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GENESIS AND GEOGRAPHY OF SOILS

Contrasting Variants of Soil Development at Archaeological Sites on Floodplains in the Forest-Steppe of the Central Russian Upland

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Abstract—The soils of archaeological sites on river floodplains with contrasting history of the Holocene soil evolution in the south and north of the forest-steppe zone on the Central Russian Upland have been studied. The conditions for the meadow-chernozemic soil development on the high floodplain in the lower course of the Savala River (Voronezh oblast) were most favorable in the Early Holocene (10.3–9 ka BP); 9 ka BP, the soil humus profile was two times deeper than it is today. The most intensive alluvial sedimentation (0.5 mm/yr) was typical of the Late Pleistocene and Early Holocene (11–8.3 ka BP), while in the Middle and Late Holocene, the rate of the upward growth of soils decreased to 0.05 mm/yr. The underdevelopment of modern chernozemic-meadow soil profiles suggests an alternation of accumulation and denudation (including deflation) of fine-earth particles on the soil surface in the Late Holocene. On the floodplain in the upper course of the Oka River (Orel oblast), the development of a monogenetic profile of medium-deep leached chernozems with the humus content of more than 7% and humus stocks in the upper meter of at least 450 t/ha took place in the Holocene. Before the beginning of the second millennium AD, the alluvium sedimentation rate was no more than 0.02 mm/yr; in the recent millennium, it has increased up to 1 mm/yr. The specificity of changes in the bioclimatic conditions and spatiotemporal specificity of anthropogenic disturbances of the natural environment caused the metachronous Holocene evolution of floodplain soils in the studied regions. The importance of radiocarbon dating of organic matter of uneven-aged soils for paleopedological and paleogeographic reconstructions is shown.

Keywords: Central Russian Upland, river floodplains, archaeological sites, synlithogenic soils, paleosols, natural and anthropogenic evolution of soils, Chernozems, Phaeozems

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INTRODUCTION

The study of archaeological sites by specialists in human and natural sciences has a long history. Soil scientists have been studying these objects since the very beginning of modern pedology [14, 41]. Such studies have been developed by many scientists and research groups [6, 9–13, 15, 26, 33]. Nowadays, pedoarchaeological studies continue to evolve and expand [28]. The main object of these studies is a soil profile preserved under the cultural layers of different historical periods or developed from the artificial parent material of different ages. For many decades, interdisciplinary studies of archaeological sites on the Central Russian Upland have been performed by historians, pedologists, geographers, geologists, and biologists [1, 8, 9, 20, 21, 29–34, 39]. In these studies, there is certain territorial division between the areas of automorphic pedogenesis, which is studied in chronosequences of background soils and soils buried under artificial earthworks (mounds, fortification ramparts, etc.) of different ages [1, 3, 9, 20, 32], and the areas of pedogenesis on river floodplains, where the studied soils are associated with the cultural layers of settlements of different archaeological cultures [2, 4–6, 21, 23–27, 29].

This article continues the discussion of issues related to the study of the second group of soils and archaeological sites located on floodplains. Every new study object is of great importance, as it enriches the database in this specific area of research localized in limited areas of geographic space. At the same time, many issues of the Holocene development of soils on floodplains remain controversial, which prompts research at new sites and in new regions.

The authors note the specificity of the development of floodplain soils for several reasons. Floodplains have complex structure and are characterized by spatial heterogeneity: there are areas of recent and ancient sedimentation, with different numbers of buried soils, with different degrees of maturity of soil profiles, and with different contribution of redox processes to soil formation [2, 4, 6, 24]. Because of this heterogeneity, the Holocene alluvial sediments on the surface of low and high floodplains have different thicknesses. This leads to different information capacities of paleopedological records and to local specificities of the Holocene development of vegetation and soils on different floodplain levels in various geographical regions [15, 19, 24]. When considering soil development in river valleys over time, differences in the environmental factors between river floodplains and drained watershed areas are clearly seen. In the forest-steppe and steppe, frosts are more frequent and frostless periods are shorter in depressions of the erosional network. On the floodplains, soil cooling and the appearance of fogs are more frequent than those on the interfluves, and the snow melts slower. The authors suggest that these factors could affect the specificity of the Holocene evolution of soils in river valleys and on floodplains, in particular [19].

The results of pedoarchaeological studies on floodplains indicate that development of paleosols buried in the thickness of soil-geological strata takes place owing to a decrease in the intensity of alluvial sedimentation, which is linked to the low water level of rivers and to the relatively dry climatic conditions during these periods [2, 4, 5, 15, 26]. According to the study of soil evolution on floodplains from the taiga to the steppe zones in the center of eastern Europe, the following periods with the warmest and driest conditions were established for the Holocene: Early Atlantic (7200–6600 BP), Late Atlantic (5600–4700 BP), Subboreal (3900–3000 BP), and Subatlantic (2300–1000 BP). During these periods with a reduced intensity of alluvial sedimentation, soils and cultural layers were formed [26]. The periods of intensive alluvial sedimentation (with maximums in 10500, 8000, 6500, 4500, 2500, and 500 BP) causing the burial of the floodplain soils coincide with the periods of climate cooling, when winter precipitation and spring runoff increased and led to intensification of soil erosion [2]. In the past millennium and, particularly, in the 17th–18th centuries AD, the process of alluvial sedimentation on the floodplains could be determined by both natural (climatically conditioned) and anthropogenic (deforestation, plowing) factors [5, 24, 25].

In this study, we continue the analysis of the historical stages of the Holocene pedogenesis and landscape evolution on floodplains in the center of the East European Plain, for which contrasting temporal development of soils and alluvial sedimentation in the Holocene has been typical.

OBJECTS AND METHODS

Pedoarchaeological research was carried out at two sites: the Mesolithic Kamenka 1 site on the Savala River floodplain in Novokhopersk district of Voronezh oblast (archaeological expedition of the Voronezh State Pedagogical University under the supervision of I.V. Fedyunin), and the Russian Medieval settlement Pleshcheevo 2 on the Oka River floodplain in Orel district of Orel oblast during salvage excavations in the zone of the oil pipeline reconstruction (archaeological excavations with the participation of specialists from the Argamach Archeological Park under the supervision of A.A. Inshakov). According to archaeological dating, the Pleshcheevo 2 settlement functioned in the 14th–15th centuries. These objects were chosen with due account for the contrasting patterns of soil development in the Holocene under the impact of temporal changes in the natural and anthropogenic factors of soil formation, including different rates of alluvial sedimentation.

The Kamenka 1 archaeological site is located in the northeast of the Kalach Upland belonging to the southern part of the Central Russian Upland [22]. The study area is in the transitional zone between forest-steppe and steppe. The monument is a Mesolithic site located on a crescent old natural levee of the high floodplain of Savala River, about 3 km west from its confluence with the Khoper River.

The study area was 4.5–5 m above the water level. The parent rocks at the archaeological site were alluvial sands and sandy loams. An oxbow depression, which marked the position of the former river bed, was found 60 m south from the top of the natural levee (a diagram of the study area and its surroundings is shown in Fig. 1a). Paleopedological and paleogeographic reconstructions for this site were made on the basis of the analysis of individual soil profiles and the spatial variation in soil properties along the catena from the top of the old natural levee at the excavation site to the oxbow depression (Fig. 2). The total length of the catena was 70 m, and the amplitude of heights (pit 1 vs pit 6) was 2 m.

The distance between pits 1–5 was 6–12 m; the distance between pits 5 and 6 was 37 m.

The vegetation cover in the studied area was represented by herbs. In the oxbow depressions, sedges with an admixture of cattail and patches of willow trees and dense shrub layer were developed. The floodplain vegetation was also characterized by patches of sparse woodlands consisting of English oak and European elm.

The cultural layer was spatially distinct, which made it possible to identify the stratigraphic position of the former soil surface, on which the Mesolithic settlement was constructed [30]. A layer at a depth of 35–55 cm had the maximum concentration of the finds of stone tools. This depth corresponded to the lower part of the profile of modern chernozemic-meadow soils (Haplic Phaeozems (Arenic) [38]) developed at the archaeological site. The soils had a sandy loam texture from the depth of 10 cm, and a sandy texture from the depth of 20 cm. This site dates back to the second half of the Boreal period (8800–8000 BP) according to its archaeological dating [30].

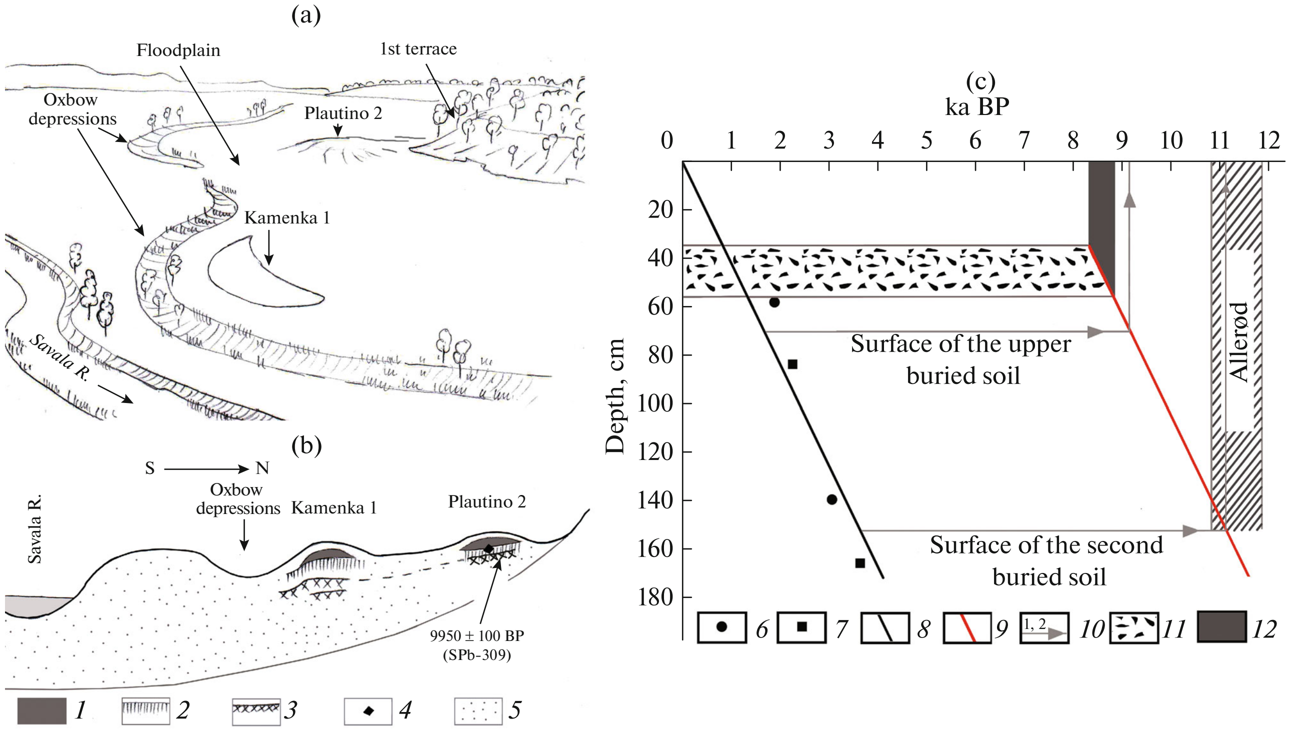


Fig. 1. (a) Schematic map of the Kamenka 1 site and its immediate surroundings, (b) cross section of the Savala River floodplain and the location of Kamenka 1 and Plautino 2 sites, and (c) reconstruction of the radiocarbon age of humus (BP) in paleosols at the final stage of the Mesolithic cultural layer formation. Designations to part (b): (*1*) Mesolithic cultural layer, (*2*) Early Holocene paleosols, (*3*) Late Pleistocene (Allerød) paleosols, (*4*) place of sampling of an ungulate mammal teeth used for radiocarbon dating, and (*5*) floodplain alluvium facies. Designations to part (c): (*6*) depth of the upper layer of paleosol and radiocarbon dates of its humus in pit 1, (*7*) the same for pit 3, (*8*) trend line of changes in the radiocarbon age of soil humus with depth according to the averaged data on pits 1 and 3, (*9*) reconstructed trend line of changes in the radiocarbon age of soil humus with depth relative the end of the Mesolithic cultural layer development (8300 BP), (*10*) average depth of the upper layer of the buried paleosol in pits 1 and 3 (horizontal arrow) and the reconstructed time of its burial (vertical arrow), (*11*) average depth of the Mesolithic layer with stone tools in pits 1 and 3, and (*12*) reconstructed time of functioning of the Mesolithic site.

The paleopedological and paleogeographic reconstructions for the Kamenka 1 site were partly based on the results of the study of the neighboring Plautino 2 site (Fig. 1a) located on promontory rise of the Salva River floodplain (probably, also an ancient natural levee) near its contact with the first terrace. The elevation above the water level was 5.5–6 m. The parent rocks were alluvial sands and sandy loams. The age of archaeological finds regularly increased with the depth, which could be due the alternation of alluvial sedimentation and the formation of cultural layers in periods of the decrease in the intensity of alluviation; the cultural layers corresponded to the final Paleolithic, Mesolithic, Neolithic, and Bronze ages [31]. The area of the archaeological site was characterized by a lower rate of alluvial sedimentation because of its location further from the river in comparison with the floodplain area closer to the river (Fig. 1b). Therefore, at the Plautino 2 site, the stratigraphic column of sediments enclosing the cultural layers of different epochs was compressed: artifacts of the Bronze and Neolithic were recorded in the layer of 20–40 cm; and the Mesolithic and final Paleolithic artifacts, in the layer of 40–100 cm [31]. A similar pattern of buried soils and cultural layers was observed on the low and high floodplains of the Utyaganka River (Arkaim natural reserve): the thickness of the Holocene deposits on the high floodplain did not exceed 1.4 m [19], while on the low floodplain it was 4–5 m [15]. In the alluvium underlying the Mesolithic cultural layer at the Plautino 2 site, bone remains of an ungulate mammal were found; the teeth dated back to the beginning of the Holocene (9950 ± 100 BP) (SPb 309) (Fig. 1b). Another important observation was the identification of humified loamy sand layer in the Mesolithic layer, in which a noticeable admixture of clay particles appeared below the cultural layer (in field descriptions, this layer was referred to as humified clayey loamy sand). Above the Mesolithic layer, the degree of humus coloration of the pedogeological strata decreased and then increased again towards the surface of the modern soil [30, 31]. Therefore, the Mesolithic cultural layer was probably formed in the upper part of the Early Holocene paleosol or, most likely, within the complex paleosol profile of the Early Holocene and Late Glacial (Allerød) periods. Palynologi-

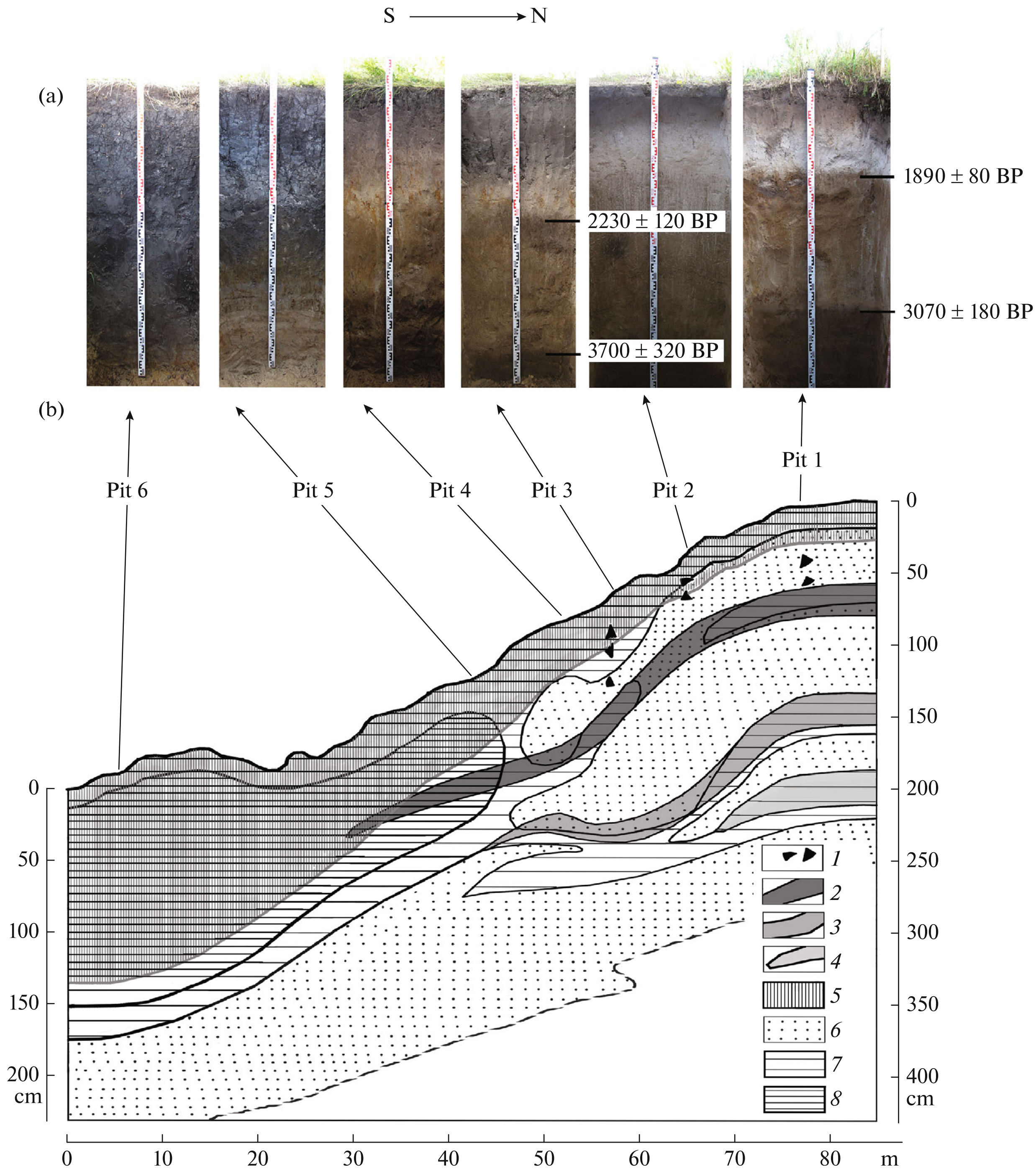


Fig. 2. (a) Photos of the front walls of soil pits along the studied catena at the Kamenka 1 site with the radiocarbon dates (uncalibrated) of humus in the upper layers (0–5 cm) of two buried paleosols in pits 1 and 3 and (b) hypsometric profile of the catena with its characteristics: (*1*) finds of the Mesolithic stone tools, (*2*) depth of the humus horizon of the upper buried paleosol, (*3*) depth of the humus horizon of the middle buried paleosol, (*4*) depth of the humus horizon of the lower buried paleosol, (*5*) humus profile of the modern soils (humus (A1) and transitional (A1B, BA1) horizons), (*6*) sand and loamy sand, (*7*) loam, and (*8*) clay (according to morphological descriptions of six soil pits supplemented with by borehole data).

cal studies (performed by T.F. Tregub) of the layer underlying humified clayey loamy sand (buried soil) and light yellow sand (parent rock of the paleosol) revealed the presence of pollen grains of spruce, pine, and birch trees and some Arctic species of herbs (*Polemonium acutiflorum*, *Artemisia tilesii*). Considering the results presented above, the authors indicated that the layer of light yellow sand was formed 17–12 ka BP, i.e., when the study area was characterized by the hyperzonal vegetation of the periglacial zone [31].

Unfortunately, there is no detailed description of the paleosol profile at the Plautino 2 site, because pedologists did not participate in the excavations.

The second object of pedoarchaeological research was the medieval Russian settlement Pleshcheevo 2 on the high floodplain of the Oka River about 300 m north of the outskirts of the Pleshcheevo village, not far from the suburban area of the town of Orel. This site was found in the forest-steppe zone near its northern boundary with the zone of deciduous forests. Excavations were carried out on a flat surface of the high floodplain of the Oka River and its left-side tributary—the Mezenka River (their junction was 300 m north of the excavation site). Modern soils were formed from layered silty carbonate-free alluvial loams about 1 m thick. This loamy layer was underlain by the dark-colored buried soils developed from loess-like loams of 2–2.5 m in total thickness. In turn, the loamy layer was underlain by ancient alluvial layered sands. The elevation of the research site above the water level in the Oka River was 6.5–7 m. At the excavation site, the surface of the high floodplain was covered by grassy–form vegetation with an admixture of weed species; the floodplain meadow was used for pasturing and haymaking.

The cultural layer of the medieval Russian settlement coincides stratigraphically with the upper part of the buried dark-colored soils and contains fragments of pottery; it has small depressions in places of former houses and household buildings. The cultural layer includes not only archaeological artifacts but also the organomineral matter from the upper part of the underlying dark-colored paleosol.

At his site, pit 1 characterized the stratigraphy of sediments and paleosols typical of the high floodplain and the buried paleosol catena at the former transition from the high to the low floodplain. Pit 2 was dug at the beginning of a gentle slope; pit 3, in the middle part of the slope; and pit 4, in the lower part of the slope available for the analysis in the archeological excavation. The distances between the pits were 5–6 m. The upper point of the paleosol catena was 1.8 m higher than its lower point, and the length of the studied slope section was 11 m. Additionally, in pit 5 located in 10 m from pit 4, the soil from the bottom of the paleohollow (2.3 m below the surface of the paleosol excavated in pit 4) was studied.

The following field and laboratory methods were applied in our pedoarcheological investigation: comparative-geographical, morphological analysis of soil profiles; catenary study; archaeological dating of artifacts; radiocarbon dating of charcoal, bones, and organic matter (humus) of soils; and laboratory analysis of soil chemical properties. The radiocarbon dating was performed in the Radiocarbon Laboratory of the Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine (Kiev, Ukraine) using the method of liquid scintillation counting (LSC) [43]. The ^{14}C isotope content was measured on a Quantulys1220 T spectrometer. Radiocarbon dates were calibrated by A.V. Dolgikh (Institute of Geography, Russian Academy of Sciences) using the OxCal v4.2.4 software [37] based on the IntCal 13 calibration curve [42]. Other analyses of soil samples were performed in the laboratories of the Belgorod National Research University and the Belgorod Center for Agrochemical Service. The pH of was soil water suspensions was determined by potentiometry (GOST (State Standard) 26423-85); the total humus content, by Tyurin's (wet combustion) method (GOST 26213-91); and the particle-size distribution, by the pipette method according to Kachinskii (GOST 12536).

We also used palynological data on the Mesolithic cultural layer obtained by T.F. Tregub and reported in the work by Fedyunin [30]. They were of great importance for the paleosol reconstructions for the Kamenka 1 site.

RESULTS AND DISCUSSION

In the autonomous position of the upper part of the studied catena at the Kamenka 1 site (pits 1 and 2), carbonate-free thin sandy loamy chernozemic-meadow soils (Haplic Phaeozems (Arenic), [38]) with signs of surface gleying were formed; the depth of the humus profiles was 26–27 cm.

In the middle part of the catena (pits 3 and 4), carbonate-free loamy meadow-chernozemic soils with deep gley features (Gleyic Phaeozems (Pachic), [38]) were identified. Their humus profiles (the total thickness of A1 and A1B horizons) reached 38–40 cm and were noticeably thicker than in the soils developed in the autonomous position.

In the lower part of the slope and in the oxbow depression (pits 5 and 6), there are deeply gleyic clayey (clay loamy in the uppermost layers) meadow-chernozemic soils (Gleyic Phaeozems Vertic, [38]) with pronounced vertic features (dense consistence, large cracks, and clayey–humus slickensides) were formed; vertic features were more distinct towards the oxbow depression. According to the existing concepts, vertic features develop under the conditions of the contrasting soil water regime, increased hydromorphism, heavy texture, and specific mineralogical composition (the presence of minerals with shrink–swell processes) [10]. In our case, along with a favorable soil climate regime, the development of vertic features was probably due to the patterns of alluvial sedimentation, i.e., the deposition of finest fractions in the oxbow depression, as well as due to the high groundwater table in its immediate vicinity. The texture of the soil located in the lower part of the catena (pit 6) was significantly heavier in comparison with the soil in the autonomous landscape position (pit 1) (Table 1). The thickness of the humus profile naturally increased towards the lower part of the catena (Fig. 2) (the total depth of A1 and A1B horizons in pit 5 was 53–55 cm; and the depth of A1, A1Bg, and BA1g horizons in pit 6 was 140–146 cm).

The genesis of this soil sequence is related to the specificity of alluvial sedimentation and soil formation in different positions of the relief. Modern processes of humus accumulation are intensified in heteronomous relief positions, where the conditions for the soil organic matter accumulation are more favorable. In the same positions, the shallow depth of groundwater enhances soil waterlogging and gleyzation (gray-blue or mottled (from dove-colored to brownish red) color pattern) in the lower half of the soil profiles. An additional indicator of seasonal waterlogging is the abundance of iron–manganic concentrations and nodules.

In pits 1–5 of the studied catena, buried soils were encountered; their maximum number (3) was found in pit 1. The position of the humus horizons of buried soils along the catena (Fig. 2) reflected different stages of soil formation and surface development of the floodplain area near the former river channel.

The surface of the lower buried soil in pit 1 was at the depth of 190 cm. The soil was identified as an underdeveloped soddy surface-gley soil (Gleyic Fluvisol (Oxyaquic), [38]) with a brownish gray humus horizon to a depth of 20 cm, with blocky-prismatic structure and indistinct granularity, sandy clay loamy texture, and with alternating blue and grayish brown microzones of 0.5–1 cm in size and with abundant fine (1–1.5 mm) nodules and concentrations of Mn and Fe hydroxides.

The buried soil in the middle part of the profile (138–190 cm) was identified as a surface-gleyic meadow soil (Dystric Gleysol, [38]) with a 40-cm-thick humus profile.

The upper buried soil (57–138 cm) had the thickest humus profile among all soils in pit 1 (including the modern surface soil): the total thickness of the [A1] + [A1B] + [BA1] horizons reached 55–60 cm). The soil profile was noticeably disturbed by burrowing animals and contained many earthworm paths filled with gray humus material. According to the set of its properties, this soil was identified as a meadow-chernozemic soil without definite features of surface or ground gleyzation (Haplic Chernozem (Pachic), [38]).

In pit 1, two upper buried soils were clearly distinguished according to the vertical distribution of silt and clay and the local maxima in the organic carbon content (Table 1).

According to the morphological analysis, the evolutionary changes of three paleosols were characterized by a decrease in the degree of soil gleyzation and an increase in the depth of the humus profiles with time. The development of geological and geomorphological processes (lowering of the base of erosion, elevation of the surface due to alluvial sedimentation) and the changes in bioclimatic conditions over time could affect the observed changes.

The upper paleosol was overlain by a thick (30 cm) layer of light yellow sandy to loamy sandy alluvium, mostly without definite features of pedogenesis. The Mesolithic cultural layer (with the maximum content of artifacts at the depth of 35–55 cm) was formed in this stratum after the end of active alluviation. The material of this layer filled deep fissures crossing the upper buried soil and extending to the depth of 150 cm from its surface. Large fissures with the width of up to 5 cm in its upper part were especially clearly visible on the left wall of pit 1; the distance between fissures of different generations varied from 40 to 60 cm in horizontal direction. As the fissures were filled with light-colored sandy alluvial material, they were formed after the alluvial deposit itself.

As follows from the stratigraphy of sediments and buried soils in the automorphic part of the studied catena (pits 1–3), all buried soils were formed before the appearance of the Mesolithic cultural layer.

Earlier, we mentioned an increased humus content of the soil-geological stratum in the Mesolithic cultural layer and in the deeper layers at the Plautino 2 site near the Kamenka 1 site. This suggests the similar genesis of the dark-colored paleosols found under the Mesolithic cultural layers at both sites. The Plautino 2 site was found in the marginal zone of the floodplain, near its transition to the first terrace, while the Kamenka 1 site was located closer to the river; this difference was reflected in a greater thickness of alluvial sediments and clear separation of the three profiles of paleosols at the Kamenka 1 site, while at the Plautino 2 site, these paleosol profiles were superimposed on one another.

In our opinion, the paleosols of the Kamenka 1 and Plautino 2 sites were chronologically analogous to the paleosols with the Mesolithic cultural layer buried under sandy deposits in the valley of the Oskol River in the south of Belgorod oblast (burial time 8250 ± 100 BP (GIN-7153)) [17], as well as the older paleosols of the Belling and Allerød periods studied at the Divnogorie site [44].

Animal bone remains found in the cultural layer of the Kamenka 1 site had insufficient weight their radiocarbon dating, in contrast to the dating material from the Plautino 2 site. At the same time, the materials obtained in our study make it possible to narrow the wide range of archaeological dating (8800–8000 BP, or the second half of the Boreal period) at the Kamenka 1 site [30].

First, it is known that at the end of the Boreal period (8300–8000 BP), the "cold event" of the early Holocene took place. This was an ecologically unfavorable period, when the steppe zone with chernozems shifted far to the north [21]. The Mesolithic cultural layer in the valley of the Oskol River (Belgorod oblast) was covered by eolian sands, which proved the

Table 1. Characteristics of soils studied at the archaeological sites Kamenka 1 and Pleshcheevo 2

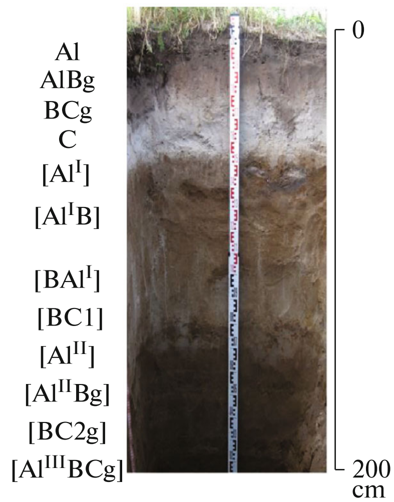
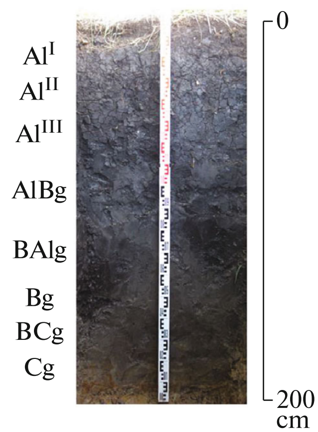
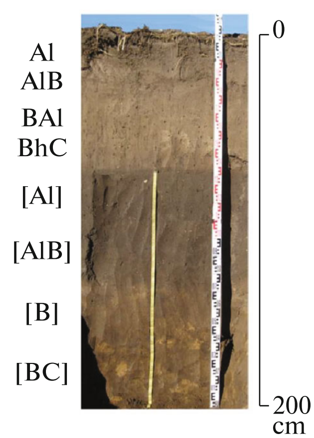
Layer, cm	C_{org}, %	pH H_2O	Particle-size fraction, %		Soil profile
			<0.001 mm	<0.01 mm	
Kamenka, pit 1					
0–10	1.66	6.68	17.4	27.8	
10–20	1.37	7.01	7.2	12.7	
20–30	0.87	7.90	5.4	7.0	
30–40	0.22	7.52	3.4	4.3	
40–57	0.07	7.19	3.7	6.2	
57–70	0.08	6.82	18.4	21.8	
70–80	0.16	6.79	14.6	16.8	
80–90	0.16	6.75	9.5	11.1	
90–100	0.15	6.79	7.8	8.9	
100–110	0.08	6.83	7.5	9.0	
110–120	0.06	6.79	4.5	6.2	
120–138	0.06	6.68	3.7	5.0	
138–150	0.09	6.75	16.1	23.4	
150–160	0.06	6.79	19.8	25.1	
160–170	0.04	6.64	10.5	11.5	
170–180	0.02	6.62	13.6	16.0	
180–190	0.04	6.56	15.8	19.1	
190–200	0.02	6.52	30.2	40.4	
Kamenka, pit 6					
0–10	5.13	6.58	36.1	55.7	
10–20	4.38	6.96	59.8	83.9	
20–30	3.46	7.20	57.9	82.6	
30–40	2.07	7.52	61.6	83.2	
40–50	1.61	7.30	64.0	96.2	
50–60	1.25	7.30	61.6	80.9	
60–70	1.01	8.06	62.6	81.9	
70–80	0.96	8.26	64.2	83.3	
80–90	0.86	7.29	60.7	79.7	
90–100	0.72	7.10	73.4	80.2	
100–120	0.77	6.98	61.0	79.1	
120–140	0.44	6.90	56.6	74.7	
140–160	0.40	7.07	47.7	63.0	
160–180	0.20	7.25	33.6	42.6	
180–200	0.02	7.20	10.7	11.2	
Pleshcheevo 2, pit 1					
0–20	2.17	7.68	25.5	34.4	
20–40	1.81	7.65	27.9	35.9	
40–60	1.36	7.80	25.4	34.6	
60–80	1.23	7.95	23.9	34.2	
80–95	1.54	7.95	25.5	43.4	
95–105 (0–10)	3.20	7.95	25.8	41.6	
105–115 (10–20)	2.76	7.93	26.5	41.0	
115–125 (20–30)	2.20	7.87	29.0	42.2	
125–135 (30–40)	1.93	7.85	30.6	43.1	
135–155 (40–60)	1.68	7.81	30.1	42.4	
155–175 (60–80)	1.47	7.80	30.9	42.3	
175–195 (80–100)	1.08	7.80	33.2	43.6	
195–215 (100–120)	0.33	7.85	30.3	39.5	
215–235 (120–140)	0.17	7.95	27.1	36.4	

Table 2. Radiocarbon dates of soil organic matter at the Kamenka 1 and Pleshcheevo 2 sites

Pit	Sample, depth, cm	Laboratory number	Radiocarbon (^{14}C) age		
			uncalibrated, BP*	calibrated, BP (2σ, 95.2%; cal BP)**	Mean and standard deviation (cal BP)
			Kamenka 1 site		
1	57–62	Ki-19517	1890 ± 80	2001–1617	1824 ± 97
	138–142	Ki-19518	3070 ± 180	3689–2797	3255 ± 220
	190–195	Ki-19519	2710 ± 250	3453–2180	2839 ± 314
3	80–85	Ki-19543	2230 ± 120	2697–1927	2242 ± 166
	162–166	Ki-19544	3700 ± 320	4964–3254	4107 ± 426
			Pleshcheevo 2 site		
	BA1, 50–52	Ki-19589	2510 ± 60	2748–2379	2582 ± 99
	BA1h, 80–82	Ki-19590	3810 ± 80	4420–3981	4209 ± 122
	[A1], 0–2	Ki-19554	1050 ± 60	1172–796	970 ± 73
	[A1B], 50–52	Ki-19552	3830 ± 60	4419–4013	4241 ± 98
	[B], 100–102	Ki-19591	6150 ± 150	7414–6676	7031 ± 177
2	[A1], 0–2	Ki-19558	1280 ± 60	1299–1067	1201 ± 66
3	[A1], 0–2	Ki-19553	1310 ± 40	1300–1178	1239 ± 40
4	[A1], 0–2	Ki-19555	1560 ± 50	1551–1350	1456 ± 55
5	[A1], 0–2	Ki-19587	1670 ± 60	1710–1414	1577 ± 80
	[A1B], 54–56	Ki-19592	2870 ± 90	2748–2379	2582 ± 99

* Radiocarbon dates are given in years before 1950 (BP).
** At two sigmas, the probability is 95.4%; calibrated dates are also given in years before 1950 (cal BP).

activation of dune movement and weak fixation of the surface of river terraces under pine forests by the vegetation cover [17]. Forest degradation occurred in river valleys, and all landscapes were characterized by the decline in the total biomass. During this time, many regions of the Earth experienced the deterioration of climatic conditions (cooling and aridization) [11, 40]. In our opinion, it was during this cold stage that deep frost fissures penetrated the Mesolithic cultural layer at the Kamenka 1 site and reached the deeper paleosol profile.

Second, according to the results of the palynological study, during the cultural layer formation at the Kamenka 1 site, the area adjacent to this site was covered by mixed forests with a significant amount of broadleaved species (*Quercus*, *Tilia*, *Acer*, *Ulmus*). In the areas free from forest vegetation, forb–grassy steppes were widespread, and leguminous herbs played a significant role in meadow communities [30]. Thus, this period was characterized by a relatively mild and humid climate. In the Boreal period, such climatic conditions could exist about 9000–8300 BP, when, according to the paleogeographic reconstruction by Spiridonova [21], forest-steppes predominated within a larger part of the Central Russian Upland, and forests were developed on the interfluves.

Consequently, the formation of the cultural layer at the Kamenka 1 site can be correlated with a high degree of probability with the chronointerval of 8800–8300 BP.

In pedoarchaeological studies, the age of monuments and cultural layers is often determined from data on the radiocarbon age of humus in the buried paleosols and of organic matter in cultural layers [8, 24, 35, 36]. At the Kamenka 1 site, the radiocarbon dating of humus from the buried paleosols was analyzed. The results showed a strong rejuvenation of the soil organic matter. An error in dating was excluded, because the sampling of the upper and middle-profile paleosols (samples taken from the topmost 2 cm of the soil profiles) was performed in two pits (pits 1 and 3), and the results which showed agreement between the results (Table 2).

The rejuvenation of humus could take place because of the openness of the studied system to the current soil formation processes, which resulted in the renewal of the carbon of soil organic matter even in the deep soil layers. In our opinion, this was facilitated by the coarse soil texture, which ensured better water and air movement in the entire soil profile.

The results obtained by other authors are consistent with this conclusion. Thus, the results of the radiocarbon dating of the chernozem under the kurgan of the Eneolithic period (5000 BP) in the Krasnodar region indicated that the humus of the upper part of the buried paleochernozem was younger than the kurgan itself. The reason was that this paleosol was not sufficiently isolated under the burial mound and mod-

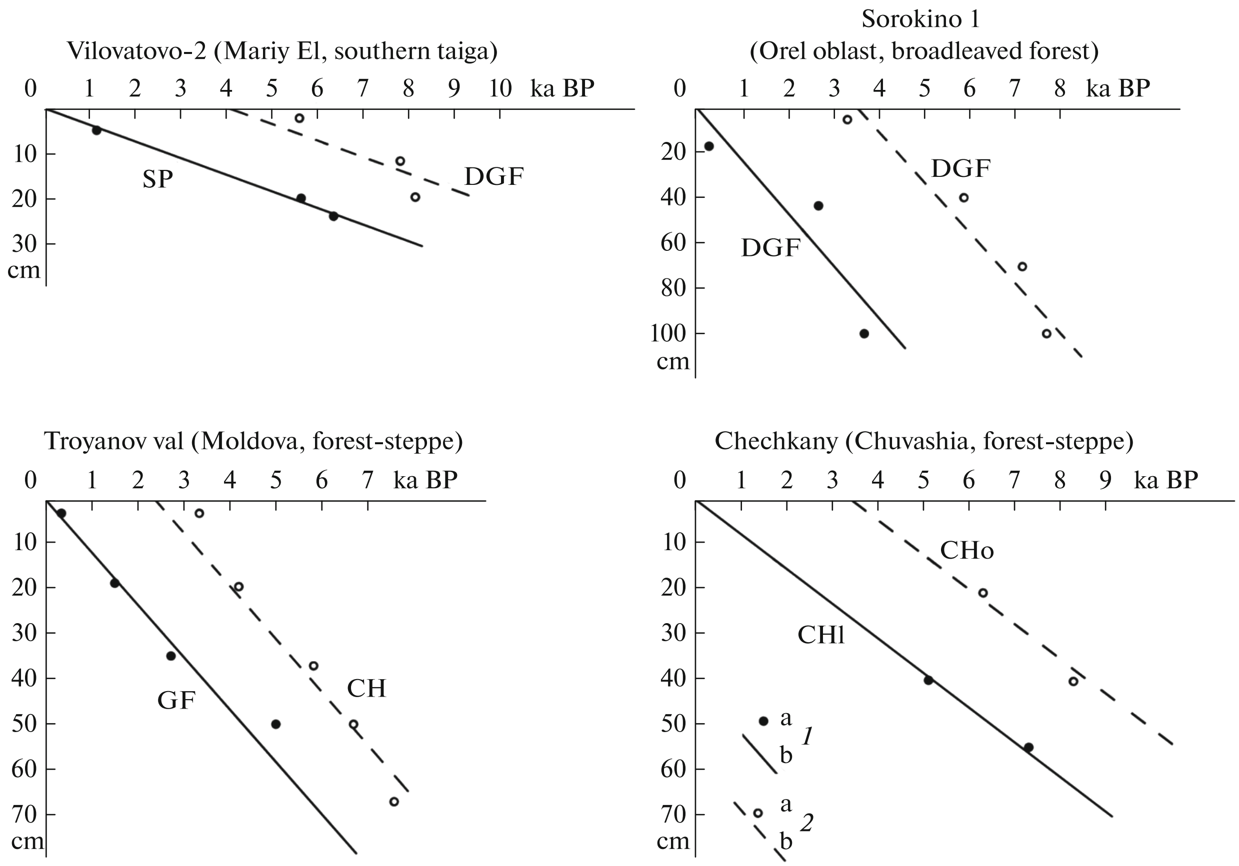


Fig. 3. Changes in the radiocarbon age of humic substances with depth in modern soils and in their analogues buried under earth mounds and cultural layers of archeological sites in different regions of eastern Europe: (*1*a) radiocarbon age of humic substances at different depths in modern soils, (*1*b) trend of changes in the radiocarbon age of humic substances with depth in modern soils; (*2*a and *2*b) the same for buried soils. Soils: SP—soddy-podzolic (Retisols), DGF—dark gray forest (subtype), GF—gray forest (type), CH—chernozem (type), CHl—leached chernozem (subtype), and CHo—ordinary chernozem (subtype). Data on the radiocarbon age of humic acids in soils at the Vilovatovo-2, Troyanov val, and Chechkany sites are taken from [3], and data on the radiocarbon age of humus in soils at the Sorokino 1 site are taken from [34].

ern processes of humus formation penetrated through the mound to a great depth and rejuvenated the humus in the [A1] and [A1B] horizons of the paleochernozem under the kurgan [8].

The phenomenon of humus rejuvenation in the Holocene soils is also confirmed by the results of comparative analysis of radiocarbon dates of humic substances in dependence on the sampling depth for the surface and buried soils in different regions and natural zones of the East European Plain (Fig. 3). The trend lines of these changes for the modern soils and buried paleosols are parallel. Hence, we can assume that the rates of humus rejuvenation in dependence on the depth are approximately the same in the surface soils and in the buried paleosols. This fact was used to reconstruct the age of the buried paleosols studied in pits 1 and 3 at the Kamenka 1 site.

According to our reconstruction, the end of the formation of the Mesolithic cultural layer (the upper boundary of the layer with the maximum concentration of finds) at the Kamenka 1 site dates back to 8300 BP. Figure 1c illustrates the reconstructed trend of the distribution of the radiocarbon age of humus with depth for this point in time (8300 BP).

According to the extrapolation, the second paleosol of meadow genesis could completed its development about 11000 BP, i.e., at the end of the Allerød period; and the upper buried soil (with the most prominent features of the meadow-chernozemic pedogenesis), about 9000 BP (Fig. 1c). In both cases, the disturbance of soil forming processes because of the intensification of floods and the covering of paleosols with new alluvial portions of alluvial sediments took place; the rate of sedimentation rate was higher than the rate of soil formation.

The meadow paleosol (second paleosol in pits 1–3), which, according to our reconstruction, was formed during the Allerød period, had prominent signs of gleying and, thus, developed under the conditions of high groundwater table. The analysis showed the proximity and even the inversion of the radiocarbon dates of humus in the upper layer of the second paleosol and in the deeper paleosol in pit 1 (at the depths of 138–142 and 190–195 cm, respectively) (Table 2). Therefore, we assume that during the Allerød period the organic matter of the paleosols was characterized by high mobility and could easily migrate to the underlying layers and rejuvenate the humus in the lower paleosols. The mobility of humus in that period could be due to the strong waterlogging of these soils.

The upper paleosol of the meadow-chernozemic pedogenesis studied in pits 1–3 had the most developed profile clearly differentiated into genetic horizons. This paleosol was formed in the sediment layer of 70–85 cm in thickness. The upper 60 cm of alluvial sediments were actively transformed by the soil formation, and the humus-accumulative profile of the meadow-chernozemic paleosol was formed within this stratum. The loamy texture of the upper soil horizons (Table 1) may indicate the processes of active subsurface weathering or the accumulation of fine alluvial fractions in the zone of low intensity of river floods. Zoogenic turbation of the soil material (by earthworms and mole rats) indicated the favorable conditions for the soil mesofauna at a relatively low groundwater table (because there were no gley features in this soil profile).

The question why the light yellow sandy to loamy sandy alluvial sediment containing the Mesolithic cultural layer was "sterile" from the signs of soil formation processes remains open. The climatic conditions of that time (9000–8300 BP) were favorable for the development of pedogenesis. One of the possible reasons for the geological homogeneity of the cultural layer and the absence of its pedogenic differentiation could be the anthropogenic mixing of the soil and regular disturbance of vegetation by ancient humans; it is probable that this area was a beach on the river bank.

The environmental history of this area in the Middle and Late Holocene could be controlled both climate changes and by changes in the hydrological regime of the nearest water course. According to the radiocarbon age of organic matter from the gleyed sapropel sediments overlying alluvial sands in pit 6 (at the depth of 165–170 cm, Table 2), it is probable that this water body became isolated from the main river channel at the beginning of the Middle Holocene and turned into a typical oxbow lake (as sapropel sediments are typical of lake basins). The soils in the lower parts of the catena within the oxbow depression had two development stages: the subaquatic (underwater) stage and, later, the hydromorphic and semihydromorphic stage. At present, its development continues under the semihydromorphic conditions. During the transition from the subaquatic to hydromorphic and semihydromorphic stages, the oxbow depression was filled with fine (silt and clay) alluvial sediments that periodically entered the oxbow depression during high floods of the Savala River and were "trapped" there. Later, vertic features appeared in these soils because of their heavy texture, the presence of clay minerals with shrink–swell properties, contrasting moisture (waterlogging–desiccation) conditions in the upper soil layers, and relatively high groundwater table [10].

Data on the history of the uppermost part of the soil-geological strata studied in pits 1–3 are limited. The alluvial origin of this layer is doubtless; its thickness is about 40 cm, and it overlies the Mesolithic cultural layer. The former features of soil formation were erased during the development of the modern surface-gleyic chernozemic-meadow soils. The sedimentation rate for this layer (0.4–0.5 cm/100 years) is significantly lower than that for alluvial sediments accumulated in the interval from the end of the Allerød to the end of the Early Holocene (4–5 cm/100 years). This difference in the rates of alluvial sedimentation can be associated with several reasons: a decrease in the water discharge of the Savala River because of climatic aridization in the Middle and Late Holocene; an alternation of alluvial sedimentation and deflation of accumulated sediments during periodic thinning of the cover of herbs on the soil surface (e.g., during droughts). Human loads and grazing pressure on the floodplain could also disturb the soil surface.

According to our study, the optimal conditions for the soil formation on the floodplain and the development of deep profiles of meadow-chernozemic soils with a noticeable influence of burrowing animals (mole rats and earthworms) were in the Early Holocene (10 300–9000 BP). In the Middle and Late Holocene, the intensity soil formation on the high floodplain of the Savala River decreased, which could be due to the influence of both natural (as a result of climate change) and anthropogenic factors.

At the second study site (Pleshcheevo 2, Orel district, Orel oblast), the soils with a polygenetic profile were studied in the central part of the high floodplain of the Oka River beyond the residential and household buildings of the medieval Russian settlement. We also studied the buried catena in the paleohollow exposed in the archeological excavation of this settlement near the low floodplain, closer to the river channel.

In all parts of the archeological excavation, two soil levels with underdeveloped light-colored surface alluvial soils and buried dark-colored chernozemic soils were clearly seen. Light-colored alluvial sediments have a silt loamy texture, and the soils buried under them have heavier texture (clay loam; in some places, silt loam). A typical section was studied in the northern part of the archaeological excavation (sector T40). In Table 1, it is referred to as pit 1 of the Pleshcheevo site. It had the following horizonation: A1 (0–23 cm)–A1B (23–50 cm)–BA1 (50–69 cm)–BhC (69–95 cm) (upper soil developed from light-colored alluvial sediments); the transition to the buried paleosol was marked by changes in the color and structure of the material. The profile of the buried paleosol consisted of the following horizons: [A1] (0–45 cm)–[A1B]

Table 3. Results of radiocarbon dating of charcoal and bone samples from the Pleshcheevo 2 site

Sample	Laboratory number	Radiocarbon (^{14}C) age				
		Uncalibrated, BP*	calibrated, BP			median (m)
			1σ, 68.2% (AD)	2σ, 95.2% (AD)	mean ± deviation (μ ± σ)	
Charcoal, large fragments, hearthstone, site no. 6	Ki-19548	420 ± 30	1438–1479	1427–1515 (87.9%) 1598–1618 (7.5%)	1476 ± 47	1460
Charcoal, C.38R, area 12, sq. 11	Ki-19550	510 ± 60	1325–1345 (13.3%) 1394–1447 (54.9%)	1296–1486	1401 ± 55	1412
Charcoal, C.42S, area 12, object no. 7	Ki-19549	430 ± 50	1422–1495 (61.2%) 1602–1615 (7.0%)	1410–1525 (75.0%) 1557–1633 (20.4%)	1492 ± 63	1470
Cattle bone	Ki-19557	570 ± 60	1308–1362 (41.8%) 1386–1419 (26.4%)	1292–1436	1363 ± 42	1358

(45–75 cm)–[B] (75–105 cm)–[BC] (105–140 cm and deeper) (the depth of horizons was measured from the paleosol surface). The entire section was carbonate-free.

The modern soil was identified as a weakly developed silt loamy meadow soil; the underlying buried paleosol was identified as a medium-deep clay loamy leached chernozem developed from the loesslike loam (Haplic Fluvisol Oxyaquic over Luvic Chernozem Pachic [38]).

The morphological analysis of this section (pit 1, Pleshcheevo site) attests to two stages of soil development on the high floodplain of the Oka River: the development of chernozem under meadow-steppe vegetation in the absence of alluvial sedimentation or under very low rates of alluvial sedimentation was replaced by the stage of synlithogenic soil formation with high rates of alluvial sedimentation, so that alluvial sediments could not be completely transformed by soil processes of insufficient intensity and preserved their initial alluvial lamination. The surface layer of the buried chernozem contains fragments of circular pottery of the Russian Middle Ages (14th–15th centuries AD), and the overlying alluvial sediment with weakly developed meadow soil contains fragments of pottery dating back to the 18th–19th centuries AD. Thus, these two parts of the section definitely consist of the soils of different ages.

The humus horizon of the modern meadow soil developed from the alluvial sediments contains 2.1% of soil organic carbon (Table 1), or 3.6% of humus; the buried chernozem is richer in organic carbon despite the long period of diagenesis that has passed since the soil burial. In the upper horizon (0–20 cm) of the paleochernozem (pit 1), the C_{org} content reaches 3% (the humus content is 5.2%). According to Demkin [13], in 500 years after the burying of paleosol, about 30% of its organic matter in the upper horizon could be mineralized. Hence, the reconstructed humus content of the upper layer of the paleochernozem was 7.5%, and the humus stock in the 1-m layer could reach 450 t/ha (taking into account the average bulk density of 1.15 g/cm^3). This fact explains the reasons for agricultural development of the floodplain of Oka River in the medieval period; its hayfields had a high productivity, and the chernozems, when plowed, could give high crop yields.

Radiocarbon dating of humus from different depths of this soil (Table 2, pit 1) allows us to refine ideas about soil evolution on the high floodplain.

The age of humus from the uppermost 2-cm-thick layer of the buried chernozem corresponds to the beginning of intensified alluvial sedimentation; it took place 1050 ± 60 BP, or 970 ± 73 cal BP (Table 3). Thus, the 1-m-thick sediment overlying the buried chernozem has been formed over the past 1000 years with an average growth rate of 9–10 cm/100 years.

At the same time, radiocarbon dates of humus sampled from the depths of 50–52 and 80–82 cm (i.e., from this layer of alluvial sediments) are considerably older than 1000 years (2510 ± 60 BP and 3810 ± 80 BP, respectively). Therefore, it can be assumed that the accumulated alluvium contained particles of organic matter from the deep soil horizons. This could be the result of soil erosion by snowmelt and rainwater flowing into the river and the input of material from the middle-profile horizons of eroded soils on slopes to alluvial sediments. Hence, the increase in the rate of alluvial sedimentation over the past millennium could be genetically related to the intensification soil erosion (both sheet erosion and gully erosion) in the river catchment.

To reconstruct the formation of the lithogenic basis for soil formation during the period of the buried cher-

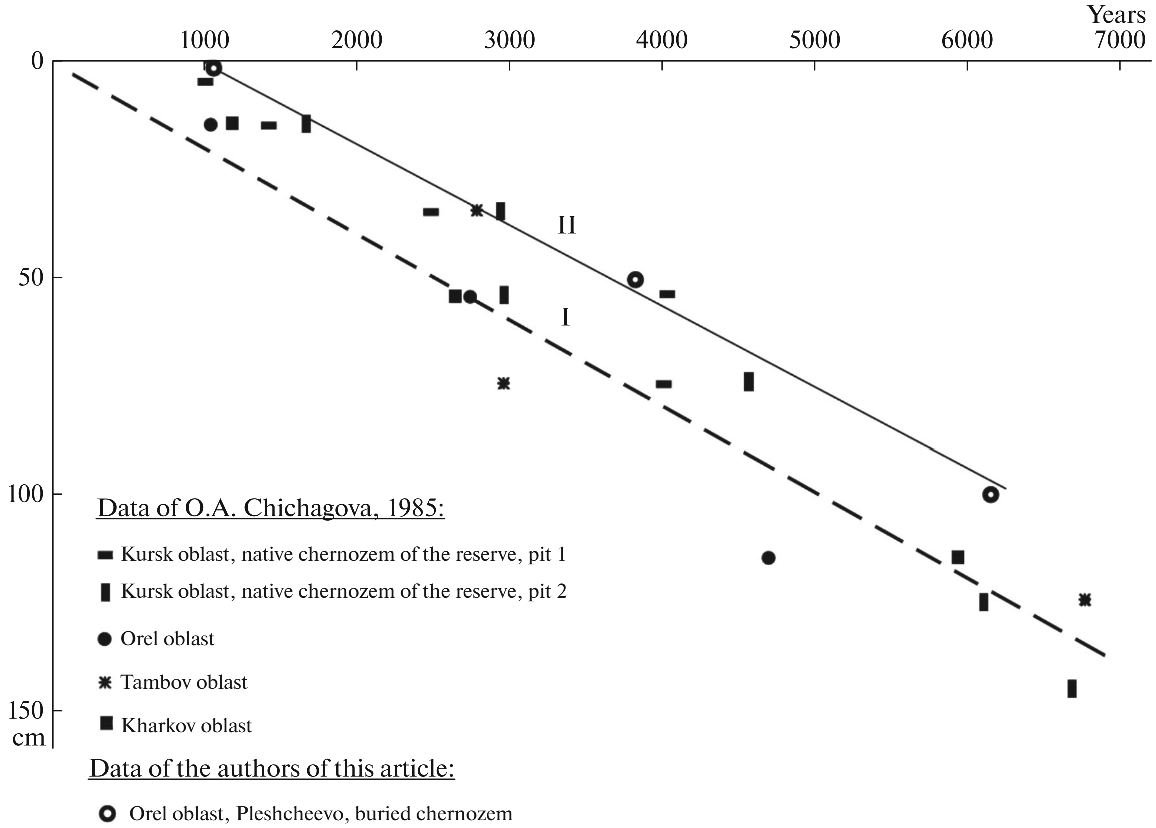


Fig. 4. Changes in the radiocarbon age of soil organic matter with depth in automorphic loamy chernozems of eastern Europe (I, averaged trend line) and in buried chernozem (pit 1) of the Pleshcheevo 2 site (II, averaged trend line).

nozem functioning, it is important to compare the trends of the distribution of radiocarbon ages of humus in the studied soil profile and in the automorphic chernozems developed on interfluves within the East European Plain (Fig. 4). Earlier, an analogous comparative analysis was performed to reveal the differences between synlithogenic soils in bottoms of ravines and postlithogenic automorphic chernozems on the interfluves [33]. The line of the averaged trend for automorphic chernozems was plotted on the basis of data on the age of humic acids at different depths in chernozems of Orel, Kursk, Tambov, and Kharkov oblasts [35]. This comparison showed that the chernozems buried on the floodplain of Oka River and the automorphic chernozems of Eastern Europe have parallel trend lines attesting to analogous changes in the radiocarbon age of humus with depth and to the similarity of biochemical conditions of carbon exchange that specify the age of soil organic matter in each layer (Fig. 4). Therefore, it confirmed the assumption that the rate of the vertical growth of the humus profile in the buried chernozem (pit 1) during its formation was higher than the rate of alluvial sedimentation, which could only take place during rare high floods.

Special studies by Aleksandrovskii [2] and Aleksandrovskii and Glasko [4] showed that the fully developed profiles of soddy-podzolic, gray forest, and chernozemic soils (Umbric Albeluvisols Abruptic, Greyic Phaeozems Albic, and Chernozems [38]) on the floodplains can only form, when the rate of alluvial sedimentation does not exceed 1 cm/100 years. In the studied buried chernozem (pit 1), the radiocarbon age of humus at the depth of 100 cm from the soil surface was 6150 ± 150 BP. the cultural layer in the upper part of this soil dates back to the second half of the 15th century (according to archeological data). Thus, the entire thickness of the chernozem in the alluvial sediments was formed in about 5600 years. Dividing the depth by the age, we get 1.8 cm/100 years, which is close to the critical rate of alluvial sedimentation reported in [2, 4].

To conclude the reconstruction of the soil-geological stratum in pit 1, it is necessary to reveal the reasons for its division into two parts: the lower part with the mature profile of the medium-deep leached chernozem and the upper part with the layered and weakly developed meadow soil. The lower soil profile was a result of a monogenetic development of meadow-steppe soil continuing for millennia. During this period, the floodplain was rarely flooded, and the alluvial sedimentation was almost absent or very slow. After the turn of 1000 BP, the rate of alluvial sedimentation sharply increased (from 1.8 to 9–10 cm/century). We argue that this period coincided with the activation of soil erosion on slopes in the river catchment, so that humus from the middle-profile soil horizons was involved in the transported sediments and suspended load of the river. If we omit the climatic hypothesis of the increasing frequency of floods in the past millennium, the most probable reason for this could be related to the increased human loads on the environment and the disturbance of natural vegetation and its water-regulating functions. In particular, forest cutting and extensive plowing on slopes of the Oka River valley could lead to the acceleration of erosion and to more intense floods. Historical data confirm this assumption: in the 9th–13th centuries, the Vyatichi tribes actively developed the basin in the upper reaches of the Oka River, and their main occupation was arable farming [16, 18]. Therefore, it can be assumed that the anthropogenic soil erosion could take place already in that time. Over time, it intensified. In the period of functioning of the Pleshcheevo 2 settlement (14th–15th centuries AD), soil erosion on slopes could be even more active.

In the context of our study, it is important to establish exact dates of the settlement functioning. Along with the archaeological method based on the artifacts, we also used the radiocarbon dating of charcoal and bone fragments found in different parts the archeological excavation (Table 3). According to the presented data, the most probable period of the settlement existence was from 1358 to 1470 AD (according to median values of the obtained dates).

There could be several reasons for the termination of the functioning of the Pleshcheevo 2 settlement. One of the most probable natural factors could be related to climate-driven (during the Little Ice Age) change in the hydrological regime of the Oka River, which led to the increased frequency of floods in the second half of the 15th century.

Consequently, the established 1000-year-long period of active alluvial sedimentation, which led to the burial of chernozems on the high floodplain of the Oka River included two stages: the early stage of relatively slow sedimentation that could not disturb the lifestyle and economic activity of people living on the floodplain (rare and short floods of the river approximately up to 1470 AD) and the late stage of active alluvial sedimentation (from the end of the 15th century until today).

The second object of paleopedological and paleogeographic reconstructions at the Pleshcheevo 2 site was studied near the eastern edge of the archaeological excavation, where a 4-m-deep and 20-m-wide buried paleohollow was found under the floodplain sediments. Its thalweg stretched perpendicular to the Oka River bank; before being buried under alluvial sediments, this paleohollow crossed the low floodplain and was drained by the river.

Charcoal fragments were found in one of the alluvial interlayers in the lower part of the paleohollow filling. Their radiocarbon dating (1333 ± 53 AD, calibrated (Ki-19551)) indicates that this interlayer was formed in the first half of the 14th century (median of the calibrated age corresponded to 1336 AD). The thickness of the alluvial deposits between this interlayer and the upper boundary of the buried dark-colored paleosol is about 1 m. Thus, the filling of the paleohollow by alluvial sediments started earlier, which was also confirmed by the results of further studies.

Soil profiles were studied in three pits forming a catena along the paleohollow slope towards the river (Fig. 5a).

Buried chernozems of this paleocatena were formed from calcareous loesslike silt loam underlain by layered ancient alluvial sands and sandy loams; the thickness of the loesslike loam decreased in the direction from the center of the high floodplain towards its edge near the river. Buried paleochernozems had well-developed mature profiles with noticeable traces of zoogenic (mole rats) activity. They were classified as leached chernozems (Luvic Chernozems Pachic [38]). In pit 2, we studied thin loamy leached chernozems ([A1 + A1B] = 48 cm); in pit 3, thin to moderately deep loamy leached chernozems ([A1 + A1B] = 53 cm); in pit 4, moderately deep loamy leached chernozems ([A1 + A1B] = 60 cm). Weak effervescence in the soil profiles in pits 2 and 3 began in the [BC] horizon from the depths of 75 and 105 cm, respectively; in the lowest position of the paleocatena (pit 4), effervescence was absent.

Moreover, in the lowermost part of the paleohollow thalweg (pit 5), the profile of a loamy meadow-chernozemic paleosol colluvium (Voronic Chernozem Pachic [38]) developed from the sandy calcareous loam was studied. The boundary between the buried soil and the overlying alluvial sediment was clearly visible due to the darker color of the buried soil. The depth of the humus profile ([A1 + A1B]) was 62 cm. Slight effervescence of the soil profile began at the depth of 62 cm; carbonates in the soil profile were not visually traced.

According to the analysis of the buried soils in different parts of the studied paleohollow, the formation of thin and (closer to the lower part of the slopes) medium-deep leached chernozems took place on the slopes of the hollow, and the meadow-chernozemic soil was formed at the bottom of the hollow.

The analysis of alluvial sediments covering the dark-colored soils in the paleohollow within the high floodplain slope showed the following results. Pit 2 marked the upper edge of the ancient slope of the high floodplain of Oka River (Fig. 5b). Today, this edge is found 17 m to the west, closer to the river. This suggests transformation of the floodplain slope, which became shorter and steeper over time owing to the alluvial sedimentation. The studied paleohollow was

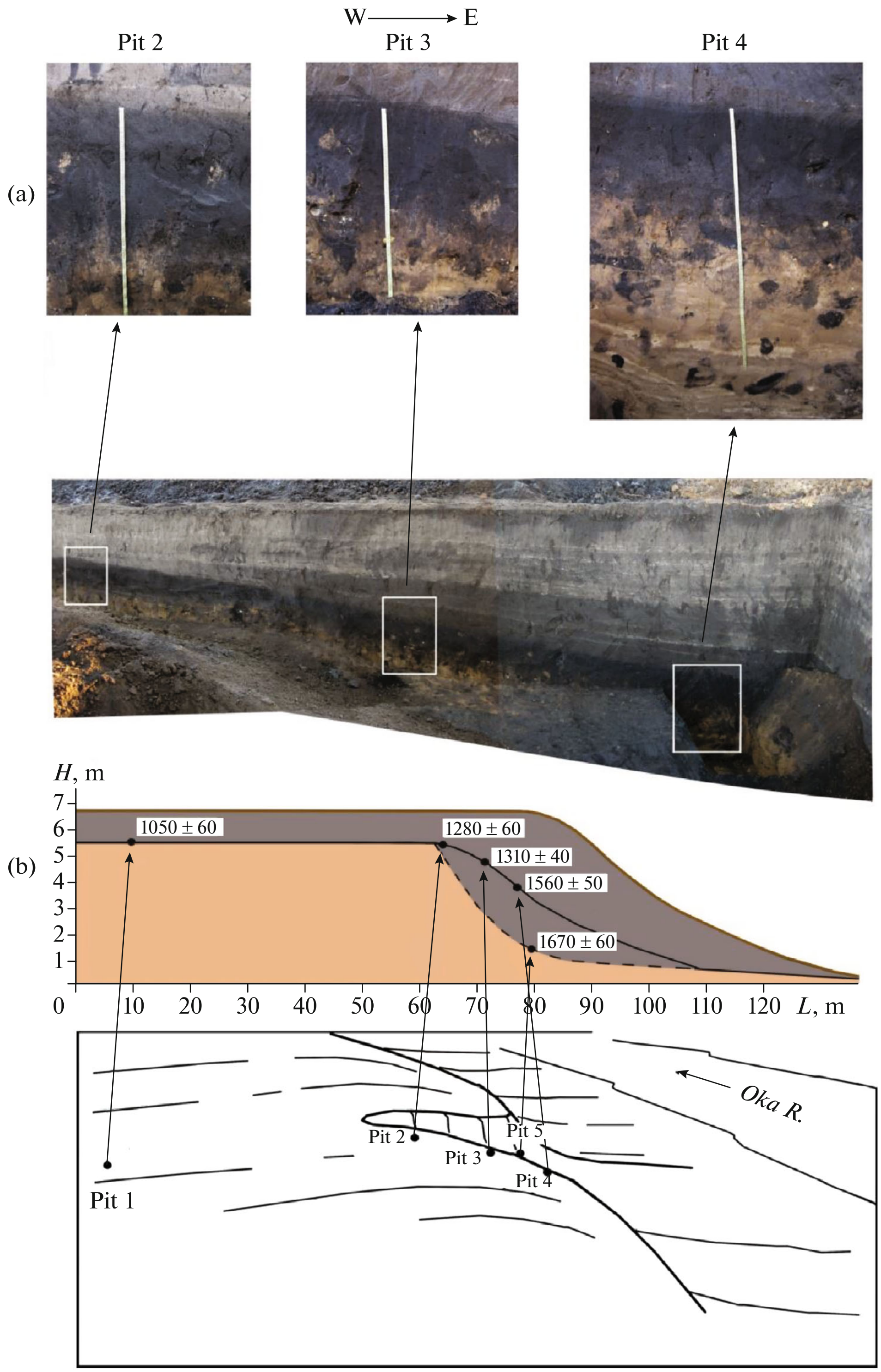


Fig. 5. (a) Location and general view of soil profiles of the paleocatena crossing the paleohollow and studied in the archaeological excavation at the Pleshcheevo 2 site and (b) radiocarbon ages (BP) of humus from the topmost layer (0–2 cm) of the dark-colored paleosol buried under recent alluvial sediment at different elevations above the river and at different distances from the edge of the floodplain. In part (b), the upper scheme shows the location of studied soil profiles and their elevation above the modern water level in the Oka River; darker color indicates alluvial sediments covering the dark-colored buried soil. The lower scheme shows the location of studied soil pits on the reconstructed ancient floodplain surface before its covering by recent alluvial sediments.

leveled by new portions of alluvial sediments; today, the high floodplain surface above the buried paleohollow is absolutely flat. Therefore, the soils of the paleocatena were covered with layered alluvial silty loams of different thicknesses: from 1.1 m in pit 2 (upper part of the catena) to 2.9 m in pit 4 (lower part of the catena). The features of alluvial layering in these sediments become more manifested with an increase in the alluvium thickness: humus-rich silt loamy alluvium alternates with lighter-colored yellowish-whitish sandy silt loamy alluvium. Closer examination attests to the presence of thin (2–8 mm) dark-colored humified and light-colored silty sand loamy microlayers within the light-colored alluvium layers. Light-colored alluvium layers have a coarser texture and attest to sedimentation from the turbulent floods, when water flows carried and deposited larger alluvial particles. According to the field observations, such layers are clearly traced on the walls of the archaeological section near the thalweg of the buried paleohollow, where the thickness of the alluvial sediments increases, and their texture becomes coarser (fine sand) in this zone. Thus, the revealed local differentiation of the alluvial material resulted from the differences in the flood water velocities in different parts of the flooded paleohollow.

Near the modern surface, the microtopography in the zone of the buried paleohollow becomes leveled. At present, the high floodplain surface is almost flat and is elevated at about 6.5 m above the water level in the river. Poorly developed and low-fertile meadow soils with the humus content of 3.5–4% are formed on the high floodplain.

The comparison of radiocarbon ages of humus from the topmost part (0–2 cm) of the buried paleosol at different distances from the edge of the floodplain and at different elevations above the water level in the Oka River (pits 1–5) showed that the age of soil organic matter increases in the direction from the central part of the floodplain towards its edge; the same tendency is seen with a decrease in the relative elevation of the floodplain surface.

This difference in the radiocarbon ages is probably related to the different durations of humus isolation from the modern soil forming processes. This could be caused by the earlier burial of soils located lower in the relief and closer to the river. Thus, the soils in pits 4 and 5 could be buried 1600–1700 BP as a result of higher frequency of floods: by that time, the Scythian–Sarmatian arid stage was completed. According to paleopedological indicators in different regions of the forest-steppe zone of East Europe, it lasted from the 4th century BC to the 2nd–3rd centuries AD [3, 7, 32]. Later (about 1310–1280 BP) the floods reached higher hypsometric levels. Alluvial sedimentation on the high floodplain in the areas furthest from the river took place only about 1000 BP (during the dry period of the Little Climatic Optimum), which could be caused by the increased anthropogenic impact on landscapes and the disturbance of water-regulating functions of forests after their partial cutting. This resulted in higher and more violent floods. The economic development of southern areas in the forest-steppe zone also predetermined changes in the palynological spectra of vegetation on meadow-steppe slopes of the balkas in approximately the same period [33].

In our opinion, the rate of alluvial sedimentation significantly increased after the end of functioning of the Pleshcheevo 2 settlement (after 1460–1470 AD). One of the probable reasons was an increase in the frequency of high floods. Along with the anthropogenic factor, the change in the hydrological regime of the river was caused by the natural processes, such as the climate cooling during the Little Ice Age with a corresponding increase in humidity of the climate. According to Sycheva, the change in the hydrological regime of rivers in the center of the East European Plain during the Little Ice Age was mainly due to natural reasons [25].

CONCLUSIONS

The conducted studies on floodplains in the forest-steppe zone of the Central Russian Upland attest to somewhat different patterns of the Holocene evolution of floodplain soils related to differences in alluvial sedimentation and to spatiotemporal specificity of anthropogenic disturbances of the environment.

In the Late Pleistocene and Early Holocene, the alluvial sedimentation on the Savala River floodplain (Voronezh oblast) had the highest rate (0.5 mm/year), while in the Middle and Late Holocene the sedimentation rates were reduced to 0.05 mm/year. Different stages in the alluvial sedimentation could be caused by the complicated interaction of natural and anthropogenic factors. In the Middle Holocene, the main factors were a decreased humidity of the climate and, hence, lower rates of alluvial sedimentation, while in the Middle and Late Holocene, an increased anthropogenic activity and disturbance of soils and vegetation in river catchments (e.g., under the impact of overgrazing) were more important. During the Allerød period, surface-gleyic meadow soil with the humus profile of 40 cm was formed on the Savala River floodplain (Kamenka 1 site). In the Early Holocene (10300–9000 BP), meadow chernozemic soils (the deepest of all studied Holocene soils with the humus profile of about 60 cm) developed from the fresh alluvial sediments; zoogenic turbation of these soils by earthworms and mole rats was active. The Late Holocene (modern) soil at this site can be classified as a surface-gleyic chernozemic-meadow soil with the humus profile of 25–30 cm.

On the Oka River floodplain in Orel oblast, the rate of alluvial sedimentation during almost the entire Holocene was no more than 0.02 mm/year; in the recent millennium, it increased up to 1 mm/year. The main factor of this increase was the anthropogenic disturbance of the natural landscape in the Late Holocene: deforestation and changes in the hydrological regime of the Oka River started in the 11th century AD and became especially active after the 14th century AD (in 1566 AD, the fortress city of Orel appeared several kilometers upstream the Oka River). Along with the anthropogenic factor, the intensification of alluvial sedimentation could also be triggered by the transformation of the hydrological regime of the Oka River during the Little Ice Age. The floodplain functioned as a terrace and was rarely flooded. The natural resource potential of the territory favored agricultural activities. Medium-deep and deep leached chernozems were formed on the floodplains in areas with sufficiently low groundwater table. These soils had no signs of waterlogging, and the total amount of humus in the 1-m layer was at least 450 t/ha. The latest stage of intensive alluvial sedimentation began at the end of the 15th century AD and was characterized by a decrease in the intensity of pedogenesis and in the diversity of soils forming on the floodplain. The rate of alluvial sedimentation was higher than the rate of pedogenesis. Alluvial sediments filled the paleogullies in the marginal parts of the high floodplain and leveled the mesorelief. Fertile chernozems of the Middle Ages were buried and replaced by incompletely developed low-humus meadow soils on the newly deposited alluvial material.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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