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ПРОБЛЕМЫ ПАЛЕОПОЧВОВЕДЕНИЯ И ГЕОАРХЕОЛОГИИ

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ОТРАЖЕНИЕ ВЕКОВЫХ И ТЫСЯЧЕЛЕТНИХ ИЗМЕНЕНИЙ ПРИРОДНОЙ СРЕДЫ В ПАЛЕОПОЧВАХ ВЕРХНЕПАЛЕОЛИТИЧЕСКИХ СТОЯНОК ВОСТОЧНО-ЕВРОПЕЙСКОЙ РАВНИНЫ В МИС 3 И МИС 2

С. Н. Седов[1,2,3,*], А. А. Синицын[4], А. А. Бессуднов[4], С. Ю. Лев[5], А. Н. Бессуднов[6], С. А. Сычёва[7], Т. В. Романис[8,9], В. С. Шейнкман[2,3], М. А. Коркка[10]

[1]Институт геологии, Национальный Автономный Университет Мексики, Университетский городок, Дель. Койоакан, Мехико, Мексика
[2]Федеральный исследовательский центр "Тюменский научный центр" СО РАН, Институт криосферы, Тюмень, Россия
[3]Тюменский государственный университет, Тюмень, Россия
[4]Институт истории материальной культуры РАН, Санкт-Петербург, Россия
[5]Институт археологии РАН, Москва, Россия
[6]Липецкий государственный педагогический университет имени П.П. Семенова-Тян-Шанского, Липецк, Россия
[7]Институт географии РАН, Москва, Россия
[8]Почвенный институт имени В.В. Докучаева, Москва, Россия
[9]Институт мерзлотоведения имени П.И. Мельникова СО РАН, Якутск, Россия
[10]Санкт-Петербургский государственный университет, Институт наук о Земле, Санкт-Петербург, Россия
**E-mail: serg_sedov@yahoo.com*

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В Восточной Европе мало исследований континентальных геологических летописей, содержащих информацию о кратковременных контрастных климатических флуктуациях во время последней ледниковой эпохи, которые задокументированы в характеристиках Гренландских ледяных кернов. Мы считаем, что восполнить этот пробел могут почвенно-осадочные серии, вскрытые на верхнепалеолитических стоянках в пределах центральной части Русской равнины. Детальное исследование и датирование палеопочв, описанных в разрезах археологических раскопов на стоянках Костёнки и Дивногорье, позволили построить сводную корреляционную схему, охватывающую вторую половину МИС 3 и МИС 2. Эта схема включает эмбриональные палеопочвы, формировавшиеся преимущественно во время потеплений и, соответствующие 8 последним Гренландским интерстадиалам. С другой стороны, формирование палеопочвы, обнаруженной на Зарайской стоянке, приходится на холодный интервал – Гренландский стадиал 2 – и соответствует потеплению в интервале 18–21 тыс. л. н. в пределах этого стадиала. Полученные результаты показывают, что палеопочвы в почвенно-осадочных толщах палеолитических стоянок могут служить весьма чувствительными индикаторами климатических флуктуаций длительностью от нескольких столетий до 1–2 тысячелетий. Несмотря на кратковременное развитие, педогенетические характеристики этих палеопочв содержат ценную информацию о локальной истории природной среды, важную для геоархеологических исследований.

Ключевые слова: Восточно-Европейская равнина, почвенно-осадочные архивы, палеопочвы, верхний палеолит, Гренландская климатическая летопись

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1. INTRODUCTION: ANTECEDENTS AND APPROACH

Reconstruction of the regional paleoenvironmental changes during the Middle and Late Valday (Weichselian) epoque has major importance for understanding of the social-ecological interactions during the initial dispersal of Homo Sapiens and posterior development of the Upper Palaeolithic cultures in Eastern Europe. General longeval tendencies of these changes deciphered from various proxies as well as their influence on the cultural development are presented in the works on A.A. Velichko and his collaborators (2012). However more recently the detailed records from the Greenland ice cores and deep-sea sediments of Northern Atlantic have shown that the short term (centennial to 1–2 millennia) but pronounced and contracting fluctuations of climate had major importance during this period (Rasmussen et al., 2014). The search for detailed terrestrial geological archives which could reflect the landscape response to these global fluctuations in the occupation region of particular Palaeolithic cultures comprises an important challenge for the current geoarchaeological research.

Soil-sedimentary sequences could provide such archives. The study of detailed loess-paleosol sections in Western and Central Europe as well as Southern Siberia provided with extensive sets of instrumental dates have shown that their development was controlled by the short-term climatic cycles: incipient soil formation took place during the warmer intervals, correlative to the Greenland Interstadials (GI) whereas sedimentary strata and cryogenic features (cryoturbations, involutions, ice wedge casts) correspond to the cold phases – Greenland Stadials (GS) (Haesaerts et al., 2010).

Within the East European plain, the terrestrial records reflecting this short-term cyclicity are very poorly documented. We speculate that paleosols encountered at the Palaeolithic sites and associated with the cultural layers could bear signals about the climate fluctuations analogous to those recorded by the Greenland ice cores and thus could be used for interregional and even global correlations. A major advantage for paleopedological research at the world-famous archaeological localities with a long research history consists in the available datasets of instrumental dates as well as various palaeoecological results. The detailed information about ancient cultures provides additional tools for developing the chronological scale, correlations as well as independent palaeoecological reconstructions.

However only in very few cases it is possible to detect reliably the levels corresponding to the individual events of the Greenland record directly basing on the instrumental age determinations, because very often the confidence intervals of the obtained dates are comparable with the duration of these events. The design of the proposed correlation scheme relies on the basic principle that attributes formation of paleosols to the periods of milder climatic conditions whereas geomorphic processes (erosion/sedimentation) and cryogenesis were more active during the phases of colder paleoclimate. In fact, this principle is a derivate from the classic scheme of landscape development by Rohdenburg (2010) who postulated the alternation of morphodinamic activity and stability phases throughout the Pleistocene; it is applied for a number of continental soil-sedimentary successions at different time scales (most consistently and successfully – to the loess sequences). Below we present our attempt to find the equivalents of the short-term climatic fluctuations of the Greenland ice core record in the paleosol-sedimentary stratigraphies of the 3 famous Upper Palaeolithic sites of Central East European Plain: Kostenki and Divnogorie in the Upper Don Basin and Zaraysk in the Middle Oka Basin (fig. 1).

2. RESULTS AND DISCUSSION

The sections of the Upper Palaeolithic sites of the Kostenki-Borshchevo archaeological district provide detailed paleosol-sedimentary sequences with multiple layers of buried soils. These soils although thin and incipient could be clearly traced and in many cases are associated with the cultural layers or levels of findings. In particular, the section Kostenki-14 (K14) contains 8 major cultural layers developed within the interval 42–27 cal ka BP and at the same time comprises in total about 16 individual paleosols grouped into 5 paleopedological units, labelled as K14/I – K14/V (Sedov et al., 2010). The section is supplied with extensive sets of radiocarbon and luminescence dates and also contains an important independent chronological marker – the layer of volcanic ash, attributed to Campanian Ignimbrite. This tephra layer known in a number of terrestrial and marine geological profiles is reliably dated to ~40 cal ka BP.

Already the attempts have been made to relate the sections in Kostenki with the Greenland ice core record. Levkovskaya et al. (2015) carried out detailed palynological investigation of the profile K12 and identified in its lowest most ancient part the paleosol levels, corresponding to GI 14, 12 and (with certain doubt) 11. It is very interesting that in the upper part of K12 above the layer of Campanian Ignimbrite these authors could not carry out similar detailed correlation. In this part of the profile they identified only one palynological megastage D and stated that "Several interstadials and stadials alternated within this long coniferous megastage (~42–12 ka BP), but their specific features are not clear". Sinitsyn (2015) demonstrated the correspondence of the main cultural layers of K14 and other key sites of Kostenki with the Greenland curve. The detailed correlation of the soil-sedimentary stratigraphic scheme of K14 with the events of the GRISP and also with the detailed terrestrial records from Carpathian region and Southern Siberia were presented by Haesaerts et al. in their talk at the conference "Multidisciplinary methods in the study and preservation of sites in the Kostenki-Borshchevo archaeological area (Voronezh, September 15–17, 2016). This correlation followed the main principle formulated above: paleosol levels were associated with the warm phases of the Greenland record (Greenland Interstadials). In many aspects the scheme which we propose in this paper agrees with that developed by Haesaerts et al.

We argue that at the current stage of research, the reliable correlation of the K14 section with the Greenland record is possible for the middle and upper parts comprised by the paleopedological units K14-I and K14-II, located above the marker horizons of Campa-

Fig. 1. Geographical location of the studied sections.
Рис. 1. Географическое положение исследованных разрезов.

nian ignimbrite. In particular, the dark-colored paleosols of the K14-II unit, known as the Upper Humus Bed forms the key block for the proposed correlation. This unit contains Cultural layers II and III with a number of radiocarbon dates from charcoal and bone, which establish its chronological interval between 31.5–36.6 cal ka BP. Within the Upper Humus Bed, the number of individual dark paleosols vary from two in the southern wall of the K14 main excavation (Velichko et al., 2009; Sedov et al., 2010), three in the profile K17, to four in the profile K14 – west (Korkka et al., 2017). We conclude that four paleosols of this most detailed variant of the Upper Humus Bed sequence could be correlated with the Greenland Interstadials (GI) 5, 6, 7 and 8 (fig. 2).

The overlying two brown paleosols of the unit K14-I described in the southern wall of the main excavation (the upper one of them is related to the Cultural layer I dated 27.0–27.9 cal ka BP) (Velichko et al., 2009; Sedov et al., 2010) could be correlated with the Greenland Interstadials 4 and 3. During the excavations of 2008 a paleodepression cut into the Upper Humus Bed was exposed; within the fill of this paleodepression additional brown paleosol levels were encountered above the Cultural layer 1 (Korkka et al., 2017), (fig. 2, 3). We suppose that these uppermost paleosols located directly below the Holocene Chernozem could be correlated with the complex Greenland Interstadial 2. If this correlation is right, we could conclude that the paleosol units K14-I and K14-II correspond to seven Greenland Interstadials from GI8 to GI2, covering the second half of MIS 3 and beginning of MIS 2.

Despite small thickness and short formation period of the paleosols their features, being produced by the fast soil forming processes, permit pedogenetic and paleoenvironmental interpretation, although sometimes ambiguous. In the sections K14 and K17 in the brown paleosols of the superior K14-I paleopedological unit we observed decrease of redoximorphic features and less organic materials and increase of aggregation (both biogenic and cryogenic) as well as carbonate neoformation due to short-range migration processes (Sedov et al., 2010). We associate these features with the cooling and aridization of paleoclimate at the end of MIS 3 – transition to MIS 2 that resulted in decrease of bioproductivity and supply of organic residues as well as soil moisture deficit which allowed only intra-horizontal carbonate recrystallization. This agrees well with the palynological data from K14

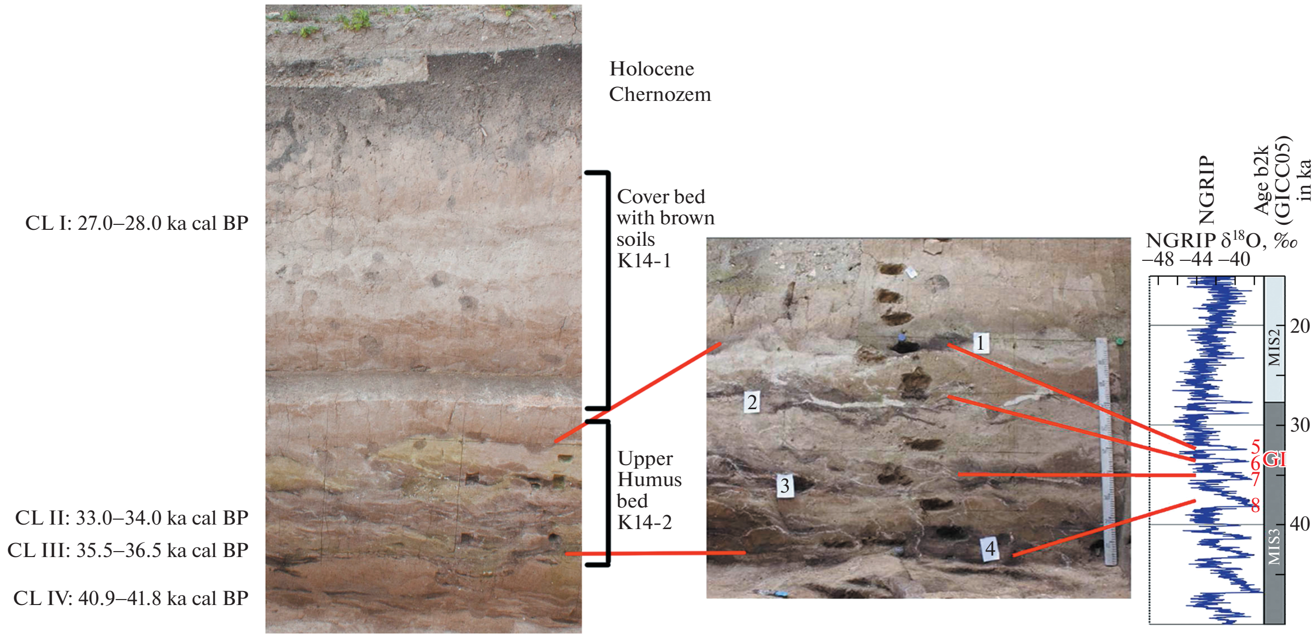

Fig. 2. Paleosols of the Upper Humus Bed in the section Kostenki14-west and their correlation with the Greenland Interstadials (GI). CL – cultural layer.

Рис. 2. Палеопочвы Верхней Гумусовой Толщи в разрезе Костёнки 14-западный раскоп и их корреляция с Гренландскими интерстадиалами (GI). CL – культурный слой.

(Velichko et al., 2009) which shows sharp decrease of tree pollen and increase of xerophytic herbs in the uppermost paleosols, as well as with the continental paleoenvironmental tendencies reflected by numerous records (loessic, lacustrine, etc.).

Detailed study of more developed dark paleosols of the K14-II Unit/Upper Humus Bed generated multiple scenarios of their pedogenesis. The first hypothesis supposed accumulation of dark organic matter in the waterlogged position affected by the groundwater discharge (Holliday et al., 2007). However further laboratory results strongly challenged the hydromorphic hypothesis. The dark horizons of the Upper Humus Bed showed strong maxima of magnetic susceptibility, typical for well drained topsoil but usually not observed in the reduced waterlogged soil environment. Micromorphological observations revealed evidence of mesofauna activity as well as presence of fungi – aerobic organisms which could not tolerate anoxic water saturated conditions. Basing on these data the alternative hypothesis of cold steppe cryo-arid soil development was put forward (Sedov et al., 2010). One more explanation is development of a Rendzina type soil under local forest stand – this version agrees best with the palynological data which show maximum of arboreal pollen (in particular spruce) in the Upper Humus Bed (Velichko et al., 2009). Characteristics of parent material – colluvial deposits are quite suitable for development of Rendzina: they contain abundant primary carbonates derived from their source materials – loessic deposits and underlying Cretaceous chalky limestone. From the other hand the hypothesis of human induced soil formation – Palaeolithic Technosol development – is justified by numerous microartifacts observed in thin sections. Within this hypothesis maxima of magnetic susceptibility in the dark horizons of the Upper Humus Bed could be explained not by pedogenic enhancement but as an effect of burning. Further laboratory research is needed to justify the latter three versions which at the present state of our knowledge could be considered as equally possible.

We further speculate that after the warmer stage corresponding to GI marked by humic paleosol development, the subsequent cold stage – GS is characterized by higher activity of the sedimentary (colluvial, eolian) and cryogenic processes, which bury and deform the paleosol developed earlier. Cryogenic features could provide certain information about paleoecological conditions of the cold stages. The most notorious are the signs of displacement and fragmentation of the thin humus horizons which are related with the slow downslope movement of the water-saturated thixotropic material – this process is known as solifluction and develops within the active layer above permafrost in the period of seasonal thawing. The winter freezing was also rather intensive as far as the solifluction structures are combined with the cryoturbation features which develop in the beginning of cold season between two freezing fronts (seasonal freezing and permafrost). Some small pockets or oval bodies of dark humus material (involutions) could be interpreted as small frost heave hummocks; such structures develop in presence of permafrost with the temperature

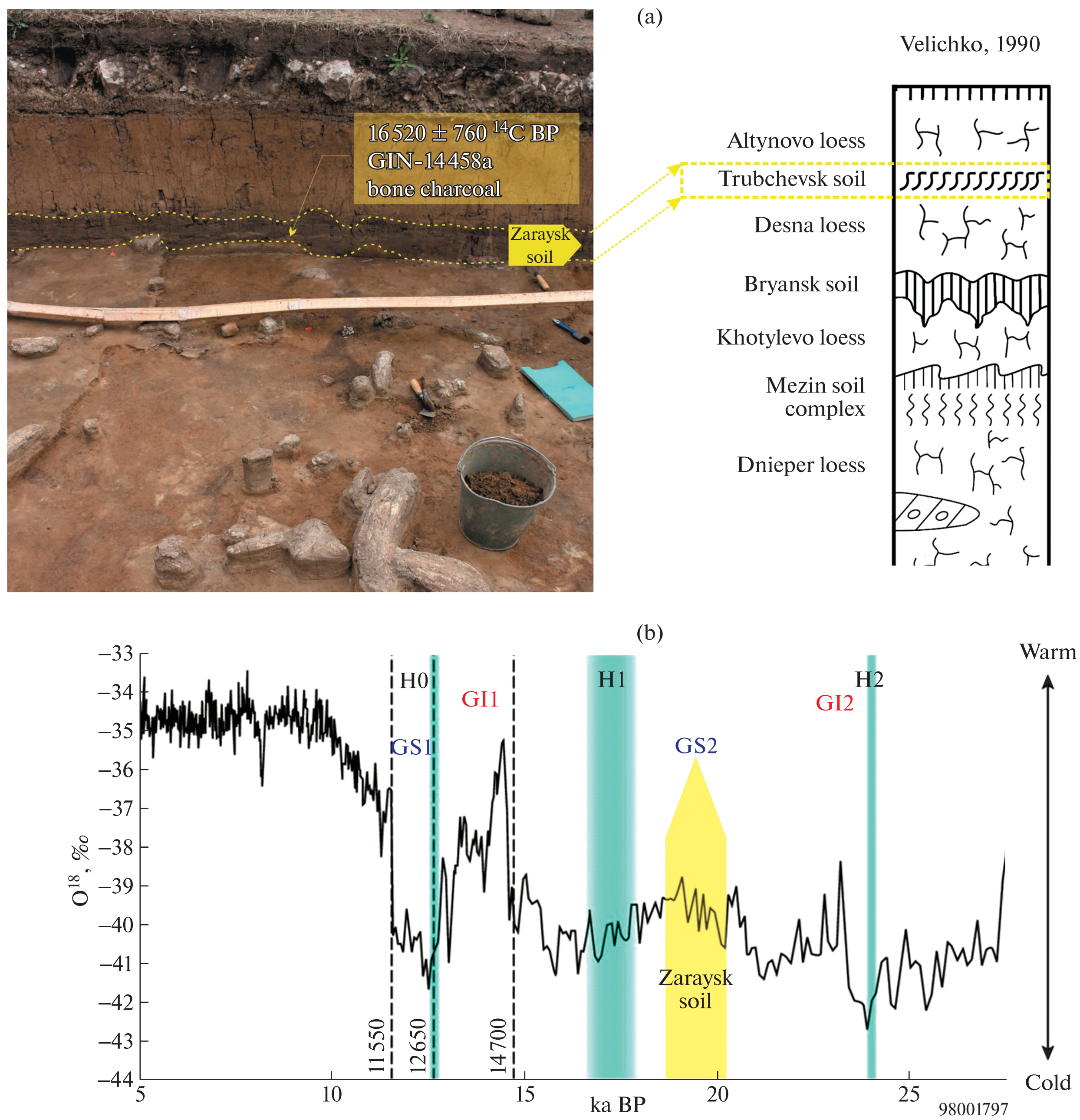

Fig. 3. Paleosol of the Zaraysk site (a) and its correlation with the East European loess stratigraphy and with the Greenland ice-core record (b).

Рис. 3. Палеопочва Зарайской стоянки (a) и ее корреляция Восточноевропейской стратиграфической схемой лёссовой формации и с Гренландской ледниковой летописью (b).

below –0.5°C. However, we suppose that the permafrost temperature was not too low – most probably above –2°C – because no ice wedge casts were observed in the studied sequence. Redoximorphic features in the layers overlying the dark humus horizons present an additional indirect evidence of permafrost. In the well-drained positions of the K14 and K17 profiles water saturation conditions, necessary for development of redoximorphic processes, could develop due to waterlogging above impermeable permafrost table.

Some specific paleoecological and correlative problems arose when studying the paleosol encountered in the Zaraysk Eastern Gravettian site; this paleosol contains the upper cultural layer, whereas the lower cultural layers of the same Kostenki-Avdeevo archaeological culture are incorporated into the underlying sandy loamy sediments (fig. 3). The interval of paleosol formation established according to the radiocarbon dates of charred bone fragments encountered in the upper cultural layer lies between 15 and 17 C14 ka BP (18–21 cal ka BP). Recently radiocarbon ages of paleosol humus were obtained in the samples from the section excavated at the location Zaraysk B in 2019; these ages fit well into the same interval. This chronological attribution allows to correlate the Zaraysk paleosol with the Trubchevsk paleopedological level of the stratigraphic scheme of the loess formation of the East European Plain by A.A. Velichko (1990); also, in the neighboring regions of the Central and Eastern Europe synchronous paleosol units have been encountered (Romanis et al., 2021). Unexpectedly the Greenland paleoclimatic record (Rasmussen et al., 2014) does not indicate within the formation interval of Zaraysk soil any warming that could correspond to a Greenland Interstadial. On the contrary this interval is part of a longeval cold phase Greenland Stadial (GS) 2 and corresponds to its medium part GS2b when the climate was only a little bit milder. We conclude that in this case, the East European continental paleosol-sedimentary records registered more pronounced fluctuation of environmental conditions than that reflected in the Greenland ice core record.

Pedogenetic features of the Zaraysk paleosol witness however its formation under rather severe paleoclimatic conditions (Romanis et al., 2021). Besides moderate accumulation of dark humus the signs of gleization – iron-manganese nodules – were observed. Taking into account that pedogenesis developed at this site in a very well drained geomorphic position (a promontory of the high right bank of Osetr river) this gleization most probably was conditioned by the impermeable permafrost horizon. Direct signs of cryogenic processes: wedges with the humus fillings at the lower boundary of the paleosol, cryoturbations and grainsize sorting of soil matrix in its the upper, confirm the conclusion about strong frost effects in the Zaraysk paleosol.

Paleosol with the Eastern Gravettian archaeological materials is overlain by a silty loamy sediment which provided parent material for development of the Holocene Grey Forest soil (Eutric Luvisol), which in turn served as a base for the Medieval cultural layer. Composition, stratigraphic and geomorphological position of this silty layer leaves no doubt in its eolian origin (Romanis et al., 2021), we further speculate that it could be correlated with the Altynovo loess horizon (Loess III) of the stratigraphic scheme by Velichko (Velichko, 1990). We relate this phase of eolian sedimentation with one of the short but strong cooling events of the Late Valday (late MIS 2) period: Oldest and/or Younger Dryas. Wedges with pale loamy infillings which penetrate from the silty layer into the dark paleosol confirm cold paleoclimatic conditions of the time of the silt deposition. Conspicuously this event of eolian sedimentation was strongest at the Zaraysk site during the last glacial period. No silty eolian deposits of comparable thickness below the Zaraysk paleosol (which would have corresponded to Desna loess, or Loess II of Velichko's scheme (Velichko, 1990) accumulated during the first half of MIS 2) were found at the site.

The cold episodes of the late Glacial alternated with the warm phases: Bølling (peaked around 14.5 cal ka BP) and Allerød (13 cal ka BP), joined together in the Bølling–Allerød warming which in the Greenland ice core record correspond to the GI 1. During these warm phases, as in the earlier GIs, stabilization of land surfaces and incipient soil development took place in the accumulative geomorphic positions. Buried Divnogorie pedocomplex presents a detailed record of the last warming of the Terminal Pleistocene, preceding the Holocene (fig. 4).

This pedocomplex was exposed in the fill of ancient ravine where also the fireplace and the evidence of an ephemeral Palaeolithic campsite were encountered at the site Divnogorie 9 in the Voronezh region, some 50 km to the south of Kostenki (Sycheva et al., 2016). Divnogorie pedocomplex consists of two, sometimes three individual paleosol levels, separated by slope deposits which form the upper colluvial unit of the ravine fill. The colluvium rests upon the thick laminated alluvial stratum with abundant bones of Pleistocene fauna, predominantly of horses. Within the upper colluvial unit two lenses of charcoal were encountered with the radiocarbon dates about 12 ^{14}C ka BP (13.7–14.2 cal ka BP). Down the ravine slope the charcoal lenses merge into poorly developed humic paleosols. Above one more brown paleosol is encountered, coloured with the ferruginous pigment. Thus, Divnogorie pedocomplex consists of two main paleosols: the upper called Divnogorie I corresponding to Allerød and the lower Divnogorie II formed in Bølling. In the smaller gullies of the ravine slope the lower Divnogorie II paleosol splits in two soils, both of Rendzic Leptosol type. The upper Divnogorie I paleosol was classified as Cambisol – incipient brown soil. All paleosols of pedocomplex are thin, poorly differentiated and contain primary carbonates due to incomplete leaching that is explained by a short period of their formation (several hundreds of years). Palynological results show that these soils could be developed under forest vegetation. In the beginning of Bølling the climate amelioration resulted in the spread of pine-spruce forests predominantly in the valley. Further warming during Allerød promoted development of forest-steppe ecosystems with forest patches consisting of pine and birch, with minor contribution of the broad leaf species.

At the fig. 5 we present the compound scheme of correlation of paleosols from all considered sections with the Greenland ice core record. This is just the first step towards understanding of how "soil memory" recorded the short-term cyclic climate changes

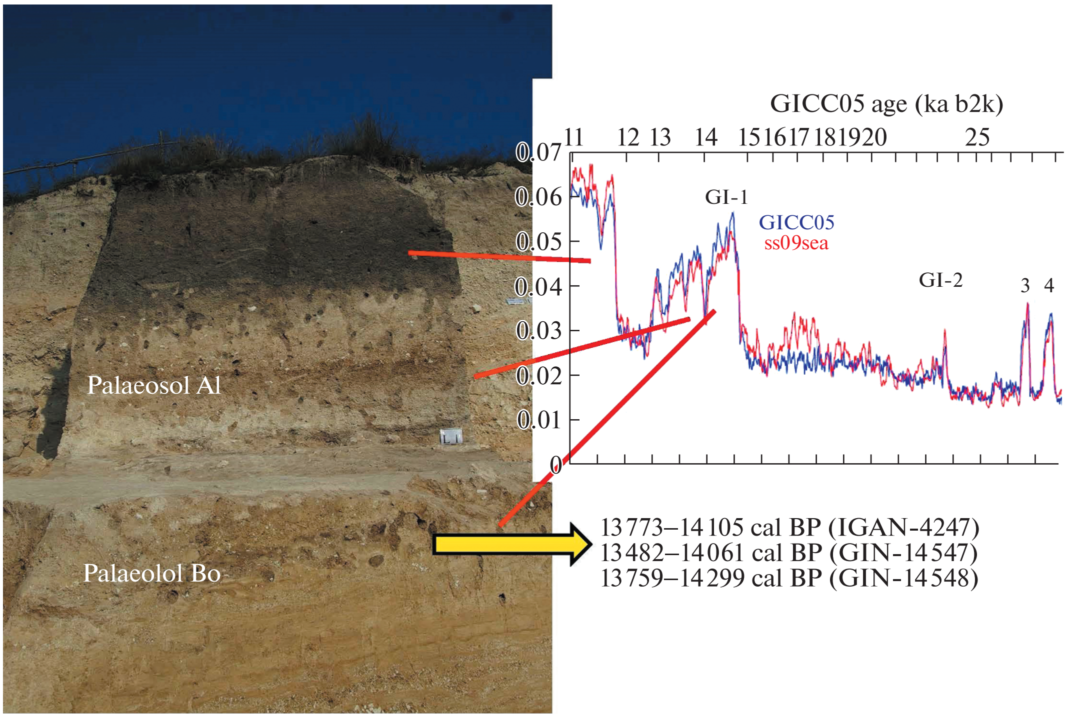

Fig. 4. Paleosols of the Divnogorie 9 site and their correlation with the Greenland Interstadial 1.
Рис. 4. Палеопочвы стоянки Дивногорье 9 и их корреляция с Гренландским интерстадиалом 1.

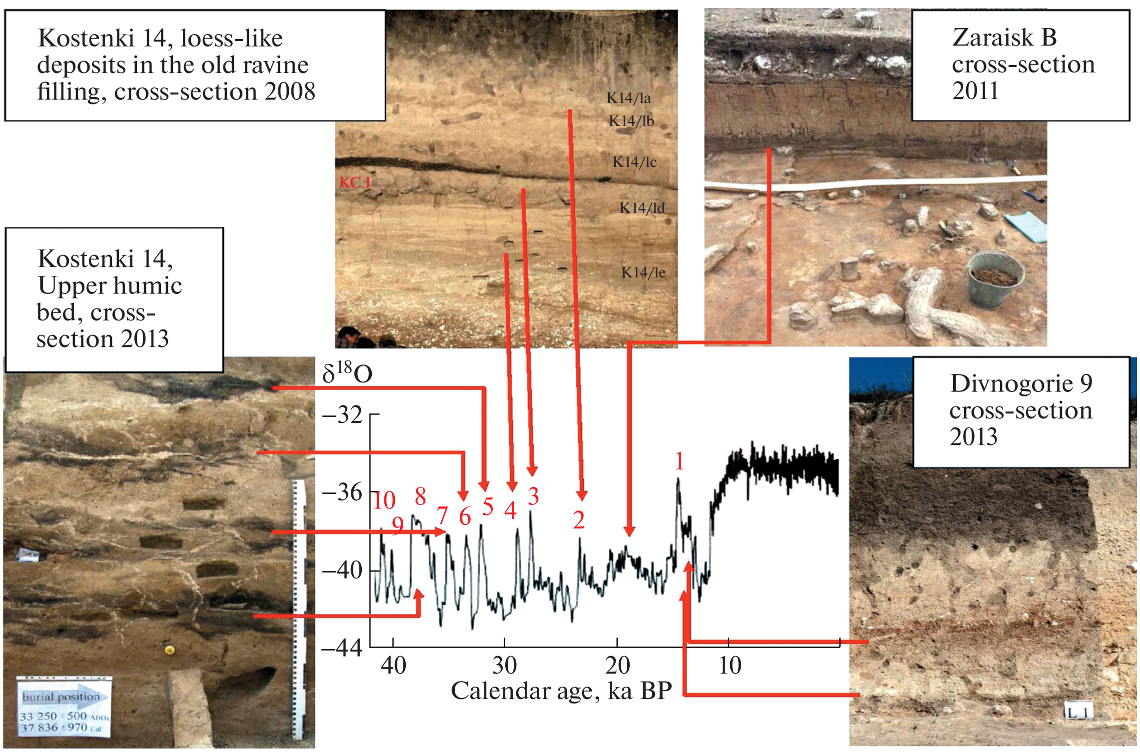

Fig. 5. Compound correlation scheme of paleosols at the Upper Palaeolithic sites of central Russian plain and the Greenland ice-core record.
Рис. 5. Сводная схема корреляции палеопочв верхнепалеолитических стоянок центра Русской равнины и Гренландской ледниковой летописи.

during the Late Pleistocene in the Eastern Europe. Further perspectives of this research include the widening of the chronological framework and incorporation into the correlation analysis of a number of new sections both from the archaeological sites and from natural soil-sedimentary bodies.

PALEOSOLS OF THE UPPER PALAEOLITHIC SITES IN THE EAST EUROPEAN PLAIN REFLECT THE ENVIRONMENTAL FLUCTUATIONS OF CENTENNIAL TO MILLENNIAL SCALE DURING MIS 3 AND MIS 2

S. N. Sedov[a,b,c,#], A. A. Sinitsyn[d], A. A. Bessudnov[d], S. Yu. Lev[e], A. N. Bessudnov[f], S. A. Sycheva[g], T. V. Romanis[h,i], V. S. Sheinkman[b,c], and M. A. Korkka[j]

[a]*Instituto de Geología, Universidad Nacional Autónoma de México, Del. Coyoacán, Mexico*
[b]*Federal Research Center "Tyumen Scientific Centre", SB RAS, Earth Cryosphere Institute, Tyumen, Russia*
[c]*Tyumen State University, Tyumen, Russia*
[d]*Institute for the History of Material Culture RAS, Saint Petersburg, Russia*
[e]*Institute of Archaeology RAS, Moscow, Russia*
[f]*Semenov-Tyan-Shansky Lipetsk State Pedagogical University, Lipetsk, Russia*
[g]*Institute of Geography RAS, Moscow, Russia*
[h]*Dokuchaev Soil Science Institute, Moscow, Russia*
[i]*Melnikov Permafrost Institute, Yakutsk, Russia*
[j]*Saint Petersburg State University, Institute of Earth Sciences, Saint Petersburg, Russia*
[#]*E-mail: serg_sedov@yahoo.com*

In the Eastern Europe there are very few studies of the terrestrial records which registered the contrasting short-term climate fluctuations during the last glacial period demonstrated by the Greenland ice core proxy. We argue that the paleosol-sedimentary sequences encountered at the Upper Palaeolithic archaeological sites within the central Russian Plain reflect such climatic fluctuations, the incipient paleosols being formed predominantly during the warm episodes corresponding to the Greenland Interstadials. Detailed research and dating of paleosols described in the sections of the archaeological sites of Kostenki and Divnogorie gave rise to the compound correlation scheme which covers the second half of MIS 3 and MIS 2. This scheme contains the levels of incipient paleosols correlative to the last 8 Greenland Interstadials. In case of the Zaraysk site the formation of the paleosol found there took place during the Greenland Stadial 2 and marks a warmer phase 18–21 cal ka BP within this cold interval. The obtained results show that the paleosols of the soil-sedimentary sequences of the Palaeolithic sites could provide a sensitive record of the climatic fluctuations of centennial to 1–2 millennia scale. Despite their incipient development the pedogenetic features of these paleosols provide valuable information about local paleoenvironments important for geoarchaeological research.

Keywords: East European Plain, soil-sedimentary archives, paleosols, Upper Palaeolithic, Greenland climate record

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