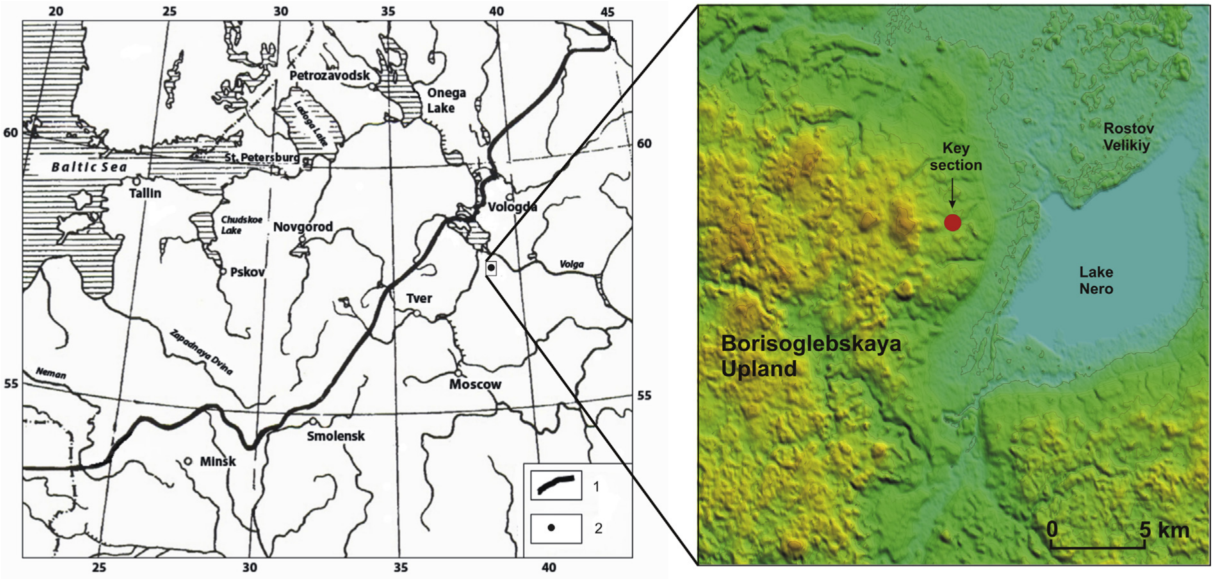

Fig. 1. Boundary of the Ostashkovo or Valday (Wűrmian) glaciation in the East European Plain (1) (Chebotareva and Makarycheva, 1982) and location of the Cheremoshnik key site (2).

paleopedologists, probably because the available terminology does not provide direct associations with certain environments. Most researchers prefer using the same terms for buried paleosols as for surface soils, but use only stable diagnostic criteria for their classification. For example, paleosols are classified as Cryosols if they have cryoturbations, regardless of the actual mean annual temperatures.

Particle size distribution was determined by sieving and the pipette method, using $Na_4P_2O_7$ as a dispersant. The results were presented according to the grain size classes of the Kachinskiy classification (most accepted for soil research in Russia) (Kachinskiy, 1965). The limits of the classes are somewhat different from those of international systems: clay <0.001 mm, silt 0.001–0.05 mm, and sand 1–0.05 mm, with further subdivisions within each class. Carbon content was measured photometrically (Kaurichev, 1986) and with a LECO SCN628 analyser.

Conventional radiocarbon dates were obtained in the Institute of Geography of RAS, Moscow (Russia), the Institute of Environmental Geochemistry, Kiev Radiocarbon Laboratory, National Academy of Science of Ukraine, the Ministry of Emergency Situations of Ukraine and in the St. Petersburg State University (Russia). A $SrO_3Al_2O_3SiO_2$ catalyst was used for benzene synthesis. The fivefold standard was prepared in the Geological Institute of the Academy of Science (1981 GIN standard) by adding a calibrated amount of ^{14}C-tracer benzene to C-dead benzene. The special practices used for dating old samples (close to the radiocarbon dating limit) are described in detail by Arslanov et al. (1993). All dates were calibrated following CalPal (2007).

$^{230}Th/U$ dating of sediments rich in organic material was carried out in the Köppen-Laboratory, St. Petersburg State University, Russia. The chemical and alpha-counting procedures for the $^{230}Th/U$ dating method followed (Kuznetsov and Maksimov, 2003, 2012). The principal issue of $^{230}Th/U$ dating of objects rich in organic material, such as peat and gyttja, is caused by the inclusion of a mineral fraction with a certain quantity of thorium isotopes, including ^{230}Th (so-called primary ^{230}Th), the content of which should be excluded in age calculation. Therefore, the isochronous approach for $^{230}Th/U$ age calculation was applied (Geyh, 2001; Geyh and Müller, 2005). The modern version of isochronous approximation is based on the agreement of isochronously-corrected ages obtained from the same coeval samples analyzed by two analytical techniques based on: (1) the acidic extraction of the sample – the “leachate alone” technique (L/L-model) – and (2) the “total sample dissolution” technique (TSD-model) (Maksimov et al., 2006; Maksimov and Kuznetsov, 2010; Kuznetsov and Maksimov, 2012; Maksimov et al., 2012). Peat samples for $^{230}Th/U$ dating were radiochemically analyzed in each 5-cm sub-layer along the peat profile. The reliability of these $^{230}Th/U$ dates was checked against significant agreement of the ages obtained using both the L/L-model and the TSD-model.

The detailed hierarchical morphological study of undisturbed blocks from paleosol horizons was conducted in the Laboratory of the Chair of Soil Science and Ecology of Soils, Institute of Earth Sciences, Saint Petersburg State University using binocular MBS-10. Structurally undisturbed soil blocks were taken from strata where evidence of MIS5–MIS1 pedogenesis was discovered. These blocks were impregnated with crystal resin in a vacuum camera and, after solidification of the resin, used to prepare thin sections in the Thin Section Laboratory for Soils and Unconsolidated Sediments in the Institute of Geology, National University of Mexico (UNAM). Micromorphological observations were conducted under an Olympus BX51 petrographic microscope, and descriptions were based on the definitions and terminology of Bullock et al. (1985).

Samples for pollen analysis were taken from the outcrop at 4–12-cm intervals. Pollen extraction from peat and gyttja was performed in accordance with the alkaline method of von Post described by Grichuk and Zaklinskaya (1948), and from sand and clay sediments with a heavy liquid in accordance with Grischuk's separation method (Grichuk and Zaklinskaya, 1948). In addition, 7-μm ultrasonic fine-sieving was used for all samples (Cwynar et al., 1979). Pollen and spore identification was carried out using published sources (Kupriyanova and Alyoshina, 1972, 1978; Moore et al., 1991) and reference collections at the Saint-Petersburg State University. 300–750 terrestrial pollen grains were counted in each sample.

Tilia/Tilia-Graph/TGView software (Grimm, 1993, 2004) was used for calculating pollen percentages and for plotting the pollen diagram. The calculated pollen percentages refer to the total sum of terrestrial pollen, which does not include the pollen of aquatic plants, spores of pteridophytes and mosses, and redeposited pollen and spore grains.

3. Study area, generic description of the key section

The study area is situated in the center of the East European (Russian) Plain (central parts of the Yaroslavl Oblast’, Rostov District). This area, which belongs to the Upper Volga River Basin, is restricted to the nearest part of the periglacial zone (58.5° N) (Fig. 1).

According to the soil-ecological zonation of Russia (Shishov et al., 2001), the study area belongs to the central parts of the Middle Russian province dominated by Albeluvisols developed as part of the South Taiga ecosystems. The climate of the Yaroslavl Oblast’ is moderately continental. The mean annual temperature

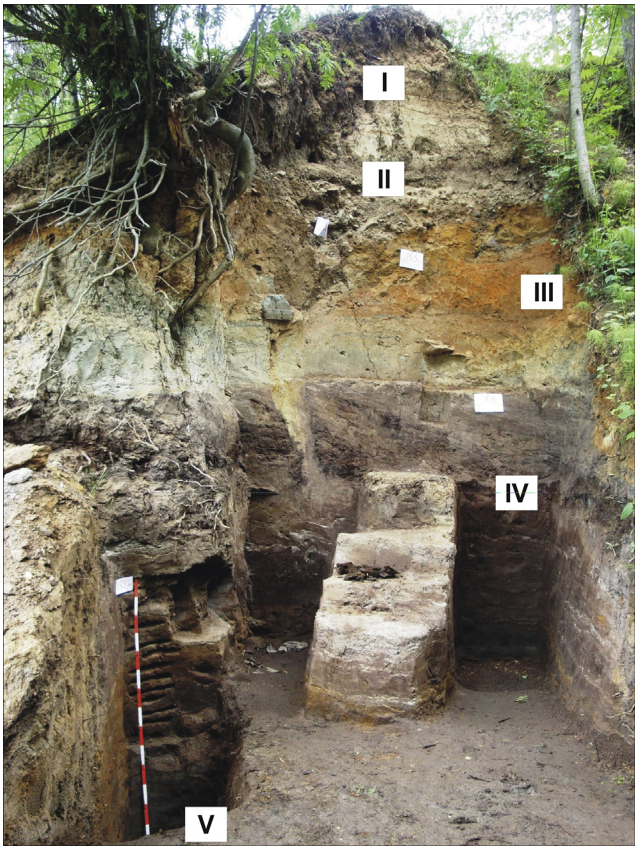

Fig. 2. The Cheremoshnik key site: General view of the exposure (2013). I–V – lithological layers.

is +3.4 °C. The mean annual precipitation is 530 mm, and the value of the precipitation/evapotranspiration ratio is 1.5, which means a considerable predominance of precipitation over evaporation. The parent sediments of the area are characterized by thin, loess-like deposits (cover or mantle loams) within unglaciated areas (Velichko, 2002). These loess-like deposits alternate with moraine loams, glaciofluvial deposits, and different types of stratified two-member parent materials.

The Borisoglebskaya Upland where the key section Cheremoshnik is situated occupies the central part of the Yaroslavl Volga Region and belongs to a complex geomorphological formation of a glacial-accumulative origin from the Moscow (Middle Pleistocene) Age (Aseev, 1970). The boundary of this upland is strongly modified by erosion, the relief is smoothed, and the local depressions between hills commonly represent ancient lake basins. The terraced Middle Pleistocene surface (145–160 m a.s.l.) of the western part of the Borisoglebskaya Upland where field work was conducted is now well-drained due to the gully-valley network.

The studied Cheremoshnik key section is dedicated to a beam aboard the accumulative terraces, a clearing in the right side of the ravine which is restricted to the previous location of “Cheremoshnik-C”. This site was last well-presented during the 27th International Geological Congress in 1984 (Sudakova et al., 1984).

This article presents Quaternary-geological, paleopedological and palynological results from the new exposure key section of Cheremoshnik within the Late Pleistocene beam-type terrace worked out over the last several years (Fig. 2). The clearing depth of the section reaches ~7.0 m, the width at the top is 6.5 m, and 3.0 m at the bottom. The surface of the terrace is 145 m a.s.l. (57.16632° N, 39.28886° E).

The stratigraphy, numerical dating of paleosols/pedosediments, deposits, lithological compounds and some features of complexly

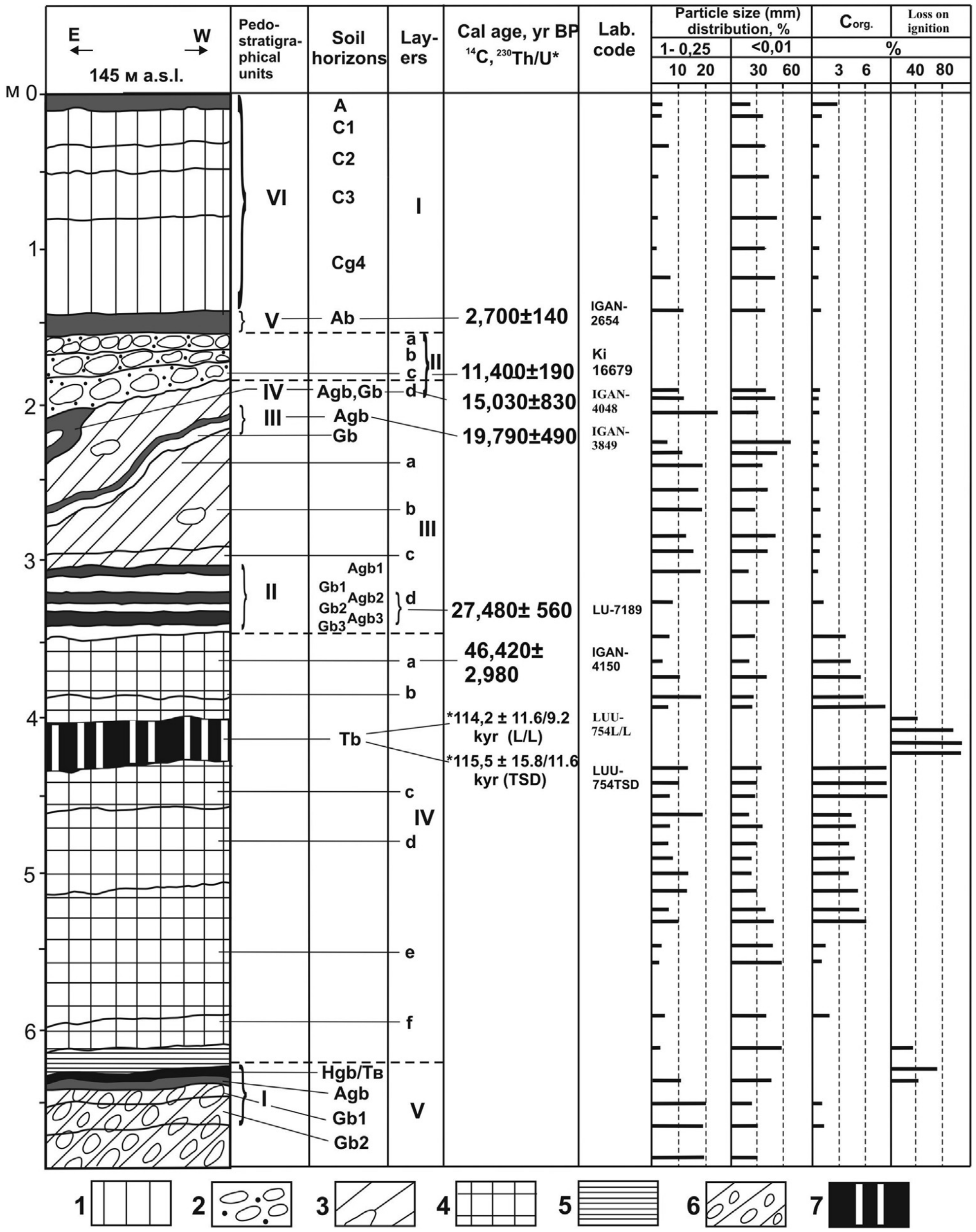

Fig. 3. Chronostratigraphy, morphology and some properties of soil-sedimentary strata of the Cheremoshnik key section. 1 – loess-like (mantle) loams; 2 – gravelly stratum; 3 – layers with rare inclusions of boulders; 4 – gyttja layers; 5 – varved clay layer; 6 – moraine deposits; 7 – peat layer.

organized heterochronous (MIS5–MIS1) soil-sediment strata of the key section Cheremoshnik are shown schematically in Fig 3. The deep, intricately arranged wedge-shaped structure in the outcrop (on the left side of the sequence, Fig. 2) in this article is not considered in detail.

4. Results

4.1. Chronostratigraphy, morphology and properties of the paleosols and sediments

The studied key section from the present surface to the bottom was some 7 m thick (Fig. 3). This sequence consisted of five lithological layers in which six pedostratigraphical units (the concept described by Costantini et al., 2007) formed, likely over the last 115,000 y (Table 1). The latter have been identified based on field and laboratory macro-, meso- and micromorphological investigations.

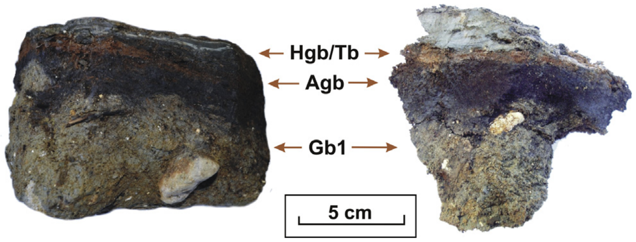

Fig. 4. Mesomorphology of the early Mikulino peat-dark humus paleosol (the first pedostratigraphical unit) formed on Moscowian moraine deposits overlain by a preserved thin layer of varved clays.

Table 1
Radiocarbon and ^{230}Th/U dating results (paleosol-sediment strata) of the Cheremochnik key section and corresponding calibrated ages.

Soil horizon/ lithological layer	Depth, m	Dated material	Laboratory cod	^{14}C age (^{14}C yr BP ±1Ʊ), ^{230}Th/U*	Calibrated age (cal yr BP)	MIS study
Ab/I	1.5–1.4	Humus fractions	IGAN-2654	2630 ± 90	2700 ± 140	1
IIc	2.1–1.8	Plant rests	Ki-16679	9870 ± 120	11,400 ± 190	1
Agb/IId	2.3–2.0	Humus fractions	IGAN-4048	12,570 ± 440	15,030 ± 830	2
Agb/III	2.7–2.1	Humus fractions	IGAN-3849	16,530 ± 380	19,790 ± 490	2
Sum of Agb2, Agb3/IIId	3.4–3.2	Humus fractions	LU-7189	22,920 ± 470	27,480 ± 560	3
IVa	3.5–3.4	Humus fractions	IGAN-4150	42,250 ± 3100	46,420 ± 2980	3
Tb/IV	4.3–4.0	Peat	LUU-754L/L LUU-754TSD	*114.2 ± 11.6/9.2 kyr (L/L),*115.5 ± 15.8/11.6 kyr (TSD)		5e

At the base of the sequence at the level of the flat bottom of the ravine (deeper than 6.25 m), the pebbly loam layer V of the Moscow till was revealed. This brown-reddish layer with an olive hue is represented by clay sandy loam in texture with inclusions of gravel and boulders and is characterized by a very high bulk density. The upper part of the loam was visibly weathered. The composition of these boulders is represented mostly by a sedimentary complex (70%) in which limestone fragments dominate, with igneous rocks (23%), mostly gabbro and granite, and metamorphic rocks (7%), generally quartzite-dominated.

At the top of layer V (6.21–6.70 m), an early Mikulino peat-dark (2.5Y3/3, dry) humus paleosol (the first pedostratigraphical unit) was formed on till deposits as it was overlain by a preserved 10-cm layer of varved clays in a period of deglaciation (Fig. 3). The thickness of the profile of this paleosol does not exceed ~0.5 m, and it consists of a set of Hgb/Tb–Agb–G1b–Gb2 paleohorizons (Figs. 3 and 4). The thickness of the peat and paleohumus horizons is only ≈2 cm (due to later compaction?). However, the paleosol profile is clearly expressed throughout the width of the clearance of the corresponding part of the section.

The Agb horizon is dark grey with a steel hue (10YR2/2; 10YR3/2, dry), loamy in texture, and is characterized by a rather high bulk density and a small blocky structure. There are inclusions of small ancient root fragments. The underlying paleogley horizons (6.23–6.50 m) are a bluish, light olive color with brownish/blackish spots on the ped faces. There are some fragments of ancient roots.

Micromorphological observations of thin sections demonstrated a highly heterogeneous granulometric and mineralogical composition typical for moraines. Among coarse sand and gravel particles, primary carbonates are abundant (Fig. 5a). Concentric and compound ferruginous nodules are frequent, sometimes associated with organic detritus (Fig. 5b). We also observed heterogeneity in the spatial distribution of particle size: some microareas were enriched with fine material, whereas the neighbouring areas consisted mostly of coarse sand grains. The limit between the areas is sharp (Fig. 5c). Such features are often produced by cryogenic sorting processes.

Layer IV, at a depth of 6.25–3.50 m, represented by a thick complex unit of the Mikulino Age, consisted mostly of gyttja deposit with an inclusion of a peat layer. At the bottom of layer IVf, varved clay deposits were formed. The granulometric composition of varved clay shows a very low amount of sand material and clay fraction predominance in comparison with the underlying moraine deposit (Fig. 3). In thin sections from varved clays, clear microlamination is observed: the laminae of fine silt alternate with layers consisting of fine clay and organic material (Fig. 5d).

Based on some morphological features (color), it was possible to subdivide the thickness of layer IV into six more thin layers (IVa–IVf), which also differ in texture: from loamy at the bottom to mostly loamy and sandy loamy in the middle and upper parts (Fig. 3). At a depth of 6.25–5.20 m (layers IVe, IVf) the gyttja groundmass contains uncommon, well-preserved macrorests potentially indicative of woody plants having a flattened shape (Fig. 6). Such an unusual shape of these macroremains may be due to compression from a powerful thickness of overlying sediments. Within the gyttja thickness, there is clear subhorizontal bedding, a weakly foliar-platy structure, inclusions of fine, sandy, albescent lenses, and large quartz grains. Small ancient branches, roots, and plant stems were found between the gyttja layers (Fig. 7).

Under a microscope the gyttja showed abundant, slightly decomposed plant fragments with parallel orientation (Fig. 5e), with an admixture of mineral sandy/silty material dispersed among plant debris. Some sand grains form clusters, which frequently become deformed at contact with laminated organic material (Fig. 5f).

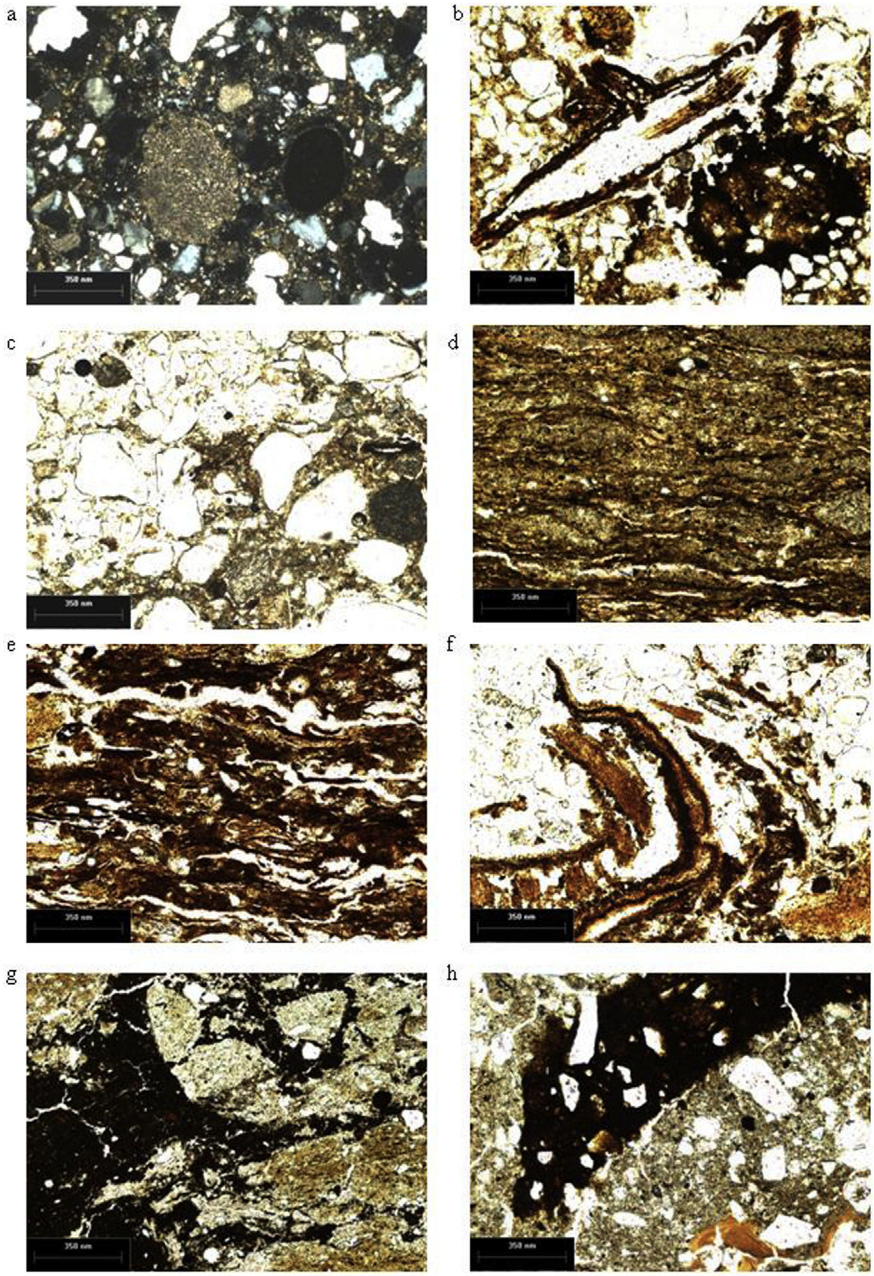

Fig. 5. Micromorphology of selected paleosol and sedimentary strata of the Cheremoshnik key site. (a) Fragments of carbonate rocks; early Mikulino peat-dark humus paleosol (the first pedostratigraphical unit), N+. (b) Circular ferruginous nodule and neighbouring partly decomposed plant fragment; early Mikulino peat-dark humus paleosol (the first pedostratigraphical unit), PPL. (c) Contact of microarea of coarse material concentration (top-left) and microarea enriched in fine material (bottom right); early Mikulino peat-dark humus paleosol (the first pedostratigraphical unit), PPL. (d) Alternation of silty and clay-organic microlayers; varved clay layer, PPL. (e) Parallel horizontal orientation of plant fragments; gyttja layer, PPL. (f) Deformation of plant fragment orientation at contact with a sand cluster; gyttja layer, PPL. (g) Mixing and fragmentation at the contact point between dark humus and pale gleyed morphons; Trubchevsk paleosol, PPL. (h) Anorthic ferruginous nodule with "broken" edge, note also light illuvial clay coating at bottom right; Trubchevsk paleosol, PPL.

Within the upper part of the gyttja layer at a depth of 4.3–4.0 m, there is a very well-preserved peat layer (Tb horizon of Histosol), pronounced throughout the exposure, characterized by a sub-horizontal length, and clearly expressed upper and lower boundaries with gyttja layers (Fig. 8). The peaty layer is dark grey with a brownish hue, layered, has a high bulk density, and contains wood residues, bark, roots, and stems. At the bottom part of this layer there are inclusions of separated quartz grains. According to botanical composition data, the peat is hypnum eutrophic and consists of *Drepanocladus* sp. – 30–35%, *Calliergon* sp. – 35%, and *Menyanthes trifoliate* – 15–20%. Unidentified remains of herbs in the botanical composition exceed 10%.

The ^{230}Th/U ages 114.2 ± 11.6/9.2 ka (L/L) and 115.5 ± 15.8/11.6 ka (TSD) of peat samples from 4.3 to 4.0 m depth are in significant strong agreement. These data indicate the peat layer's formation during MIS5 (Mikulino, Eemian Interglacial).

The radiocarbon age of the thin (~5 cm) upper part of layer IVa is 46,420 ± 2980 cal. BP (IGAN-4150). This implies a sharp change in the sedimentation rates within the 0.5-m layer of Mikulino sediments, which differ by a factor of 2.5 (Fig. 3).

Fig. 6. Uncommon well-preserved plant macrorests incorporated into gyttja groundmass at a depth of 6.25–5.20 m (layers IVe,f).

Layer III (3.5–1.8 (2.1) m), which overlies gyttja layer IV, is represented by Middle and Late Valdai (MIS3–MIS2) loams with rare inclusions of boulders. Based mostly on color, the thickness of this layer was subdivided into four layers (zones): a–d. Rare ferruginous channels were observed in the matrix of this layer at a location of ancient roots, thin diffusive ochre rings and rare inclusions of small charcoal fragments. Based on granulometrical composition, these layers are mostly loamy and sandy loamy in texture (Fig. 3).

The second detected pedostratigraphical unit of the Bryansk paleosol (MIS3) was formed within layer IIId (3.5–3.1 m) (Fig. 3). This unit consists of a set of paleohorizons (Agb1–Gb1–Agb2–Gb2–Agb3–Gb3 belonging to three small, adjacent profiles classified as Gleysols) clearly marked along the entire length of the clearing; the thickness of the whole unit varies between 0.3 and 0.4 m (Fig. 9). In the upper part of this pedocomplex, the Agb1 and Gb1 horizons were separated into some thin subhorizontal layers which evolved into a loamy groundmass of gullied-channel sediments. According to field observations, three full paleosol levels (cycles) similar in morphogenetic features can be distinguished.

Paleohumus horizons of all three cycles are relatively thin (<5 cm) and clearly separated within the pedocomplex, primarily by color – gray with a bluish hue (5Y7/1; 5Y6/2, dry). The upper Agb1 horizon is light grey with an olive hue (5Y6/1, dry). The paleogley horizons (with a thickness of ~12 cm) are blue-gray. Taking into account the low carbon content of paleohumus horizons, a radiocarbon measurement of the humic acids obtained from both the middle Agb2 and bottom Agb3 horizons of the pedocomplex was obtained, 27,480 ± 560 cal. BP (LU-7189).

A characteristic feature of the soil-sediment strata of this sequence is the presence of a well-preserved profile of the Late

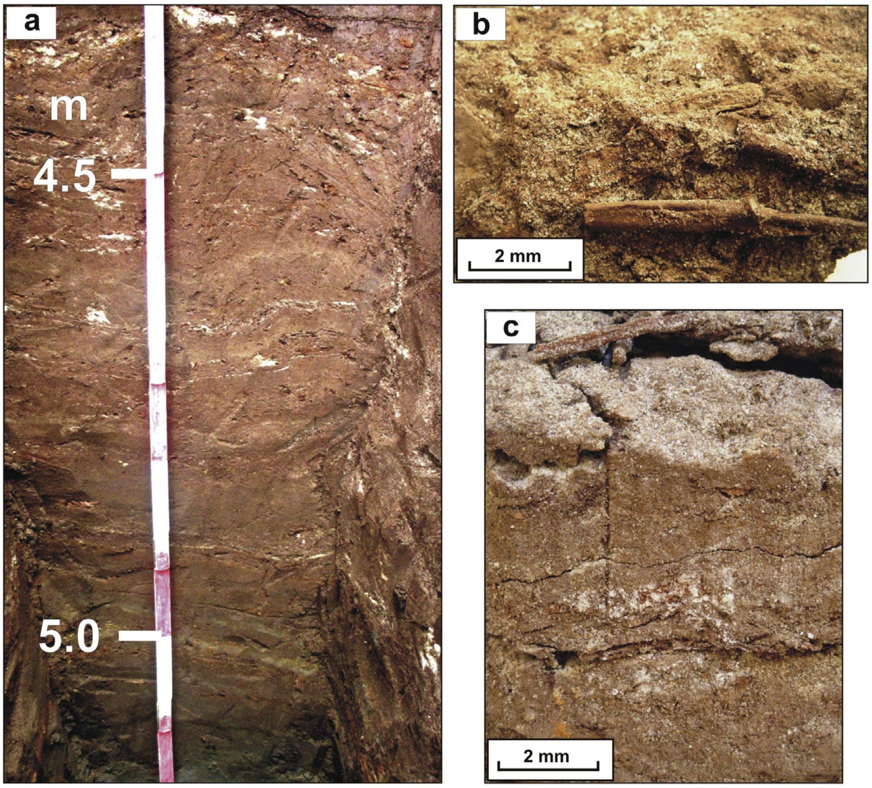

Fig. 7. Gyttja layer IV. (a) General view. (b) Ancient steam fragments within the gyttja layer (view from the top). (c) Inclusions of fine sandy lenses and ancient steam fragments within the gyttja layer (side view).

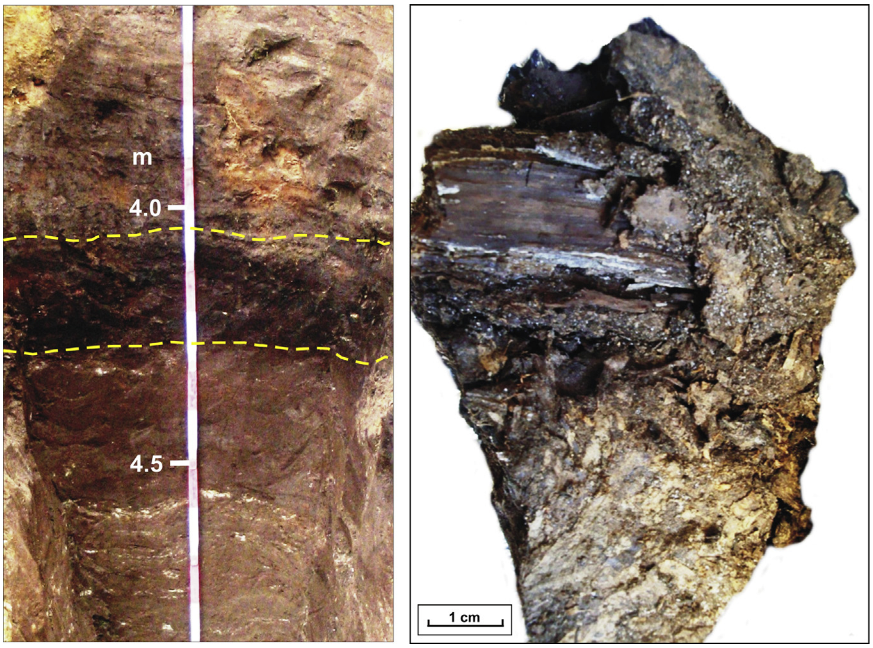

Fig. 8. Well-preserved peat layer (Tb horizon of Hystosol) underlain and overlain by gyttja layers.

Valdai (MIS2) paleosol (the third pedostratigraphical unit) situated between the IIIa and IIIb lithological layers (Fig. 3). The paleosol was classified as a Gleyic Turbic Cryosol because of the presence of cryoturbation features. The radiocarbon date from the paleohumus horizon of this soil is 19,790 ± 490 cal. BP (IGAN-3849) and is associated with the Trubchevsk soil, an incipient paleosol unit corresponding to the Late Valdai (Würm, MIS2) in the Loess–Paleosol Chronostratigraphic scheme for European Russia (Velichko, 2002).

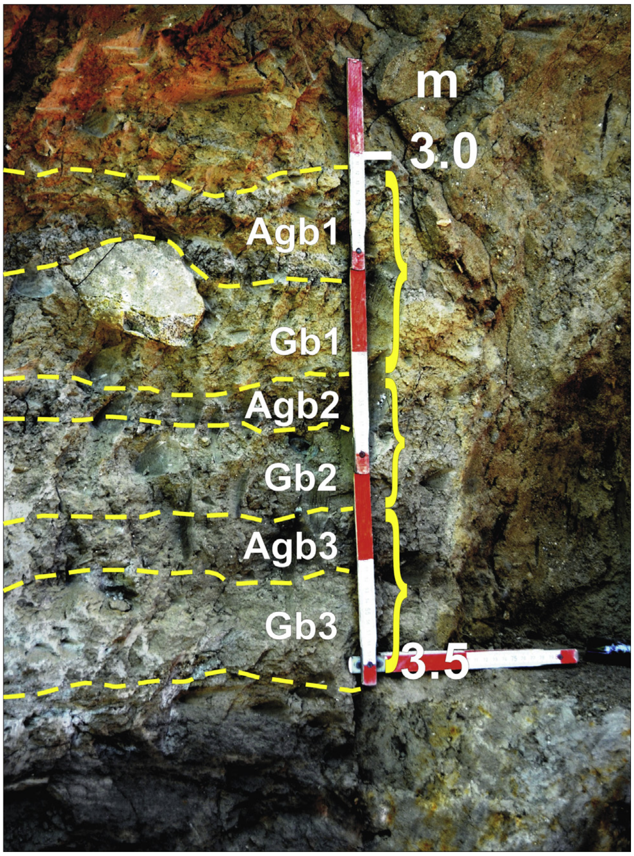

Fig. 9. Bryansk paleosol (MIS3). A set of paleohorizons belonging to three small adjacent profiles of Gleysols.

The thin but clearly identifiable dark humus-gleyed paleosol was formed on Middle–Late Valdai gullied-channel sediments at a depth of ~2.7–2.1 m and stands out sharply against the background of overlying and underlying layers over a length of 6.5 m (Fig. 10). This paleosol has a profile consisting of two horizons, Agb–Gb (Gleyic Turbic Cryosol), and is distinguishable from enclosing deposits by a heavier texture (fine silt and clay fractions dominate). The thickness of the paleohumus horizon is ~1.2 cm, and that of the paleogley horizon is ~5.2 cm. Despite the visible bend of the subhorizontal paleosol boundary along the entire length of the clearing of the section, there are no discontinuous zones within the paleosol body. This shows that the paleosol formed in the thickness of gullied-channel sediments, marking the paleosurface open to subaerial pedogenesis in the Late Valdai.

The Agb horizon is dark and grey-brown (2.5Y4/3; 2.5Y5/1, dry), porous, and has no coarse materials in the groundmass. The Gb horizon is bluish/light olive. The Agb horizon is sandier in texture, has a clear, thin, platy structure, and is porous. On the ped faces, thin ferruginous cutans and small Fe-concretions developed. In the intrapedal mass, there are ancient roots and concentric diffusive Fe-new formations around them and Fe–Mn-spots and smudges on the ped faces. Horizontal clearance of the paleosol surface indicated a visible relict of a cryogenic polygonal microrelief represented mainly by hexagonal block-polygons (Fig. 11).

Micromorphological observations show an extremely heterogeneous composition in this paleosol. Areas enriched in humus pigment alternate with the pale mineral gleyed material, with a complex boundary showing mixing and fragmentation of horizons (Fig. 5g). Ferruginous nodules are frequent, some showing an angular fragmented shape (anorthic nodules) (Fig. 5h). We attribute these features to cryoturbation processes. Thin illuvial clay coatings appear in some pores, which we associate with clay illuviation from the overlying Holocene soil.

Thus, we can assume that pedogenesis during late MIS3 (Middle Valdai) and MIS2 (LGM–late Glacial) produced soils with a similar

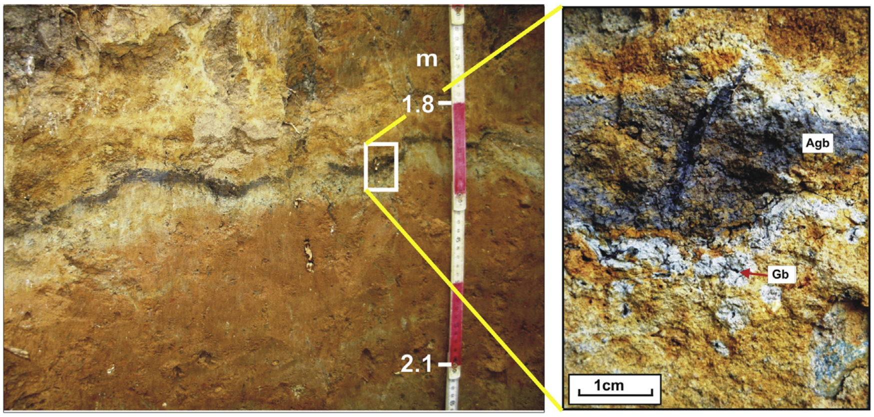

Fig. 10. Trubchevsk (MIS2) soil (Gleyic Turbic Cryosol) formed on Middle–Late Valdai gullied-channel sediments.

set of genetic horizons – Ag–G. However, those formed during MIS2 are less developed and more deformed by cryogenesis and slope processes.

The next lithological layer, layer II (1.8(2.1)–1.5(1.7) m), totally differs from the underlying and overlying layers and is attached to a mould (Fig. 3). The latter has a narrow gully shape with near-vertical sides at the narrowest part of the bottom. This gully has a width of 2.5 m at the top and 0.8 m at the bottom. The narrowest bottom part of the gully does not exceed 0.4 m. The ground mass of the buried ravine, in contrast with normal, horizontally layered loess-like deposits on the sides (within the beam-type terrace), is represented by a detritus unit with clear features of a sequential gravelly stratum.

In the detritus unit are four (IIa–d) separate horizons, each with a thickness of 0.25–0.4 m. In total, the coarse material is a different size than the small boulders in the rubble at the bottom, has various (mostly high) degrees of roundness, and the matrix is coarse sandy. Every horizon of the stratum differs from the neighboring ones, primarily by the percentage of clastic material, from 10 to 15% in IId to 70–80% in IIc. From the bottom IId to the upper IIa horizons there is a clear decrease in the percentage of local rocks and an increase in the fraction of Scandinavian crystalline rocks. Within the upper IIa horizon, the clastic material is noticeably better rounded, and flat pebbles lie in a densely-packed and oriented position. According to the radiocarbon date of plant remains incorporated into the IIc gravel stratum (at a depth of 2.1–1.8 m), this layer was deposited at approximately 11,400 ± 190 cal. BP (Ki 16679).

Fig. 11. Trubchevsk (MIS2) soil (Gleyic Turbic Cryosol). The relict cryogenic polygonal microrelief represented mainly by hexagonal block-polygons. Horizontal section.

The fourth pedostratigraphical unit formed within layer IId (2.3–2.0 m) on a local depression at the base of a deep wedge (Fig. 3). It is represented by redeposited fragments of paleohumus-gleyed soil material. The angular fragments of the Ag (7.5YR5/3; 10YR5/4, dry) and Gb horizons were strongly incorporated into the groundmass of the paleopedolithosediment (Fig. 12). The ^{14}C date from a fragment of the humus horizon of this sediment was 15,030 ± 830 cal. BP.

Layer I (1.5–1.7 m) was represented by a relatively thin layer of late Valdai loess-like (mantle) loam. In comparison to the middle and upper parts of this layer, the lower parts are notably enriched with a sandy fraction (Fig. 3). There is a total absence of gravel and pebble material within layer I. The latter contains horizontal stripes of bleached sandy loam.

No clear LGM loess layer was identified in the studied sequence. However, on a regional scale, loess-like sediments are widely spread in the watershed positions (Rusakov and Sedov, 2012). We suppose that in the studied section located in the beam-type terrace, these sediments were destroyed by erosion. Partly they were redeposited, mixed with coarser material and incorporated into other sedimentary units, probably layers III and II.

Associated with this layer is the fifth pedostratigraphical unit, which consists of a late Holocene laminated pedosediment (Ab

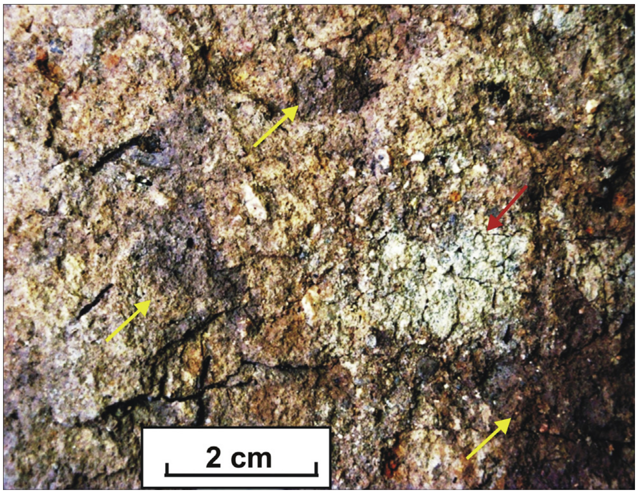

Fig. 12. Fourth pedostratigraphical unit, layer IIId (2.3–2.0 m). Redeposited fragments of paleohumus-gleyed soil material. Angular fragments of Agb (yellow arrows) and Gb (red arrow) horizons notably incorporated into groundmass. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

horizon – color 10YR5/3; 10YR6/3, dry) located at a depth of 1.4–1.5 m. It was dated at 2700 ± 140 cal. BP (IGAN 2654). This horizon, which formed on loess-like sandy loams, has distinct horizontal spreading and contains small charcoal fragments. Thin ferruginous cutans and ochre manganese spots developed on ped faces of the horizon.

Finally, the sixth pedostratigraphical unit (surface to 1.4 m) having the profile A–C1–C2–C3–Cg4 is represented by the recent Regosol developed on loess-like loam deposits (also layer I). The color of the A horizon is 2.5Y6/2 (dry).

4.2. Organic matter content and loss on ignition

The $C_{org.}$ content and loss on ignition in early Mikulino soil is relatively high: in the Hgb/Tb horizon, loss on ignition exceeds 63.86%, in the Agb horizon 40.44%, and in paleogley horizons the $C_{org.}$ content varies between 0.16 and 0.28%. The varved clay layer overlying this paleosol is characterized by high contents of loss on ignition (39.11%).

The content of organic carbon in the lower gyttja layers (IVe–IVf) does not exceed 3.0%, whereas in the middle and upper parts of the gyttja layers (IVa–IVd) there is an increase to 4.0–6.5%. The content of loss on ignition of the peat horizon is relatively high, and varies between 36.96 and 86.80%.

The $C_{org.}$ content in the Bryansk paleosol gradually increases from the upper to the lower humus horizons (Agb1 – 0.22%, Agb2 – 0.28%, Agb3 – 0.64%). The paleogley horizons are characterized by smaller carbon content (0.14–0.40%).

In lithological layers IIIa–IIIc overlying the Bryansk paleosol (3.1–1.8(2.1 m)), the content of $C_{org.}$ is low and varies between 0.11 and 0.24%. The content of carbon in the Trubchevsk soil does not exceed 0.34%. The $C_{org.}$ content within the profile of the upper Holocene soil varies between 0.47 and 0.87%.

4.3. Pollen stratigraphy on soil-sedimentary strata of the key section

Nine local pollen assemblage zones (LPAZ) were determined according to changes in the composition of spore-pollen spectra and based on visual inspection of the pollen percentages diagram (Fig. 13). LPAZ related to the Mikulino (Eemian) Interglacial in the northwestern and central parts of the Russian Plain by Grichuk (1982, 1989) were compared with zones M1–M6.

Pollen and spores are abundant in the studied sediments, except for the upper part of the section at a depth interval from 3.27 m to 3.03 m. However, the degree of preservation of pollen and spores varies along the section. The greatest number of crumpled, broken and mineralized microfossils, as well as a significant percentage of pre-Quaternary spores and conifer pollen, was observed in till loams at depths of 6.50–6.23 m. This composition of spore-pollen spectra characterizes till deposits.

LPAZ 1, (6.50–6.25 m): This lowest zone is characterized by a high content of *Betula nana* (20–30%), such as *Alnaster fruticosus* (10%), pollen of herbs (35–55%) and prequaternary conifer pollen and spores (15%). A high percentage of grass pollen was indeterminable due to poor preservation.

LPAZ 2, (6.25–6.06 m): Maximum percentage of *Picea* and *Betula sect. Albae* (up to 25%) among terrestrial pollen (up to 33%), as Poaceae (up to 35%) among herbaceous pollen. Pollen of aquatic and coastal water plants appears in this zone and is represented by *Myriophyllum*, *Sparganium*, *Typha*. LPAZ 2 is correlated with zone M1.

LPAZ 3, (6.06–5.55 cm): This LPAZ is marked by an increase of *Pinus* pollen (up to 70–78%) and a decrease of *B. sect. Albae* (up to 7%). Relatively high values of aquatic pollen (10%), with *Myriophyllum* dominating. LPAZ 3 is correlated with zone M2.

LPAZ 4a, (5.55–4.60 m): The spore-pollen spectra show changes: increased pollen *B. sect. Albae* to 20–45% and decreased *Pinus* to 40–45%. *Picea* pollen completely disappears. Initial appearances of broadleaf tree pollen including *Ulmus* and *Quercus* and relatively high percentages of aquatic plant pollen (8–9%) are indicated in this zone. LPAZ 4a is correlated with zone M3.

LPAZ 4b, (4.60–4.22 m): *Pinus* and *B. sect Albae* dominate (around 30–40%). Maximum values of *Viburnum* pollen (14%) and Cyperaceae (20%). The percentage curve of *Ulmus* pollen reaches a peak (5%) in the upper part of this zone. LPAZ 4b is correlated with zone M3.

LPAZ 5, (4.22–3.95 m): A sharp increase of *Alnus* (up to 40%) and *Corylus* (up to 15%) is observed. There is a peak of *Quercus* pollen (5–7%) in the lowest part of the zone. *B. sect. Albae* decreases to 10%. Pollen of coastal water plants almost completely disappears. The total amount of herb pollen decreases in the spectra to 7%. LPAZ 5 is correlated with zone M4.

LPAZ 6, (3.95–3.46 m): High content of warm-climate tree taxa including *Corylus* (25–45%), *Alnus* (10–30%), as well as broadleaf species: *Tilia* (2–12%), *Quercus* (1–5%), *Carpinus* (1–3%) and *Ulmus* (1–2%) are a distinctive feature of this zone. There is a maximum percentage of *Tilia* pollen and *Carpinus* in this section. *Osmunda cinnamomea* exists in this zone only. Some grains of *Picea* appear. LPAZ 2 is correlated with zones M5,6.

LPAZ 7, (3.46–3.25 m): The zone is dominated by *B. nana* (20–75%) and *Alnaster* (15–25%). One of the main characteristics of the zone is an abundance of Polypodiaceae (70–80%). There are high values of *Alnus* and *Corylus*, which are probably redeposited.

LPAZ 8, (3.25–3.03 m): Only a few pollen grains due to poor preservation, which are represented by *Picea*, *Pinus, B. nana*, *Alnaster fruticosus* and *Corylus* among tree and shrub pollen, as well as *Cyperaceae*, *Poaceae*, *Asteraceae*, *Rosaceae*, *Ranunculaceae* among herbaceous pollen, and some spores of Polypodiaceae and *Botrychium*.

LPAZ 9, (3.03–2.98 m): This zone is represented by a single spore-pollen spectrum. Maximum percentages of *Pinus* and Poaceae among terrestrial pollen. The total amount of tree pollen attains 50%. Percentage values of *B. sect. Albae*, *B. nana* and *Alnaster fruticosus* not greater than 5–7%. Some grains of *Alnus*, *Tilia*, *Quercus*, and *Carpinus* are present.

Sediments from the upper part of this section (depth from 2.98 m to 0 m) contain only a few pollen grains of *Picea*, *Pinus*, *Betula*, Polypodiaceae and *Sphagnum*, and are not presented on the pollen diagram.

An exception is the redeposited fragments of paleohumus-gleyed soil material (Ag and Gb horizons) cemented by loamy deposits within a depth interval from 2.5 m to 2.0 m (lithological layer IId). The pollen spectrum of one sample is characterized by the dominance of tree and shrub pollen such as *B. sect. Albae* (54%), *B. nana* (11%), *Pinus* (9%), *Alnus* (5%) and a few pollen grains of *Salix* and *Quercus*. Among non-arboreal pollen, Poaceae (7%) and *Artemisia* (5%) dominate. Asteraceae, Chenopodiaceae, Rosaceae and *Thalictrum* are present as single pollen grains. Spores are represented mainly by Polypodiaceae. *Botrychium*, *Ophyoglossum*, *Huperzia selago* and *Sphagnum* are represented by a significantly smaller amount.

In addition, pollen data was obtained for one sample from level IIc (at a depth of ~1.75 m), which is stratigraphically above layer IId. The main characteristic of the spore-pollen spectra is the abundance of *B. sect Albae* (68%), *Pinus* (13%), *Alnus* (10%) pollen and Polypodiaceae spores (18%). In general, our pollen data for the Mikulino Interstadial (LPAZ 2–6 and zones M1–M6) more or less correlate with previous findings (Gorlova, 1972; Grichuk et al., 1973; Novenko et al., 2005).

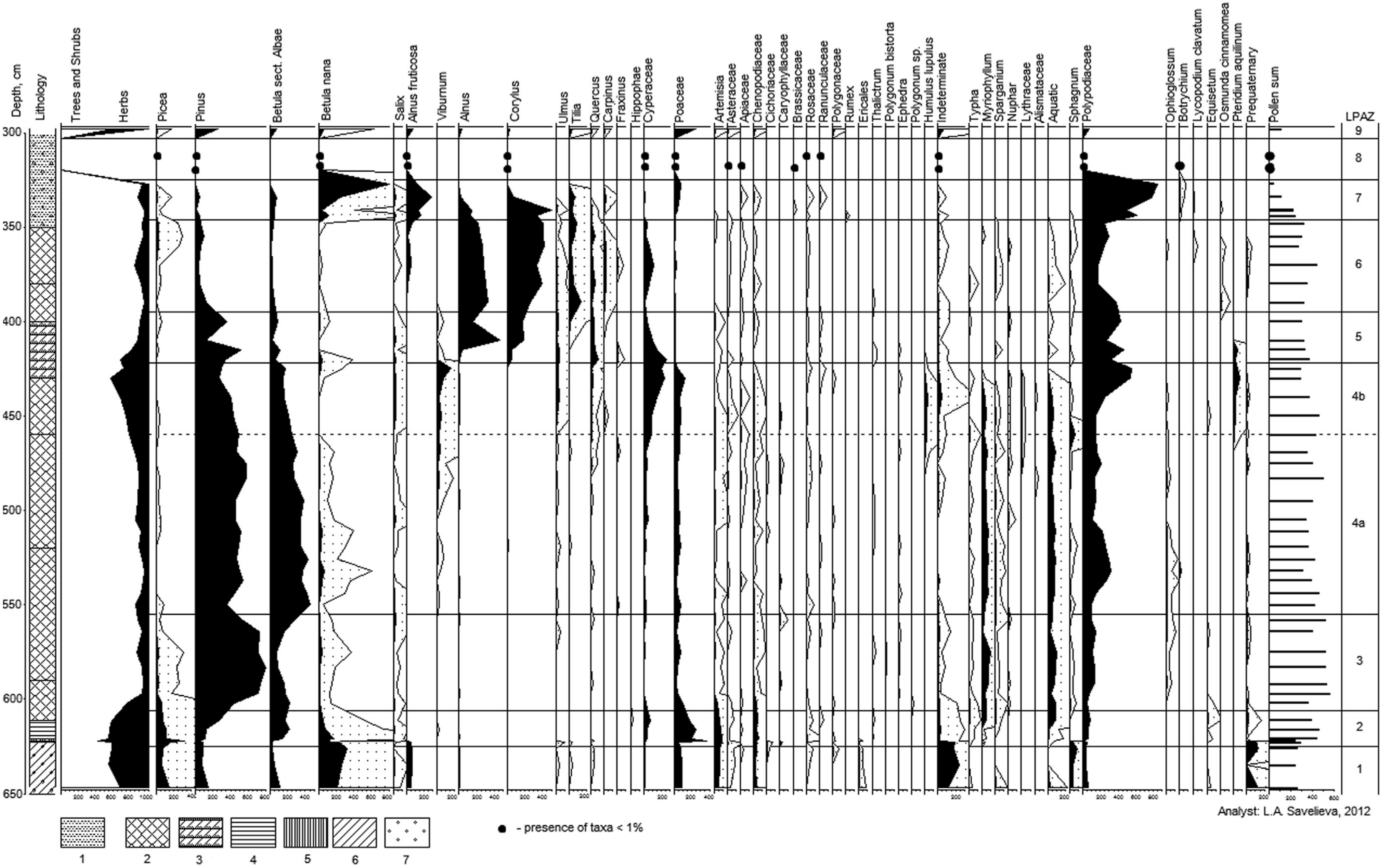

Fig. 13. Pollen and spore diagram for the Cheremoshnik key section. Lithology: 1 – loam; 2 – gyttja; 3 – peat; 4 – clay; 5 – humus layer; 6 – till; 7 – boulders.

5. Discussion

5.1. Absence of the Valdai (MIS4–MIS2) moraine within the investigated area

One of the main discussion questions that has stood out for a long time is the existence of moraine deposits of the last (Würmian, Valdai, Ostashkovo) glaciation within the investigated area. Among publications supporting the overlapping of this area by an ice sheet are those of Sudakova (2012), including the Cheremoshnik site as the most representative. Our comprehensive complex study has undertaken examination of this key site as the main sequence in the Upper Volga region. The following arguments are forcing authors to reexamine questions about the extent of the last glacial cover.

1. Moraine deposits were not found in the studied key section (ravine) Cheremoshnik, on its sides along the entire length or in any of the nearby quarries. Supporters of recognizing the upper clastic sediments (“moraine”, “moraine-like”, “deluvial-solifluction” deposits) did not explain the complete absence of similar deposits throughout the left bank of the Puzbol stream, 100–150 m north of the Cheremoshnik key section (Sudakova et al., 1984), taking into account that the beam-type terraces there have the same absolute elevation and slope.
2. The studied sequence at a depth of ~3.5–2.5 m (layer III) in the age interval dated by humus paleosol horizons (MIS3–MIS2) consists of coarse loamy sediments with low content (usually 2–5%, up to 5–10% in the lower part) of debris pebble inclusions and a few small boulders. These loamy subaerial deposits have no features of glacial origin. Results of spore-pollen analysis in the lower part of layer III consistently indicate periglacial–glacial forest-tundra conditions (LPAZ 7–9).
3. Finding the plant residues – mostly fragments of macro residues and well-preserved paleosols (MIS3–MIS1) – within the upper (above the Mikulino gyttja and peat horizon) layers of continental deposits provided by four serial radiocarbon dates in the range of 27 to 9.9 ka cal. implies no glaciation during that period in the investigated key section and its nearest environs.
4. The nearest Puzbol key section (Borisoglebskaya Upland, ~2.0 km east of the Cheremoshnik key section) is characterized by a presence of a thickness of loess-like loamy deposits (2.5–3.0 m) underlain by lake clayey sediments in which the MIS3 paleosol (^{14}C age of the paleosol humus horizon is 39,700 cal. BP) was formed (Rusakov and Sedov, 2012). These sediments overlie typical Moscow moraine, excluding the presence of moraine from the Valdai glaciation.
5. Our results correspond with Shik (2010) concerning sediment stratigraphy and chronostratigraphy of the Quaternary in the center of the Russian Plain. The author relies on materials from state geological surveys of varying scales and uses all available drill data, hence coming to the unequivocal conclusion of the presence of a single Late Pleistocene Moscow glaciation in the territory. In the basin adjacent to the Cheremoshnik ravine hollow Lake Nero, no moraine deposits have been found above the clearly allocated Mikulino sediments. The gravelly layer in the upper part of the profile (layer II) is not till.

5.2. Chronostratigraphical and paleogecological significance of strata (MIS5–MIS1)

Here, for the first time in the Upper Volga region, evidence shows the early stage of Mikulino pedogenesis represented by a peat-dark humus paleosol formed at the base (6.21–6.70 m) of the sequence on the Moscow (MIS6) pebbly loam. Micromorphological features point to incipient hydromorphic pedogenesis with gleyzation and the accumulation of undecomposed plant residues. These features were accompanied by cryogenic grain sorting and pedoturbations, pointing to cold climatic conditions, corresponding to a deglaciation period. This pedogenesis was later abruptly interrupted by varved clay deposits. A change from subaerial to subaqual environmental conditions is confirmed by pollen data. The sediments demonstrate rhythmic lamination on a macro- and microscale typical for meltwater-fed lakes. Even in gyttja, there is some evidence of structure deformation and turbation, possibly produced by frost effects.

The ^{230}Th/U ages 114.2 ± 11.6/9.2 ka (L/L) and 115.5 ± 15.8/11.6 ka (TSD) of peat samples from the 4.3–4.0 m depth are in strong agreement. These dates more or less correspond to MIS5e. The generalized diagram of the Cheremoshnik section (Fig. 3) shows that the ^{230}Th/U and ^{14}C dates are distributed in accordance with the stratigraphical sequence of layers. The results of pollen analysis confirm the ^{230}Th/U dates and reflect Mikulino environmental conditions of peat layer formation. All of these data indicate the reliability of the ages obtained and the time of peat layer formation during MIS5e (Mikulino, Eemian Interglacial). Similar combined pollen and ^{230}Th/U dating results were obtained for a number of peat profiles from the Russian Plain, which had been formed during MIS5. Their age has been estimated to be 109.5 ± 6.2 ka (L/L) for the Mikulino Site (Smolensk Province, Russia), 98.4 ± 7.9 ka (L/L) and 105.9 ± 10.4 (TSD) ka for the Murava Site (Belarus) and 100.6 ± 5.0 ka (L/L) and 110.0 ± 6.2 ka (TSD) for the Fili Site (Moscow) (Kuznetsov and Maksimov, 2003, 2012; Maksimov et al., 2006; Maksimov and Kuznetsov, 2010). The increase in the carbon content of underlying and overlying gyttja layers which include the subhorizontal peat horizon indicate a relatively quiet and *in situ* process of accumulation of the Mikulino deposits.

The radiocarbon date from the sum of both humus horizons of Gleysols from the paleopedocomplex developed within the groundmass of gullied-channel sediments (lithological layer IIId) overlying the deposits is 27,480 ± 560 cal. BP (LU-7189), which allows the attribution of the pedogenesis of the paleosols to the Bryansk Interstadial. The latter took place during 33,000–24,000 BP (Markova et al., 2002) and corresponds to the Stillfried B or the Denecamp in Western Europe (Faustova and Velichko, 1992; Bolichovskaya, 1995) and the end of MIS3 (Shackleton et al., 1991). This interval included several interstadials of the Middle Wűrm epoch with relatively mild climatic conditions (Antoine et al., 2001).

Within the East European Plain, the Bryansk paleosols (MIS3) were examined in various places (Velichko and Morozova, 1972; Morozova, 1981; Alifanov et al., 2000; Velichko et al., 2000; Gugalinskaya, 1982; Gugalinskaya et al., 2001; Velichko, 2002; Glushankova, 2008; Sedov et al., 2010; Kovda, 2013). Analogues of Bryansk paleosols have been described in different regions of Western Europe (Haase, 1963; Lieberoth, 1964; Paepe, 1966; Ruske and Wünshe, 1968; Seppala, 1971; Jersak, 1973; Semmel, 1989; Zöller and Löscher, 1997). Most of the MIS3 paleosols were formed on loess and loess-like deposits.

Considering the formation of the pedostratigraphical unit of the Bryansk paleosol, the complex and multiphase origin of the considered paleosol unit is notable. Three full paleosol cycles can be distinguished (Fig. 9). They reflect separate periods of active pedogenesis processes. The sequence of genetic soil horizons within each of these levels – the Agb–Gb horizons – makes it possible to interpret the paleosol profiles as monogenetic. The Gb horizon corresponds to the phase of the gley pedogenesis, and the Agb horizons reflect the accumulation of humus in combination with the gley process. Every rhythm of pedogenesis which formed a new paleosol is similar to the previous one. In the key section of Cheremoshnik, soil formation of each rhythm sequence of the Bryansk soils is serial: paleosols were formed on gullied-channel sediments which had been received from watershed and slope positions.

These rhythmic series of the Bryansk paleosols formed within beam-type terrace conditions reflect serious climate change in their morphology. A similar picture of the rhythmicity of soil formation of the Middle Valdai paleosols can be observed in other key sections, but in more southern areas (Sedov et al., 2010; Voskresenskaya et al., 2013).

According to maps showing the Bryansk Interstadial soil cover reconstruction in Europe (Velichko and Morozova, 1982) and in the East European Plain (Velichko, 2002), the Bryansk paleosols formed within the soil-sediment stratum of the Cheremoshnik key section display the northernmost occurrence of the MIS3 paleosol in Europe. In this connection, the paleosols described in this paper complement the whole picture of the Bryansk soils which developed within their northernmost occurrence in the nearest periglacial zone – the key sites of Shetinskoe, Koskovo and Puzbol (Rusakov and Korkka, 2004; Rusakov et al., 2007; Rusakov and Sedov, 2012). The Puzbol key section containing the MIS3 paleosol is situated only ~2.0 km east of the Cheremoshnik key section, also within the Borisoglebskaya Upland. The modern analogues of the Bryansk Soil are the Gelic Umbrisols developed in Central Yakutia, Eastern Siberia in a severe, extra-continental climate (Velichko and Morozova, 1982).

The special chronostratigraphical position in the structure of the soil-sedimentary stratum of the Cheremosnik key section has the third pedostratigraphical unit – Trubchevsk soil (MIS2). Much less is known about the character of the pedogenesis in the weakly-developed paleosols dating back to the coldest Late Valdai glacial maximum (MIS2).

Some paleosol horizons in the sediments of that period are known in Western Europe (Haesaerts and Van Viet-Lanoë, 1981; Antoine et al., 2001) and in Russia (Sycheva, 2003; Velichko et al., 2007; Glushankova, 2008), though these paleosols developed ≈ 200 km to the south of the key section Cheremoshnik. However, the information on the paleoenvironmental conditions and processes that shaped these paleosols is insufficient.

Having a relatively well-developed profile (Agb–Gb), the Trubchevsk Gleyic Turbic Cryosol of the key section Cheremoshnik differs from other Trubchevsk paleosols developed within the southern part of the periglacial zone of the East European Plain, where these soils present morphologically mostly in the form of weak pedogenesis. Micromorphological observations point to gleyzation and weak, hydromorphic, dark humus accumulation in this paleosol. Usually, Trubchevsk paleosols resemble layers of green-bluish gleyed loess with brownish ferruginous spots (Velichko, 2002). This paleosol (MIS2) divides Valdai loesses II (Desninsk) and III (Altynovo) (Velichko and Starcel, 1994; Morozova, Nechaev, 2002; Velichko, 2002).

The Gleyic Turbic Cryosol developed within the upper part of the sequence affected by strong frost/cryogenic deformations, also clearly observed in thin sections, which is common for Trubchevsk paleosols of the East European Plain as a result of the Yaroslavl stage of cryogenesis (Velichko, 2002). Despite the presence of cryogenic impact, the well-preserved paleosol profile of the Trubchevsk soil of the Cheremoshnik sequence marks the exposure of the ancient surface to the initial pedogenesis during short-term climate softening and biota development in the final stages of the Late Pleistocene.

A special place in the pedostratigraphy of the key section has paleopedosediment localized in the bottom part of the gravelly stratum (IId, 2.3–2.0 m) at the base of a deep wedge and represented by redeposited fragments of paleohumus-gleyed soil material (Fig. 12). Based on our field observations, we believe that the angular separated fragments of the Agb and Gb horizons which had evolved into a gravelly stratum were parts of the previous paleosol (likely Gleyic Turbic Cryosol) of the Late Valdai Age (15,030 ± 830 cal. BP), with pollen assemblage indicative of an open birch forest with grasses, mosses and ferns. Finding this dated pedosediment (≈ 15 ka cal. BP) dated the time of occurrence of the deep wedge after the maximum phase of Valdai glaciation.

There were at least two phases of MIS2 pedogenesis in the Cheremoshnik key section (the first phase was the Trubchevsk paleosol described above). This shows the completeness of the pedogenesis record in the soil-sediment stratum of the studied sequence during short-term warming of the final stage of the Late Pleistocene. Thus, the paleosols (MIS2) of Cheremoshnik are the northernmost position of these soils in the central part of the East European Plain.

The genesis of the gravelly stratum (layer II) holds an important meaning for the landscape environment evolution of the Late Pleistocene within the investigated area. This stratum differs both from moraine and solifluction sediments. All detected features indicate that the sedimentation process of each layer (IIa–d) was the result of a temporary stream characterized by varying force and periodic drying. These temporary streams might have brought allochthonous material from the nearest watershed area and deposited it near the ravine's mouth of the main water channel, Pra-Cheremoshnik.

Stem-like carbonized fragments of swamp vegetation (probably sedge and rush) were found in the thick gravel-pebble stratum of layer II. These plant fragments firstly had traveled by water and then were buried in the thickness of layer II downstream. This allowed us to reliably estimate the time of occurrence of the hollow and the duration of the influx process of gravel-pebble material. Based on two radiocarbon data sets from layer II (Fig. 3), the existence period of this layer up to the filling and overlapping by loess-like loams was from ≈15,300 to 11,400 cal. BP, the Younger Dryas.

Late Holocene pedogenesis (fifth and sixth pedostratigraphical units) at the top of the key section, expressed in the formation of the Ab horizon (≈2700 cal. BP) and recent Regosol, did not lead to well-developed soils. Texturally well-differentiated soils, represented by Cutanic Albeluvisols, are typical only for the watershed and gentle slope positions of the Borisoglebsk Upland. Soil formation in the beam-type terrace of the key section took place on redeposited loess-like (mantle) loams. This fact does not exclude the synlithogenic process of soil formation.

Considering the Late Pleistocene and Holocene paleosol units (MIS5–MIS1) of the Cheremoshnik section, the good preservation of soil profiles and stability of their paleopedological features is a result of alternation of active pedogenesis and active sedimentation periods. The dominant individual pedogenic processes (IPP) from paleosols formed in the soil-sediment strata of the Cheremoshnik key section during MIS5–MIS1 period are to be described by the following characteristic time (CT) (Targulian and Goryachkin, 2004): 1) fast IPP, CT– $n \cdot 10^1–10^2$ y: gleyzation, aggregation and cracking; 2) medium-rate IPP, CT– $n \cdot 10^2–10^{3-4}$ y: humus and peat formation.

5.3. Reconstruction of vegetation during MIS5–MIS2

The pollen assemblage from zone 1 suggests open forest vegetation and quite cool climatic conditions. The high proportion of herbs and shrubs and the absence of organic material indicate a semi-open environment. A spruce and pine open forest with shrubs and periglacial vegetation occupied the surrounding area.

This stage is compared to the final stages of the Moscow Glaciation.

Milder and more humid climate developed. A spruce forest with birches and pines developed (LPAZ 2). However, the climate remained relatively cool. The abundance of spruces and the emergence of coastal water and wetland plants (*Myriophillum*, *Sparganium*, *Typha)* indicate a humid climate. This stage is matched with the beginning of the Mikulino Interglacial – zone M1.

The next stage of vegetation development is expressed in a sharp change from spruce forests to pine forests with birch (LPAZ 3). The significant increase in *Pinus* and *B. sect. Albae* percentages demonstrates that trees extended to this site. The climate became warmer. This stage is correlated with zone M2.

Pine and birch-pine forests with populations of broadleaf species such as *Ulmus* and *Quercus* characterize LPAZ 4a and 4b. *Viburnum* and *Humulus lupulus* grew in the undergrowth of those forests (LPAZ 4b). The climate became warmer and quite favorable for the emergence and dispersal of nemoral flora. This stage is correlated with zone M3.

LPAZ 5 and 6 correspond to the optimum conditions of the Mikulino Interglacial. At the beginning of the Interglacial, optimum pine forests dominated; however, *Alnus* was widespread. *Corylus* and *Alnus* together with broadleaf trees (*Tilia*, *Quercus*, *Carpinus* and *Ulmus*) were prevalent in the surrounding area in the second part of the optimum (LPAZ 6). Inclusions of fern spores *O. cinnamomea* in zone 6 are noted. At the present time this fern forms thickets in wet meadows of a forest only in the Russian Far East. *O. cinnamomea* was widely distributed throughout Europe in the Mikulino Interglacial (Grichuk, 1989). The climate of this time is characterized by optimum temperature and humidity conditions favorable for the wide development of nemoral broadleaf forests. These stages are correlated with zones M4–M6 (Grichuk, 1982) and were dated by the uranium–thorium method to 114.2 ± 11.6/9.2 ka or 115.5 ± 15.8/11.6 ka (depth of 4.30–4.40 m).

Dramatic changes in the vegetation cover occur at the onset of LPAZ 7 with a shift from arboreal vegetation to shrub tundra conditions (*B. nana* and *Alnus fruticosa* dominated). They can be correlated with the beginning of the Valdai glaciation. The rapid changes in vegetation from zones 6–7 (≈3.50 m depth) may represent hiati in the record. The hiatus may have been the result of erosion and sedimentation processes of the final part of the interglacial optimum (zones M7 and M8 according to Grichuk, 1982). Thus, according to pollen data and the correspondence of radiocarbon age to the time of the Middle Valdai – 46,420 ± 2980 cal. BP, the upper layer of gyttja was formed in the Mikulino Interglacial. This suggests a significant hiatus between zones 6 and 7 (~60 ka).

The vegetation in LPAZ 8 and 9 was probably semi-open, with a sparse cover of birch and pine trees and grasses. Climate conditions were cold. The formation of the upper sediments (from 3.50 m to 2.98 m) and LPAZ 7, 8 and 9, presented on the pollen diagram (Fig. 13), presumably can be attributed to the period of Valdai glaciation. Fragmentary pollen data and low pollen concentrations do not allow us to distinguish the stages in more detail. Within LPAZ 7, a radiocarbon date of 27,480 ± 560 cal. BP (depth of 3.4–3.2 m) was obtained.

The following stages are not shown in the spore-pollen diagram. By the end of the Late Glacial (Agb horizon, layer IId), climatic conditions were too cold for the development of forest communities. The vegetation was mosaic, and an open birch forest with a combination of steppe meadows and wetland habitats dominated. The radiocarbon date of this zone is 15,030 ± 830 cal. BP (depth of 2.30–2.2 m).

Scarce pollen data were received from layer IIc of the Holocene. Probably, birch and pine forests with alder were widespread in the surrounding area in the beginning of the Holocene after 11,400 ± 190 cal. BP.

6. Conclusion

The main results can be summarized in the following:

1. Significantly more complete and reliable chronological arguments for almost all components (horizons) of the Cheremoshnik key section have been obtained for the site; for the first time the chronostratigraphy and paleography of the region's MIS5–MIS2 period are described in detail.
2. For the first time, sedimentary paleosol series (MIS5–MIS2), including the Early Mikulino, Bryansk, and Trubchevsk paleosols, are distinguished, classified, and morphologically characterized and dated. They represent the northernmost occurrence of fossil soil in Europe, dominated by features of gleyzation, cryogenic aggregation, cracking, and humus and peat formation.
3. According to numerous observations, the upper loams with minimal contents of rubble from regional dispersion (layer III) are related to continental and basin, but not glacial, LGM deposits; the overlying local series of clastic layers (often mistaken for moraine-like and/or deluvial-solifluction deposits) indicates the flow of temporary streams in the local trough 12.6–9.5 cal. BP.
4. For the first time, the age of the buried peat layer of the key section Cheremoshnik and its connection to the Mikulino Interglacial have been quantitatively established using radiochemical and biostratigraphical research. The isochronous-corrected ^{230}Th/U ages of 114.2 ± 11.6/9.2 ka (L/L) and 115.5 ± 15.8/11.6 ka (TSD) of the peat layer provide a good estimate for the Mikulino deposit. The ^{230}Th/U ages are in strong agreement with the biostratigraphical identification of the Mikulino peat sequence as part of LPAZ 2 and LPAZ 6 (zones M1–M6, according to Grichuk, 1982). All the ^{14}C and ^{230}Th/U dates reflect their correct stratigraphic sequence.
5. Pollen data allowed reconstruction of the paleovegetation changes and reveal the sequence of paleogeographic events from the final stage of the Moscow glaciation to the climatic optimum of the Mikulino Interglacial. The final stages of the Mikulino Interglacial were not preserved here due to erosion and sedimentation processes.
6. The relief, lithological characteristics of dated layers, and their climatic values, indicates the entire Cheremoshnik site (and the entire Borisoglebskaya Upland) to be an unglaciated (preglacial) zone during MIS3–MIS2.

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References

Alifanov, V.M., Bader, L.A., Gugalinskaya, L.D., Sulerzhitsky, L.D., 2000. Paleosols on the Paleolithic campsite Sungir. In: Paleosols and Modern Soils as Stages of Continuous Soil Formation, 2000. Abstracts and Field Excursion. Guidebook of V

International Symposium on Paleopedology. Suzdal, July 10–16, 2000, pp. 57–66.

Antoine, P., Rousseau, D.-D., Züller, L., Lang, A., Munaut, A.-V., Hatté, Ch., Fontugne, M., 2001. High-resolution record of the last interglacial–glacial cycle in the Nussloch loess–palaeosol sequences, Upper Rhine Area, Germany. Quaternary International 76/77, 211–229.

Arslanov, Kh.A., Tertychnaya, T.V., Chernov, S.B., 1993. Problems and methods of dating low-activity samples by liquid scintillation counting. Radiocarbon 35 (3), 393–398.

Aseev, A.A., 1970. Ancient Continental Ice Formations of Europe. Extended Abstract of Doctor's Dissertation in Geography, Moscow, p. 29 (in Russian).

Bolichovskaya, N.S., 1995. Evolution of Loess-soil Formation within the Eastern Eurasia. Moscow State University Press, Moscow, 288 p. (in Russian).

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., Babel, U., 1985. Handbook for Soil Thin Section Description. Waine Research Publications, Wolverhampton, UK.

CalPal, 2007. The Cologne Radiocarbon Calibration & Palaeoclimate Research Package. HULU. www.calpal-online.de.

Chebotareva, N.S., 1959. The stratigraphy of the Quaternary sediments in the center of the Russian plain. In: Ice-cap in the European Part of the USSR and Siberia. Moscow State University Publishing House (in Russian).

Costantini, E.A.C., Napoli, R., D'Egidio, G., 2007. Adding information about soils and paleosols to geological maps, through the application of the “pedostratigraphic level” concept. Quaternary International 175 (1), 125–139.

Cwynar, L.E., Burden, E., McAndrews, J.H., 1979. An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. Canadian Journal of Earth Sciences 16 (5), 1115–1120.

FAO, 2006. Guidelines for Soil Description. FAO, Rome.

Faustova, M.A., Velichko, A.A., 1992. Dynamics of the last glaciation in northern Eurasia. Sveriges Geologiska Undersokning Series Ca 81, 113–118.

Geyh, M.A., 2001. Reflection on the ^{230}Th/U dating of the dirty material. Geochronometria 20, 9–14.

Geyh, M.A., Müller, H., 2005. Numerical ^{230}Th/U dating and palynological review of the Holsteinian/Hoxnian Interglacial. Quaternary Science Reviews 24, 1861–1872.

Glushankova, N.I., 2008. Paleopedogenesis and the Natural Environment of Eastern Europe in the Pleistocene. Madzhenta Publishing House, Moscow–Smolensk, 348 p. (in Russian).

Gorlova, R.N., 1972. Some results of recent studies of interglacial deposits of the Rostov District of Yaroslavl Region. In: Marginal Formations Glacial Glaciations. Nauka Publishing House, Moscow.

Grichuk, V.P., 1982. Vegetation of Europe during Late Pleistocene. In: Gerasimov, I.P., Velichko, A.A. (Eds.), Paleogeography of Europe During the Last 100 000 Years. Nauka Publishing House, Moscow, pp. 92–109 (in Russian).

Grichuk, V.P., 1989. History of Flora and Vegetation of the Russian Plain During the Pleistocene. Nauka Publishing House, Moscow, p. 182 (in Russian).

Grichuk, V.P., Zaklinskaya, E.D., 1948. The Analysis of Fossil Pollen and Spore and Using These Data in the Paleogeography. Geographis Publishing House, Moscow, p. 240 (in Russian).

Grichuk, V.P., Gubonina, Z.P., Zelikson, E.M., Monoszon, M. Kh, 1973. Interglacial deposits in the Rostov-Yaroslavl district. In: Palynology of the Pleistocene and Pliocene. Nauka Publishing House, Moscow, pp. 188–203 (in Russian).

Grimm, E.C., 1993. TILIA 2.0 Version b.4 (Computer Software). Illinois State Museum, Research and Collections Center, Springfield.

Grimm, E.C., 2004. TGView. Illinois State Museum, Research and Collections Center, Springfield.

Gugalinskaya, L.A., 1982. Soil Formation and Cryogenesis in the Center of the Russian Plain in the Late Pleistocene. ONTI Ntsbi AN SSSR, Pushchino, 204 p. (in Russian).

Gugalinskaya, L.A., Ivannikova, Alifanov, V.M., Antoshechkina, N.A., 2001. Pedocyclites in Gray Forest and buried Bryansk soils of the Vladimir Opol'e and biological methods of their diagnostics. Eurasian Soil Science 34 (10), 1031–1042.

Haase, G., 1963. Stand und Probleme der Lösserforshung in Europa. Geographishe Berichte H 27, 97–129.

Haesaerts, P., Van Viet-Lanoë, B., 1981. Phénoménes périglaciaires et soil ossiles observes Maisiéres-Canal, a Harmignies et a Rocourt. Biultyn. peryglacalny 28, 291–324.

IUSS Working Group WRB, 2006. World Reference Base for Soil Resources 2006. A Framework for International Classification, Correlation and Communication, second ed. FAO, Rome. World Soil Resources Reports No. 103.

Jersak, J., 1973. Litologia i stratygraphia lessu Wyzun Poludniowej Polski. Lod_z. Acta Geographica Lodziensia 32, 143 (in Polish).

Kachinskiy, N.A., 1965. Physics of Soils. Part 1. Higher School Publishing House, Moscow, 323 p. (in Russian).

Kaurichev, I.S. (Ed.), 1986. Practical Work on Soil Science. Agropromisdat Publishing House, Moscow, p. 336 (in Russian).

Kovda, I.V. (Ed.), 2013. XIIth International Symposium and Field Seminar on Paleopedology. Paleosols, Pedosediments and Landscape Morphology as Archives of Environmental Evolution. 10–15 August, 2013, Kursk, Russia, p. 109.

Krasilnikov, P., García Calderón, N.E., 2006. A WRB-based buried paleosol classification. Quaternary International 156/157, 176–188.

Kupriyanova, L.A., Alyoshina, L.A., 1972. Pollen and Spores of Plants from the Flora of European Part of USSR, vol. 1. Acad. Sci. USSR, Komarov. Bot. Inst., Leningrad, 170 p. (in Russian).

Kupriyanova, L.A., Alyoshina, L.A., 1978. Pollen and Spores of Plants from the Flora of European Part of USSR. Acad. Sci. USSR, Komarov. Bot. Inst., Leningrad, 184 p. (in Russian).

Kuznetsov, V.Yu., Maksimov, F.E., 2003. New approach to geochronology of interglacial sediments of the Russian Plain based on the U–Th dating of buried peat. Doklady Earth Science 393 (8), 1132–1135 (in Russian).

Kuznetsov, V., Maksimov, F., 2012. Methods of Quaternary Geochronometry in Palaeogeography and Marine Geology. Nauka Publishing House, St. Petersburg, p. 191 (in Russian).

Lavrushin, Yu.A., Chistyakova, I.A. (Eds.), 2001. Problems of Stratigraphy of Quaternary Deposits and Paleogeography of the Yaroslavl Region. Materials of the Symposium. Yaroslavl., July 2001. GEOS Publishing House, Moscow, p. 158 (in Russian).

Lieberoth, J., 1964. Einige Bemerkungen zu paleopedologischen Problemen beider Gliederung der lösse. Berichte der Geologishen Gesellschaft in der DDR, pp. 689–695, 9 H.6.

Mack, G.H., James, W.C., Monger, H.C., 1993. Classification of paleosols. Geological Society of America Bulletin 105, 129–136.

Maksimov, F.E., Kuznetsov, V.Yu, 2010. New version of the ^{230}Th/U dating of the Upper and Middle Pleistocene buried organic-rich sediments. Bulletin of St. Petersburg State University Series 7 (3), 103–114 (In Russian).

Maksimov, F., Arslanov, Kh., Kuznetsov, V., Chernov, S., 2006. ^{230}Th/U and ^{14}C dating of Upper and Middle Pleistocene Interglacial and Interstadial organic deposits from the East- European Plain and Siberia. In: Frechen, M. (Ed.), Pleistocene Environments in Eurasia Chronology, Paleoclimate and Teleconnection. INTAS Final Workshop. Hannover, Geozentrum, 2–3 November, pp. 45–49.

Maksimov, F.E., Laukhin, S.A., Arslanov, Kh.A., Kuznetsov, V.Yu., Shilova, G.N., 2012. First ^{230}Th/U date of Middle Pleistocene peat bog in Siberia (key section Krivosheino,Western Siberia). Geochronometria 39 (4), 241–251.

Markov, K.K. (Ed.), 1977. Strata of the Glacial Deposits of the Russian Plain. Moscow State University Publishing House, p. 235 (In Russian).

Markova, A.K., Simakova, A.N., Puzachenko, A. Yu, 2002. Environments of the Russian Plain during the Middle Valdai Briansk Interstade (33,000–24,000 BP) indicated by the fossilmammals and plants. Quaternary Research 57, 391–400.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis. Blackwell Scientific Publications, Oxford, 216 p.

Morozova, T.D., 1981. Evolution of the Soil Cover of Europe in the Late Pleistocene. Nauka Publishing House, Moscow, 281 p. (in Russian).

Morozova, T.D., Nechaev, V.P., 2002. The Valdai periglacial zone of the East European Plain as a district of ancient cold pedogenesis. In: Routes of Evolutionary Geography (Summaryand Prospects). Geography Institute Publishing House, Moscow, pp. 93–106.

Moskvitin, A.I., 1967. Pleistocene Stratigraphy of the European Part of the USSR, 156. Trudy GIN AN. Nauka Publishing House, Moscow, 238 p. (in Russian).

Nettleton, W.D., Olson, C.G., Wysocki, D.A., 2000. Paleosols classification: problems and solutions. Catena 41, 61–92.

Novenko, E.Y., Velichko, A.A., Suganova, I.S., Junge, F.W., Boettger, T., 2005. Dynamics of vegetation at the Late Pleistocene Glacial/Interglacial transition (new data from the Center of the East European Plain). Polish Geological Institute Special Papers 16, 77–82.

Novskiy, V.A., 1968. The Genetic Types of Pleistocene Moraines on the Russian Plain. Ocherki po istorii geologo-geograficheskikh znanij. Yaroslavl, pp. 155–164 (in Russian).

Novskiy, V.A., 1971. The Upper Pleistocene of Yaroslavl Region, 87. Uchenyue sapiski YaGPI, Yaroslavl, pp. 3–48 (in Russian).

Novskiy, V.A., 1975. Pleistocene of Yaroslavl Region. Nauka Publishing House, Moscow, 220 p. (in Russian).

Paepe, R., 1966. Comparative stratigraphy of Würm loess deposits in Belgium and Austria. Bulletin Societe Belge geologie, paleontologie, et hydrologie 75, 203–216.

Rusakov, A.V., Korkka, M.A., 2004. The Bryansk fossil soil of the extraglacial zone of the Valdai glaciation as an indicator of landscape and soil forming processes in the center ofthe Russian plain. Revista Mexicana de Ciencias Geologias 21, 94–100.

Rusakov, A., Sedov, S., 2012. Late Quaternary pedogenesis in periglacial zone of northeastern Europe near ice margins since MIS 3: timing, processes, linkages to the landscape evolution. Quaternary International 265, 126–141.

Rusakov, A.V., Korkka, M.A., Kerzum, P.P., Simakova, A.N., 2007. Paleosols in the moraine- mantle loam sequence of northeastern Europe: the memory of pedogenesis rates andevolution of the environment during OIS3. Catena 71, 456–466.

Ruske, R., Wünshe, M., 1968. On the classification of Late Pleistocene loess deposits in the Southeastern and Eastern Foreland of the Hartz Mountains. Geologie Jahrgang 17, 288–297.

Sedov, S.N., Khokhlova, O.S., Sinitsyn, A.A., Korkka, M.A., Rusakov, A.V., Ortega, B., Solleiro, E., Rozanova, M.S., Kuznetsova, A.M., Kazdym, A.A., 2010. Late Pleistocene paleosol sequences as an instrument for the local paleographic reconstruction of the Kostenki 14 key section (Voronezh Oblast) as an example. Eurasian Soil Science 43, 876–892.

Semmel, A., 1989. Paleopedology and geomorphology: examples from the Western Part of Central Europe. In: Bronger, A., Catt, J.A. (Eds.), Paleopedology: Nature and Application of Paleosols Catena Suppl, vol. 16. Catena Verlag, Cremlingen-Destedt, Germany, p. 143e162.

Seppala, M., 1971. Stratigraphy and material of the loess layers at Mende, Hungary. Bulletin of the Geological Society of Finland 43 (1), 10–123.

Serebryannyi, L.R., Chebotareva, N.S., 1963. Some discussion questions on paleogeography and stratigraphy of Quaternary deposits of the Northwest and Centre of the East. In: Anthropogen of the Russian Plain and its Stratigraphic Components. Russian Academy of Sciences Publishing House, Moscow, pp. 74–85 (in Russian).

Shackleton, N., Berger, A., Peltier, W.R., 1991. An alternative astronomical calibration of the Lower Pleistocene timescale based on ODP Site 677. Transactions Royal Society of Edinburgh 81, 252–261.

Shik, S.M., 2010. On the limits of the distribution of glaciers in the central part of European Russia. Bulletin 1 Komissii po izucheniju chenvertichnogo perioda 70, 100–107 (in Russian).

Shishov, L.L., Komov, N.V., Rodin, A.S., 2001. Soil Cover and Land Resources of the Russian Federation. Moscow, p. 400 (in Russian).

Sudakova, N.G., 1974. The Key Section of Cheremoshnik Ravine. Inzenerno-geologicheskoe izuchenie moren. Yaroslavl, pp. 35–43 (in Russian).

Sudakova, N.G., 2012. Actual discussion questions of glacial events in the Centre of the East European plain. Bulletin 1 Komissii po izucheniju chenvertichnogo perioda 72, 60–72 (in Russian).

Sudakova, N.G., Dashevsky, V.V., Pisareva, V.V., Chebotareva, N.S., Shik, S.M., 1984. Quaternary deposits near the town of Rostov-Yaroslavsky. In: 27th International Geological Congress. Excursion 10-B. Guidebook. Moscow, p. 26.

Sukachev, V.N., 1954. On the joint finding remnants of dwarf (Arctic) birch and water shield in the interglacial sediments. Doklady of the Russian Academy of Sciences 94 (3) (in Russian).

Sukachev, V.N., Nedoseeva, A.K., 1954. About plant cover change during Risss-Wűrmian Interglacial. Doklady of the Russian Academy of Sciences 94 (3) (in Russian).

Sycheva, S.A., 2003. Evolution of Buried Balka Landscapes in the Forest-steppe Zone of the Russian Plain, vol. 1. Izvestiya Rossiyskoy Akademii Nauk, Serya Geographiya, pp. 113–123 (in Russian).

Targulian, V.O., Goryachkin, S.V., 2004. Soil memory: types of record, carriers, hierarchy and diversity. Revista Mexicana de Ciencias Geológias 21, 1–9.

Targulian, V.O., Goryachkin, S.V. (Eds.), 2008. Soil Memory: Soil as a Memory of Biosphere–Geosphere–Anthroposphere Interactions. LKI Publishers, Moscow, p. 692 (in Russian).

Tjuremnov, S.N., Vinogradova, E.A., 1952. Interglacial deposits near Rostov Yaroslavsky. Uchenye zapiski Yaroslavskogo pedegogicheskogo universisteta 14 (24) (in Russian).

Velichko, A.A. (Ed.), 2002. Dynamics of Terrestrial Landscape Components and Inner Marine Basins of Northern Eurasia during the Last 130 000 Years. GEOS-Press, Moscow, p. 232 (in Russian).

Velichko, A.A., Morozova, T.D., 1972. The Bryansk Paleosol, its Stratigraphic Meaning, and the environmental conditions. In: Loess, Buried Soils, and Cryogenic Phenomena on the Russian Plain. Nauka Publishing House, Moscow, pp. 44–54 (in Russian).

Velichko, A.A., Morozova, T.D., 1982. Soil cover of the Mikulino interglacial and the Bryansk interval. In: Gerasimov, I.P., Velichko, A.A. (Eds.), Paleogeography of Europe during the last 100 000 years. Nauka Publisher House, Moscow, pp. 81–92 (in Russian).

Velichko, A.A., Starkel, L. (Eds.), 1994. Paleogeographical Basis of the Modern Landscapes. Results of the Russian-polish Research. Nauka Publishing House, Moscow, p. 205 (in Russian).

Velichko, A.A., Morozova, T.D., Nechaev, V.P., 2000. The Bogolyubovo Section. Loess-soil-cryogenic Formation of the Vladimir Opolye. Paleosols and Modern Soils as Stages of Continuous Soil Formation. Abstracts and Field Excursion Guidebook of V International Symposium on Paleopedology, Suzdal, July 10–16, 2000, pp. 48–56.

Velichko, A.A., Morozova, T.D., Panin, P.G., 2007. Polygenetic soil complexes as systematic phenomena of Pleistocene macrocycles. Izvestiya Rossiiskoy Akademii Nauk, Serya Geography 2, 113–123 (in Russian).

Voskresenskaya, E.V., Korkka, M.A., Otcherednoy, A.K., 2013. Comparison of Middle Valdaim Interstadial weak-developed paleosol at the sites Khotylevo I and Kostenki 14. In: Materials of the XIIth International Symposium and Field Workshop on Paleopedology (ISFWP) Paleosols, Pedosediments and Landscape Morphology as Environmental Archives. Kursk, Russia, August 10–15, 2013, p. 47.

Zöller, L., Löscher, M., 1997. The last glacial-interglacial cycle in the loess section at Nussloch and underlying upper Tertiary loams. In: Internal Working Meeting of ISSS-Commission V and INQUA-Commission on Palaeopedology, Sept. 22–Sept. 28, Germany, pp. 3–11.