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Paleosols in the moraine-mantle loam sequence of northeastern Europe: The memory of pedogenesis rates and evolution of the environment during OIS3

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Abstract

Morpho-analytical features of the paleocatena (a complexly organized heterochronous sequence), which contains 2 pedostratigraphical units: formed on the Holocene mantle loams Umbric Albeluvisol and the underlain Middle Valday (Wűrmian) paleopedocomplex developed on Moscowian (Riss II) moraine deposits, are described. The buried pedocomplex consisted of: 1) the paleohumus and paleogley (2Atgb–2Gtb–3Atgb) and 2) paleohumus (3Atgb–3AtGb) horizons. Thus, these pedostratigraphic units reflect two studies of pedogenesis marked by two paleohumus horizons. The horizons of the paleopedocomplex are separate parts of the profile classified as the Umbric Gley soil formed during OIS3. The ^{14}C age of the three paleosol horizons varied between 24,350–30,900 yr BP. The studied paleopedocomplex is the only one known containing the Middle-Valday paleosol formed on moraine deposits, which is a clear sign of the northernmost occurrence of the Bryansk fossil soil in Europe. A detailed hierarchical morphological study of the paleopedocomplex, including meso- and submicromorphological and magnetic susceptibility analyses, allowed us to identify the Late Quaternary pedogenic processes under severe extra-continental climate, including gleyzation, aggregation, cracking and humus formation. Good preservation of these individual pedogenic processes is shown to be a soil memory under the overlapping press of Holocene pedogenesis. It was shown that the clay coating in the Middle Valday of the pedocomplex is a part of the Holocene soil formation. Based on the palynological data, it is possible to subdivide the development of paleovegetation of the area into four stages during which the paleosol horizons had being formed. At the beginning and the final stage of the Middle Valday, the forest–tundra landscapes with inclusions of tundra–steppe associations predominated. During the optimum of Bryansk Interstade, the periglacial pine-birch formations were widespread.

Keywords: Paleosols; Late Quaternary pedogenesis; The Bryansk fossil Soil; OIS3; Evolution of the Environment; East-European Plain

1. Introduction

A study of the Late Quaternary paleosols during the OIS3 is quite important not only for understanding of the Late Pleistocene pedogenesis, but also for interpreting the trends of paleoenvironment evolution which are recorded in the chronosequences containing buried soils. Until now, numerous literature data on the paleosols formed during the OIS3 within the East-European plain have been published, but all of the studied soils were mainly formed on loess and loess-like (mantle) loams, chiefly within the loess district situated relatively far to the south of the boundary of the last Late Pleistocene glaciation at its maximum. There are various interpretations of the Late Quaternary (OSI3) soil stratigraphic units. The paleosols themselves are studied incompletely, and there are no analogues within surface and buried Holocene soils in Europe (Velichko and Morozova, 1972; Morozova, 1981; Velichko and Morozova, 1982; Velichko, 2002). One of the main problems hampering the study of the aforementioned paleosols is the presence of the cryogenic deformations in soil profiles and the cryogenic pedomorphism resulting from an influence of the last, severe glacial epoch.

The main goal of this work is to examine the complexly organized heterochronous sequence as a part of the paleocatena consisted of 2 pedostratigraphical units, viz. the Holocene soils formed on mantle loams and the Late Quaternary pedocomplex formed on moraine deposits. According to the literature, the studied sequence marks the northernmost occurrence of the buried

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paleosol (OIS3) in Europe. Another aim of the present study is to estimate the pedogenesis rates during the final stage of OIS3.

2. Description of the paleocatena, materials and methods

The present work is based on original field measurements of the soil structure and parent rocks during the large-scale mapping expedition to the North, starting from the center of East-European Plain (west part of Vologda Oblast, Tcherepovetz District). According to the soil–ecological zoning of Russia (Shishov et al., 2001), the studied area belongs to the northern part of Middle-Russian province where Umbric Albeluvisols predominate and are developed under south taiga conditions. The mean annual temperature of the air is +2.4 °C, mean annual precipitation is 540 mm and the coefficient of moistening is 1.1 (station Vologda), which means a predominance of precipitation in comparison with evaporation.

The investigated area is restricted to the west part of the Vologda upland and constitutes a part of the northwest edge of Sheksna–Kostroma interfluve. One of the main important geomorphological features of this interfluve is the absence of the pronounced hummocky topography of an end moraine. The study area is situated in the nearest part of the periglacial zone to the boundary of Valday (Wűrmian) glaciation (58°49′ N, 38°19′ E) (Fig. 1).

To estimate the main morphological and lithological features of this territory, an 8-km transect was investigated. It consisted of a series of terraces and terraced surfaces of different ages, rising as ledges, starting from the Rybinsk Reservoir (110 m a.s.l.), which is located in the tectonically conditioned Mologo–Sheksna lowland, to the interfluvial surfaces of Vologda upland (220 m a.s.l.).

First traced at the lowest level of topography (<120 m a.s.l.), there were several steps of the Late Pleistocene lake abrasion terraces linked to ancient shorelines (Zarrina et al., 1973; Markov, 1977). Parent materials covering this surface were the abraded moraine and fluvioglacial deposits alternating with lacustrine loamy sands and loams.

The abrasion moraine rises above the abrasion terraces as a step (10°) to the Middle Pleistocene terraced surface composed of the main Middle Pleistocene (Riss II or Moscowian) moraine (140–170 m a.s.l.), which occupies a large part of the studied area (6-km long). The surface at this level was characterized by flat plain topography, with individual flat-topped hills of 10–15 m high and of a gentle topography. Soil forming rocks that occur in this territory belonged to different kinds of the Quaternary deposits. The mantle loams were restricted to the areas closest to the abrasion step and to flat areas between hills. The mantle loams underlain by moraine deposits at the depth of 1.0 m were less widespread. Elevated topographic levels of this

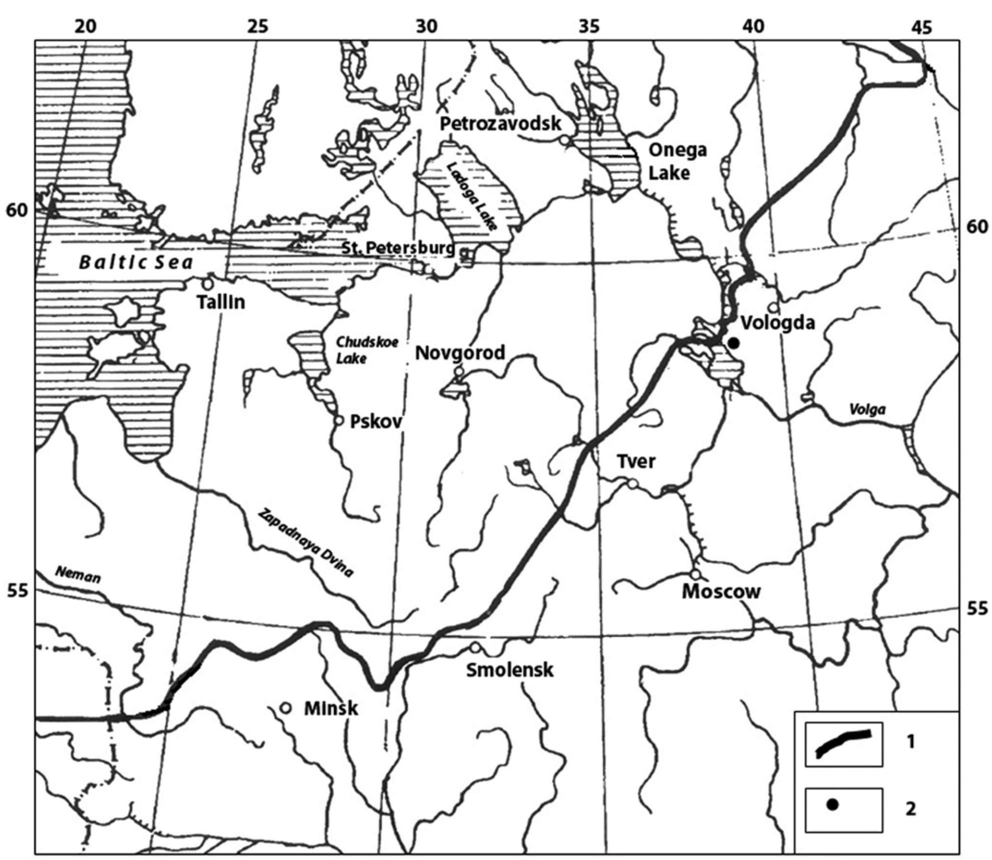

Fig. 1. Boundary of the Valday (Wűrmian) glaciation in the East-European Plain (Chebotareva and Macarycheva, 1982) and location of the studied sequence. 1: Boundary of Valday (Wűrmian) glaciation; 2: location of the sequence.

terraced surface (up to 170 m a.s.l.) were covered with moraine deposits.

The surface at highest levels (170–200 m a.s.l.) constituted the western end of the Vologda upland and was composed of the main Moscow glaciation moraine, which is the soil forming rock for this territory.

The main attention was paid to the study of morpho-lithological features of the Middle-Pleistocene terraced surface and the present day soil cover formed on them, which includes paleosol fragments. Earlier (field study in 2000–2002), we studied the morpho-analytical features of the Late Quaternary paleosol of the paleocatena within this level of topography (Rusakov and Korkka, 2004). That sequence was found in the sand–gravel quarry and was situated 2.3 km North-East of the Rybinsk reservoir. Based on a single ^{14}C analysis obtained for the humus horizon of the paleosol (33,200 ± 2000 yr BP — JIY-4600), it was shown that the buried soil formed on moraine deposits was of the age of early Bryansk Interstadial.

The current paper is based on new original field investigations in the same quarry done in 2003-2005 and resulted in much more correct estimations of the paleopedogenesis and evolution of the environment during the OIS3 within the area.

The paleocatena, which includes carefully investigated paleopedocomplex, is confined to the Middle-Pleistocene terraced surface (160 m a.s.l.) (Fig. 2). The paleocatena is situated in the local gently flat interfluvial surface in good drainage position; the down cut of the nearest local hydrographic network exceeded 15–20 m. The vertical thickness of the cleaning within the paleocatena from surface to the bottom was some 3 m. The studied area of paleocatena consisted of 2 parts. The first (left) one was situated at the place of ancient shallow depression and was 7.5 m long. The second (right) part was restricted to the very gentle slope (<0.5°) and was 13.0 m long. A total length of the paleocatena, including non cleared surfaces, was 33 m. Change in elevation from the south part of paleocatena to the north did not exceed 1.0 m.

The studied paleocatena consisted of the three lithological layers. The upper one (layer I; c. 0.7 m) was represented by the Late Valday brown yellowish mantle loams. These deposits can be distinguished from ordinary mantle loams developed within immense territory of the periglacial zone, by the inclusions of coarse skeletal material, pebbles and gravel. Another morphological feature of the studied mantle loams is the presence of leached silty sands as bottom layers of the thickness of 0.03–0.10 m. This is clearly seen on the second part of the paleocatena (Fig. 2). Sometimes, these mantle loams were characterized by the inclusions of thin clay and/or loamy layers sporadically distributed within the mantle loam layer. The boundary between this layer and the underlain one was wavy and strongly irregular.

The layer II (c. 0.7–2.10 m) was clearly distinguished from the overlain one and consisted of the Riss II (Moscowian) moraine deposits. On the right part of the paleocatena this layer was reduced (Fig. 2). The moist color of the layer was brown to brown-black as a result of the presence of the paleohumus horizons here. Moraine loams were very compact, poorly sorted and contained little skeletal material, viz. gravel, pebbles and boulders. The boundary between layer II and the underneath one was wavy.

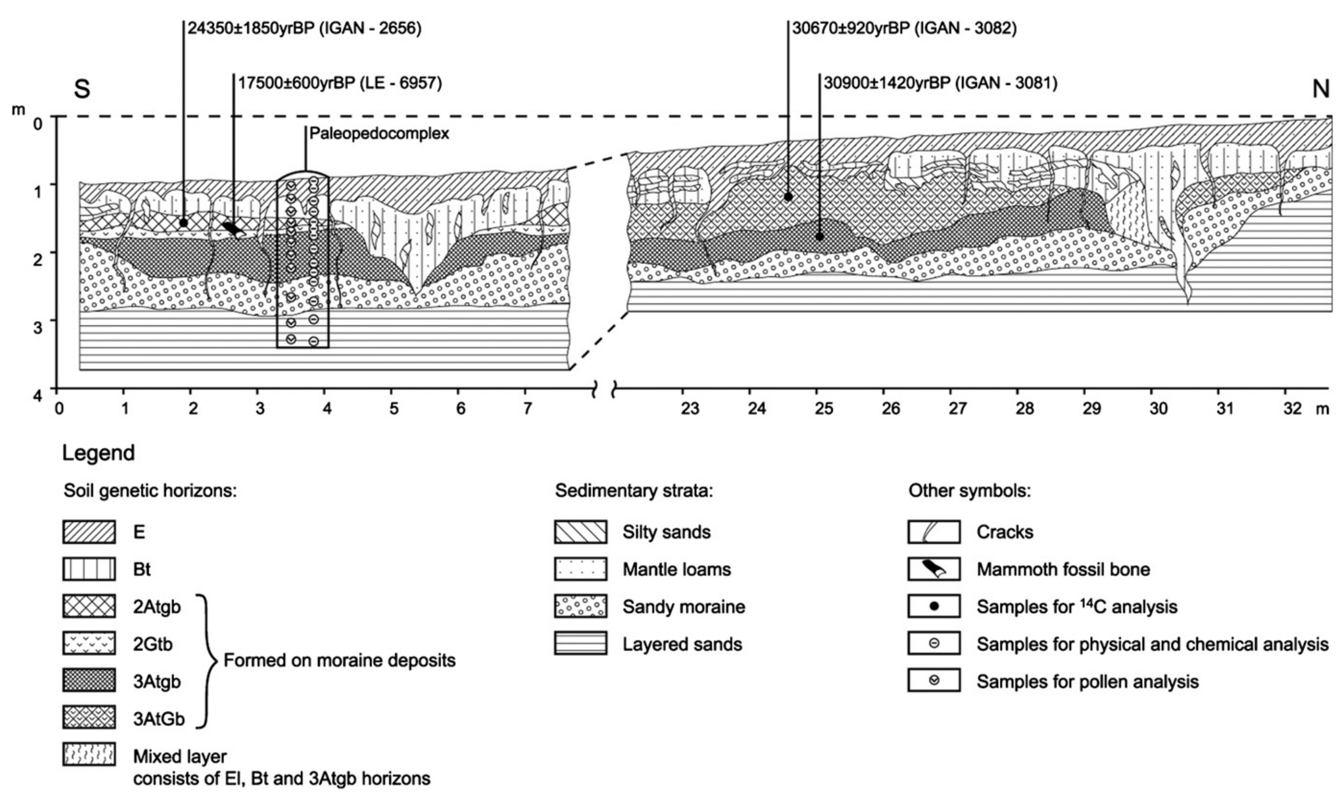

Fig. 2. The paleocatena (a complexly organized heterochronous sequence), which includes the studied paleopedocomplex containing the Middle-Valday paleosol horizons.

Layer III (c. 2.10–3.0 m) contained the yellow-brown sandy till loams enriched with coarse sand, grass and boulders. At its bottom sandy loamy material changed to the layered coarse sandy and gravel deposits.

All the studied layers of the paleocatena contained strong frost/cryogenic deformations represented by wide and deep wedges and cracks/fissures. The wedges, which exceeded 2.5 m wide (Fig. 2), were restricted to layers II and III and were filled in by the loam silty materials from the upper mantle loams. The deep fissures (from layer I downward to the depth of c. 3.0 m) were spread sporadically within the entire thickness of the paleocatena. The fissures were partly filled in by the yellowish mantle loams and the leached coarse sand material.

According to our field study, the paleocatena included two pedostratigraphic units likely formed over the last 30,000 yr. The first unit was represented by the Holocene (modern) Umbric Albeluvisols (the upper A horizon was stripped off to enlarge the quarry). The Holocene soils were formed on the mantle loams. These soils were developed also in the wedges where their thickness could exceed 2.0 m. We observed that processes of textural differentiation, which lead to the formation of the Holocene Umbric Albeluvisols, can develop within the whole 2-m thickness of the mantle loams which fill the cryogenic wedges.

The second pedostratigraphic unit represented by the Late Pleistocene pedocomplex was formed on the till loams only. It consisted of a series of buried adjacent soil horizons and/or paleoprofiles. Thus, on the left part, the paleocatena contained the well-preserved paleosol unit displaying the profile 2Agtb–2Gtb underlain by 3Agtb horizon. The first two horizons were 0.1–0.2 m thick, the 3Atgb one was 0.3–0.7 m thick. The same 3Atgb horizon was recorded in the right part of the paleocatena at the bottom of the pedocomplex, but the overlain part of paleosequence was represented by the 3AGtb horizon only. It means that this horizon replaced the 2Agtb and 2Gtb horizons developed in the left part of the paleocatena. There was a really sharp graduation between Holocene and Late Quaternary soils.

To study pedological features and palynological investigation, the chronosequence included both Holocene and Late Pleistocene (OIS3) pedocomplex and all the lithological layers were chosen. This chronosequence represented by paleopedocomplex was restricted to the left part of the paleocatena between cryogenic fissures (Fig. 2).

Particle-size distribution was determined by sieving and the pipette method, using $Na_4P_2O_7$ as a dispersant. Humus content was measured photometrically (Kaurichev, 1986). The radiocarbon dates from humic acids of paleosols were determined at the Institute of Geography of RAS, Moscow. The fossil bone was dated in the Institute of the History for Material Culture RAS, St. Petersburg. The detailed hierarchical morphological diagnostic of undisturbed blocks from paleosol horizons was made in the Laboratory of Geography of soils at the Faculty of Soil Science of Moscow State University. This diagnostic consisted of mesomorphological investigations, using binocular stereomicroscopes MBS-10 and Stemi-2000C Carl Zeiss and submicromorphological investigations, using Scanning Electron Microscope JEOL jsm-35CF. All morphological photo images were obtained and processed using computer system ImageScop S, which consists of digital camera Olympus Cammedia 5050Z and program of image processing.

Magnetic susceptibility (χ), which is a measure of the concentration of magnetic minerals, was measured on Faculty of Geology, Dept. of Geophysics of St.-Petersburg State University using χ-meter IMBO Shulgin system (St.-Petersburg).

3. Results

As clearly seen from table, pedological features of the Late Quaternary soil horizons are well developed and preserved. The color of both buried humus 2Atgb and 3Atgb horizons is quite similar and clearly differs from that of the paleogley 2Gtb horizon. All the horizons are very compact and cemented; according to our field measurements, the bulk density within these horizons is found to be 1.8–1.9 g cm^{-3}. Despite this bulk, the buried horizons are characterized by well-developed structure, gradually transforming throughout the profile from the nutty–granular blocky to the nutty–prismatic type. A careful

Table 1
Main morphological features of the studied paleopedocomplex consisted of the Late Quaternary paleosols

Horizons, depth, cm	Color	Structure	Soil new formations
2Atgb, 60–68	Brown-black with reddish hue (10YR4/2, dry)	Well developed nutty-granular and subangular blocky	Sporadic rusty and gleyed smudges. Complex organized cutans consist of: 1) thin brown argillans on ped faces (all orientations); 2) reddish brown thin argillans in the channels of large pores and cracks (mostly developed in the upper part); 3) pale yellowish siltans 2–3 mm thick on crack walls enriched by silt material from upper mantle layer
2Gtb, 68–78	Reddish-olivaceous with rusty spots (2,5Y6/4, dry)	Subangular blocky and large prismatic	Rusty smudges, mangans between/on horizontal surfaces of peds. Cutan complex consists of: 1) thin reddish brown argillans on vertical faces of peds and in the channels of large pores; 2) sporadic pale yellowish siltans on vertical surfaces within interblocky space
3Agtb, 78–135	Dark brown-black with yellowish and alivaceous zones (10YR3/2; 2,5Y7/6, dry)	Large nutty-prismatic	Sporadic gleyed smudges with yellowish ochroid ferruginous spots (mostly developed within middle and bottom parts of the horizon), Fe–Mn-nodules. Cutan complex consists of: 1) seldom thin reddish brown argillans on vertical faces of peds and large pores; 2) dark brown argillans 3-5 mm thick on vertical faces of peds, large cracks and pores; 3) a detectable amount of pale siltans on vertical walls of cracks

examination of the soil new formations (Table 1) has shown that all buried horizons have 1) the features of gley processes and 2) the complexly organized cutan structure. The latter is represented by the strong argillans, which were developed in all part of the paleopedocomplex, and the siltans, which were formed mostly in the two upper 2Atgb and 3Atgb horizons.

Reasoning from these morphological features of the pedocomplex, it is worth stressing upon the significant presence of large pores developed in the moraine deposits (mostly in the 2Agtb and 2Gtb horizons) and also on the presence of small pieces of charcoal fragments incorporated into the groundmass of paleohumus horizons. In all horizons of the paleopedocomplex, there was a detectable amount of boulders largely covered with argillans.

Mesomorphological investigations have shown a very compact organization of pedal masses of the paleohorizons and also a strong development of argillans (Fig. 3a–c). The latter cover the ped faces of all horizons and coat the sides of large pores (Fig. 3d).

Further submicromorphological investigations of the buried horizon have allowed us to describe the following morphological features of the studied paleopedocomplex. For instance, a

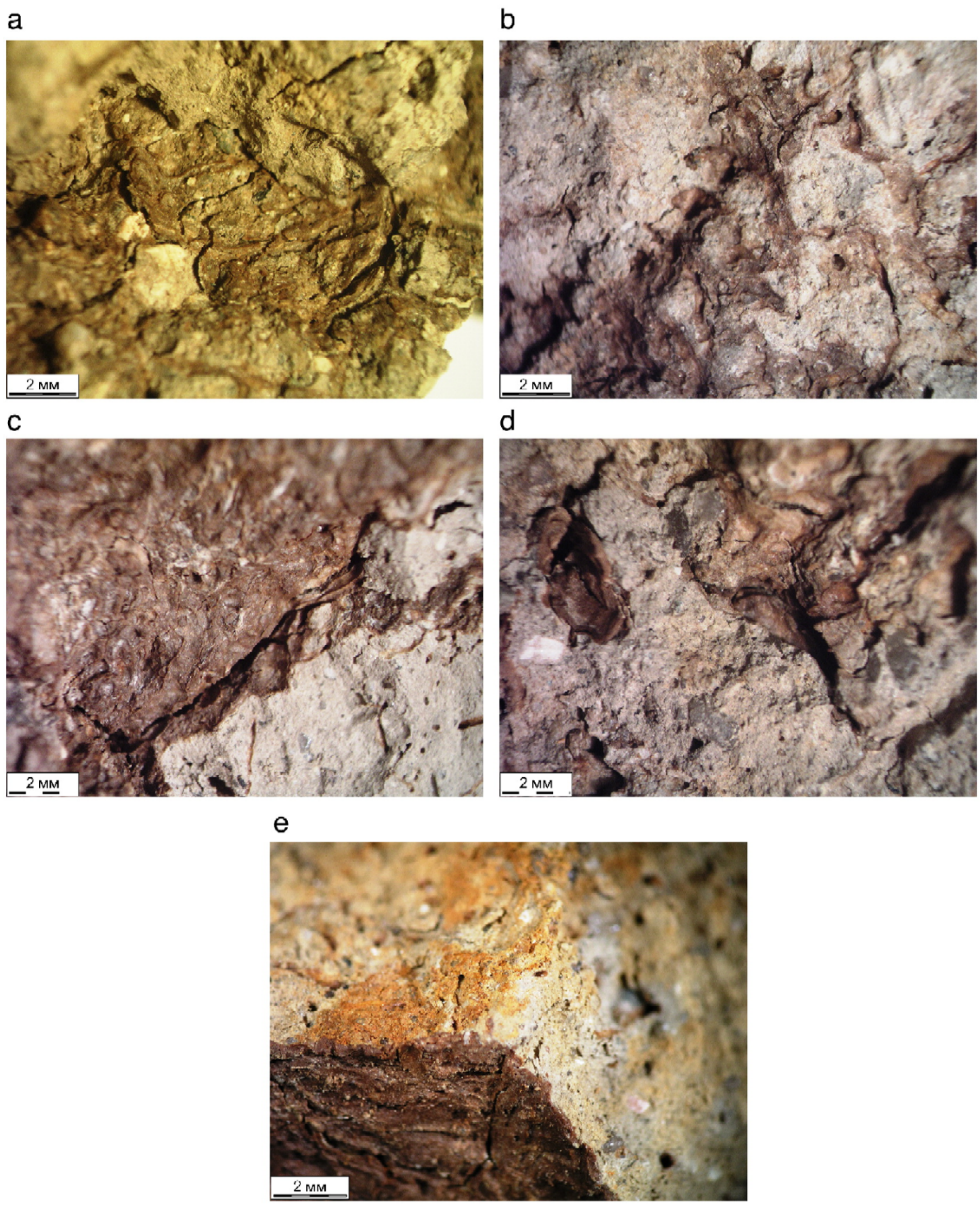

Fig. 3. Mesomorphology of the Middle-Valday paleosol horizons. Strong development of argillans on ped faces: (a) 2Atgb horizon; (b) 2Gtb horizon; (c) 3Atgb horizon. (d) Argillans in the channels of large pores, 2Gtb horizon. (e) Contact argillans and ferrigineous cutans developed within microagregate space, 2Atgb horizon.

sharp boundary is clearly seen between the lithological layers in which the Holocene and Late Quaternary paleohorizons were developed (Fig. 4a). The B horizon groundmass of the modern soil, which is formed in the mantle loams, is quite incoherent and clearly possesses large, intrapedal pores. In contrast, the 2Atgb horizon is rather cemented and compact. There is an obvious difference in particle or microaggregate size between the mantle and moraine loams: those of the latter are much bigger.

Fig. 4b–e shows the organization of cutan complex in the studied paleopedocomplex. There are similar morphological features of the clay coating in the B horizon of Holocene soil and the buried humus horizons. A clearly layered, flaky clay coating has been detected in the 2Atgb and 3Atgb horizons of the pedocomplex. Argillans densely cover the wall of peds and areas within large pores (Fig. 4d–e).

Particle-size distribution data (Fig. 5) show the clear predominance of the loess fraction within the horizons of the

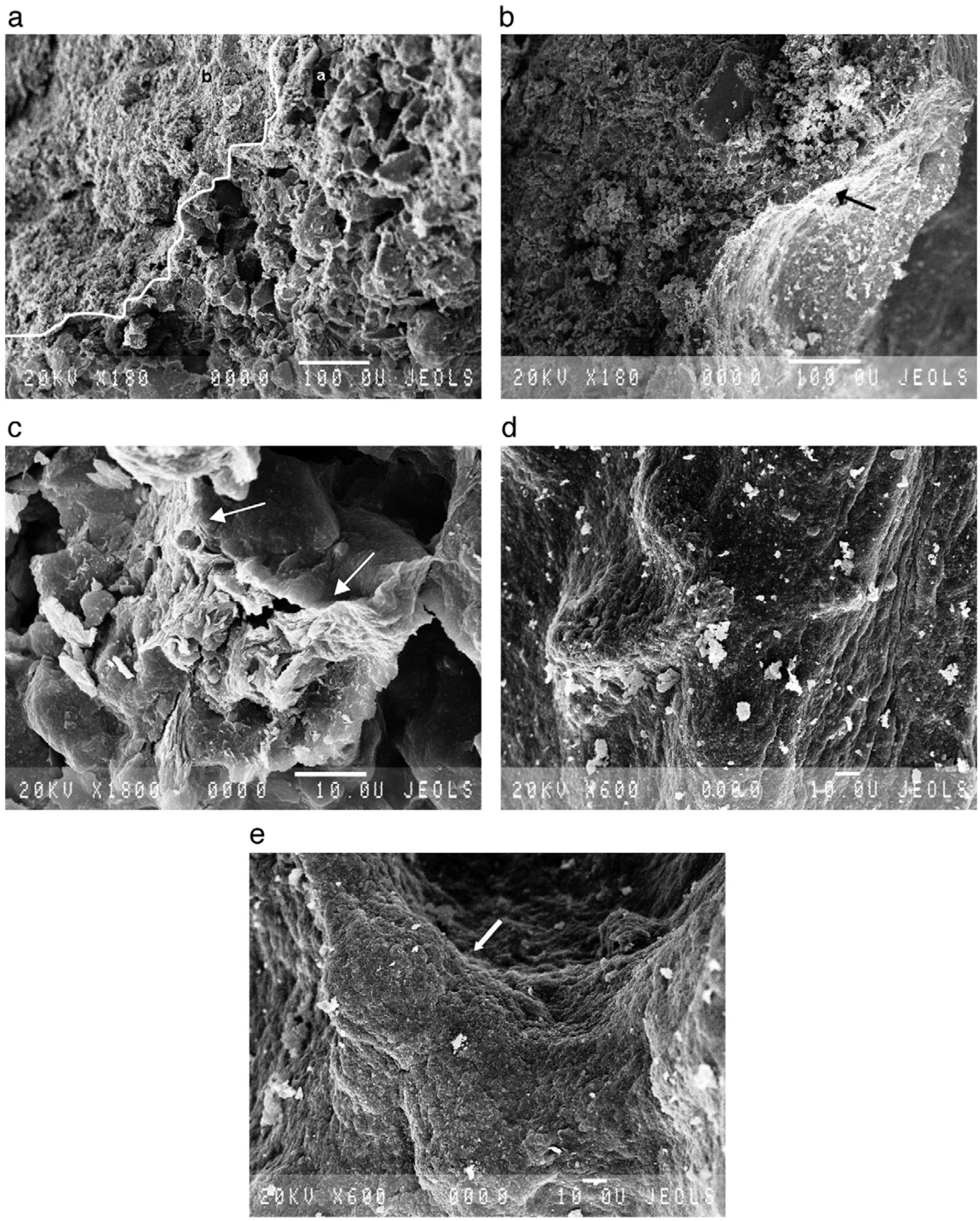

Fig. 4. Submicromorphology of the Middle-Valday paleosol horizons and Holocene soil. (a) Sharply contact between Bt horizon of the Holocene soil (on the right part, a) and 2Atgb horizon of the paleosol (the left part, b). (b) Well developed argillans on ped face, 2Atgb horizon (marked with arrow). (c) Argillans on ped faces of the Bt horizon of the modern soil (marked with arrows).(d) Layered flacky cley coating on ped faces of 2Atgb horizon. (e) Argillans within large pores of the 2Atgb horizon (marked with arrow).

Umbric Albeluvisol, which is quite common for the soils developed on mantle deposits. In this part of strata, there is a decrease of the sandy fraction and also of the medium and fine silt fractions. A distribution of clay content within the horizons of Holocene soil shows a moderate eluvial–illuvial differentiation.

In contrast to the modern soil, all the paleohorizons formed on the moraine deposits, are poorly sorted and contain a considerably higher amount of sand fractions. Buried soil horizons are distinguished from the overlaying soil by a markedly lower content of loess fraction and a higher content of clay fraction. It is especially clearly seen in the 2Gtb horizon, which has the lowest content of coarse sand within the entire profile of the paleopedocomplex. The buried paleohorizons are sandy clay in texture.

Despite the high content of large skeletal material in the underlying paleopedocomplex layers, the fractions < 1 mm, as it has been shown above, are enriched with thin particles, indicating the complex texture of this part of the sequence.

The C_{org}. content in the Holocene soil is low and decreases down the profile (Fig. 5). Regardless of the brown-black color, the amount of organic carbon in the fossil soil horizons is relatively low as well. The highest C_{org}. content was determined for the upper part (83–85 cm) of the second 3Atgb humus horizon of the paleopedocomplex. Generally speaking, the data on C_{org}.in the pedocomplex corresponds to the organic carbon content (0.3–0.7%) in the Late Quaternary paleosols formed on the loess deposits of the East-European plain (Velichko, 2002).

Parameters of the magnetic susceptibility of the Holocene Umbric Albeluvisol formed on the mantle loams (Fig. 5) show much higher values of χ in the plow horizon, a sharp decrease in the eluvial horizon and a moderate increase in its illuvial part. These data are common for texturally differentiated soils. Compared to this part of the paleopedocomplex, samples of the Late Quaternary soil horizons show much less values of the magnetic susceptibility as a result of a continuous press of gleyed processes during the formation of paleosol.

4. Discussion and conclusions

Three radiocarbon measurements made on the humic acids obtained from the paleohumus horizons of the paleopedocomplex (Fig. 2) have revealed the age of 24,350–30,900 yr BP, placing the formation of the paleosol horizons during the Bryansk (Dunaevo or Dniester) Interstadial. This period corresponds to the Shtilfried B, the Grand Bya, or the Denecamp in terms of the classifications adopted in Western Europe (Faustova and Velichko, 1992; Bolichovskaya, 1995). The Bryansk Interstadial took place at 31,000–25,000 yr BP (Chebotareva and Macarycheva, 1982), corresponding to the OIS3 (Shackleton et al., 1991).

The Bryansk Soil and the soils formed during the Middle Valday Interstade have been described from different regions of western and eastern Europe (Haase, 1963; Lieberoth, 1964; Paepe, 1966; Ruske and Wünshe, 1968; Ruske and Wünshe,

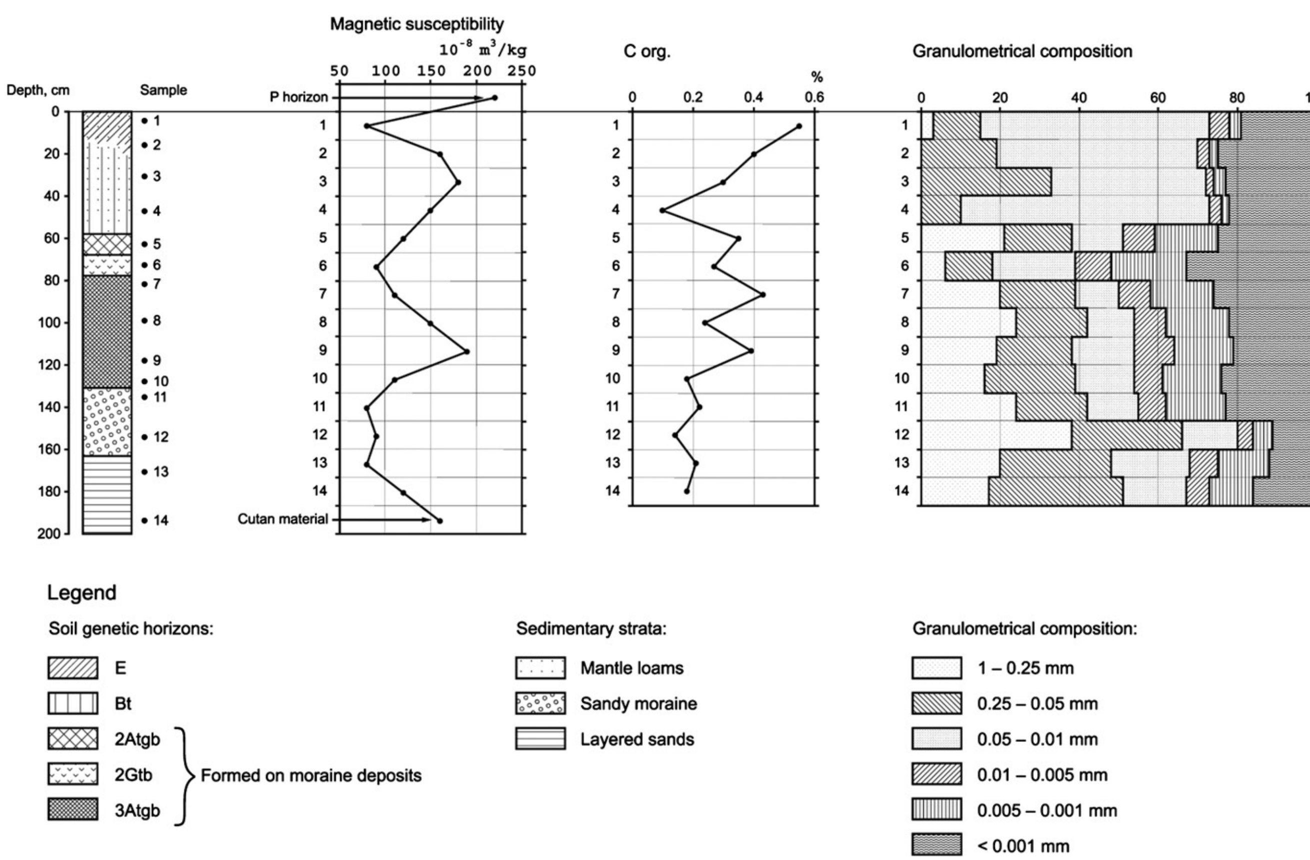

Fig. 5. Magnetic susceptibility, content of organic carbon ($C_{org.}$) and granulometrical composition of the studied paleopedocomplex.

1968; Seppala, 1971; Velichko and Morozova, 1972; Jersak, 1973; Morozova, 1981; Morozova, 1982; Semmel, 1989; Zöller and Löscher, 1997; Velichko, 2002). The sequences, including the Bryansk Soil, confined to the center of the East European Plain, were widely discussed during the work of the V International Symposium on Paleopedology, Russia, Suzdal, 2000 (Velichko et al., 2000; Alifanov et al., 2000) and the Joint Workshop Meeting “Loess and paleoenvironment”, Russia, Moscow, 2003 (Velichko et al., 2003). It is worth noting that all the aforementioned paleosols were formed only in the loess and loess-like deposits.

According to the obtained data, we have classified the Bryansk Soil as the Umbric Gley soil represented by separated paleohorizons (Fig. 2). Besides the presence of 2Gtb horizon in the paleopedocomplex, there were features of gley processes in all the paleohorizons, which took place in the Middle Valday, such as sporadically rusty and glayed spots and smudges, Fe–Mn-nodules, ferruginous cutans. For example, the latter are clearly seen in the horizontal ped faces within the soil block of the 2Atgb horizon; on the vertical ped wall of the block, these cutans are markedly broken by thick continuous argillans (Fig. 3e). The clear presence of charcoal pieces within the intrapedal mass is also related to the Late Quaternary pedogenesis.

Earlier (Rusakov and Korkka, 2004), we examined some micro-morphological features of the Bryansk Soil of the same paleocatena. We interpreted planar voids, incomplete pedality, blocky structure, specific redoximorphic features (especially ferruginous infillings in the channels), charcoal microfragments and ferruginous nodules incorporated in groundmass as resulting from the pedogenic processes during the formation of the Bryansk Soil.

Parameters of the magnetic susceptibility show low values in the Bryansk Soil horizons (minimum in the 2Gtb horizon somewhat higher in 2Atgb horizon) compared to the upper Holocene soil (Fig. 5). We have assumed that this is a result of the development of previously strong gley processes, which destroyed magnetic ferruginous minerals in the paleosol; this distruction was only partly compensated by their synthesis in 2Atgb horizon. The modern and buried humus horizons are distinguished by this feature (Fig. 5). The big content of clay fraction and the sum of fractions<1 mm are probably related to the gley processes that occurred in the entire paleogley horizon.

Besides the described paleopedological features developed during the Middle Valday, another important evidence of that period seems to be the presence of the shin-bone of a young mammoth (identified by Drs N. Burova and P. Mashenko from the Palaeonthological Institute, the Russian Academy of Sciences). This specimen was incorporated in the moraine deposits in the lower part of paleocatena at an angle of about 45° in 3 paleolayers: 2Atgb, 2tGb and the upper part of 3AtGb horizon (Fig. 2). The radiocarbon date obtained (17,500 ± 600 yr BP) shows that the fossil bone is relatively younger than the paleosol layers in which it was incorporated. We suppose that the mammoth bone was integrated into the paleosol after its development, due to solifluction or cryogenic processes which activated during Late Valday.

On the basis of maps showing the Bryansk Interstadial soil cover reconstruction in Europe (Velichko and Morozova, 1982) and in the East-European Plain (Velichko, 2002), we can confirm that the studied paleolpedocomplex displays the northernmost occurrence of the Bryansk Soil. Yet, this paleolpedocomplex is situated in the territory for which a reconstruction of the OIS3 soil cover has not been completed. According to the examined maps, the nearest recorded occurrence of the Bryansk Soil lies 300–500 km to the south of the area at hand. In that area, the soil cover was represented by the Cryogenic Gley Soil combined with the Umbric Cryogenic Gley Illuvial–calcareous Soils. The modern analogues of the Bryansk Soil are the Gelic Umbrisols developed in the central Yakutia, i.e. in eastern Siberia with a severe, extracontinental climate (Velichko and Morozova, 1982).

To examine the environmental evolution of the studied area during the OIS3, 12 samples were taken from the paleopedocomplex (Fig. 2), the underlain layers and the overlain Holocene soils for a palynological analysis. The pollen mainly belonged to the following plants: *Pinus*, *Betula*, *Betula nana*, *Artemisia*, *Asteraceae*, *Umbelliferae*, *Bryales* and *Polypodiaceae*, whereas the pollen value of the examined samples happened to be irregular (Fig. 6). The maximum amount of pollen was observed in the middle part of the paleopedocomplex on moraine deposits (the upper and middle parts of the 3Atgb and 2Gtb horizons) and in the B horizon of the Holocene Umbric Albeluvisol developed on silty loams. The bottom part of the 3Atgb horizon (at the depth of 110–120 cm) and the underlain sandy moraine were poorly enriched with pollen and spores.

Based on the obtained data, it is possible to subdivide the development of the paleo-vegetation, during which the paleopedocomplex horizons were formed, in four stages.

The first stage (the 3Atgb horizon at the depth of 110–113 cm). Pollen of herbs and spores predominated in the palynological spectrum, viz. the pollen of *Poaceae*, *Cyperaceae*, *Rosaceae*, *Plumbaguinaceae*, *Caryophyllaceae* and *Cehnopodiaceae* and spores (*Bryales*, *Sphagnum*, *Botrichium*) predominate. The amount of tree and shrub pollen did not exceed 10%. Thus, the beginning of the Bryansk Soil formation was under the influence of tundra plant associations, with a little participation of forest–tundra phytocoenoses.

The second stage (the 3Atgb horizon at the depth of 90 cm). The amount of trees and shrub pollen exceeded 54%, especially that of *Pinus*, *Betula*, *Juniperus*, *Salix*, *Alnus* increased in the palynological spectrum. These data seem to support the existence of forest–tundra plant formations, likely to be the prevailing type of vegetation at that time.

The third stage (the 2Gtb horizon at the depth of 68–78 cm). In this layer of the paleopedocomplex, the palynological spectrum was dominated by tree and shrub pollen (67 %), and spores exceeded 15 %. Pine and birch pollen predominated, but spruce and alder pollen have also been detected. There were inclusions of *Lycopodium clavatum* and *L. complanatum* grains in the palynological spectrum. The palynological spectrum of this stage reflects the optimum of climate conditions during the Bryansk Interstadial, when the periglacial north taiga landscapes were alternating with the dominant forest–tundras.

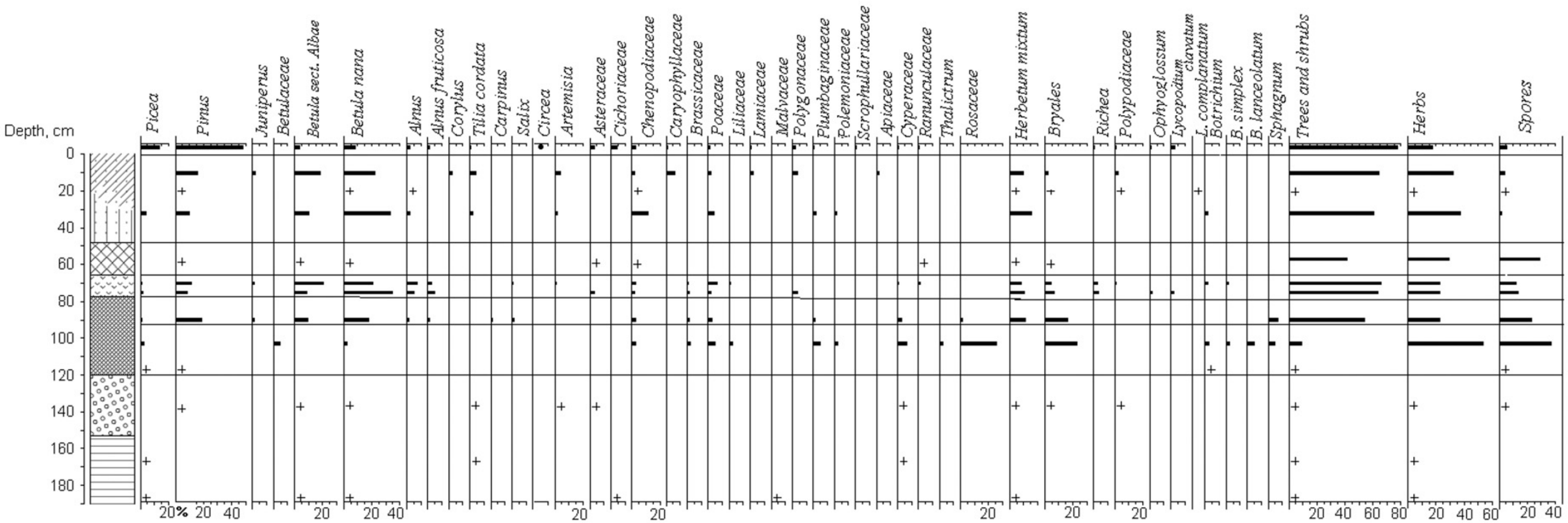

Fig. 6. Palynological spectrum of the studied paleopedocompex. Symbols of pedostratigraphy and sedimentary strata are the same as on Fig. 2.

The forth stage (the 2Atgb horizon, overlain by mantle loams, at a depth of 60–68 cm). In this layer, a reduction of tree pollen and a complete lack of spruce and alder pollen have been registered, whereas the amount of pigweed pollen abruptly increased. This change in palynological spectrum indicates the aridization of climate and, with regards to landscape, the predominance of forest–tundra formations with inclusions of tundra–steppe floral associations.

The pollen–spore spectra of the Holocene Umbric Albeluvisol has indicated the predominance of arctic birch, pigweed and herb pollen. During the Late Valday period, periglacial shrub–tundra plant associations alternated with forest–tundra and tundra–steppe landscapes were widespread within the periglacial zone of East-European Plain (Markova et al., 2002). The palynological spectrum of modern soil (Fig. 6) suggests that the spruce–pine and pine–birch formations were widespread during the developing of the Umbric Albeluvisol.

Thus, reasoning from the obtained data it is safe to conclude that the paleoenvironment of the Bryansk Interstade was heterogeneous. At the beginning of the Middle Valday period and at its final stage, the forest–tundra vegetation predominated. During the optimum of Bryansk Interstade, the periglacial pine–birch formations were widespread. Analogous data on the palinological spectra have been obtained for many paleosequences of the East-European Plain with regards to the area between 56°–61°N (Arslanov et al., 1966; Chebotareva and Makarycheva, 1974; Valueva et al., 1979; Lavrushin and Spiridonova, 1998). It has been shown (Markova et al., 2002) that the most characteristic landscape developed within the East-European Plain between 54°–59°N at that time was the periglacial forest–tundra–steppe. This vegetation was made up by a mixture of forest plant formations (birch, pine and spruce), plant formations of meadow steppe, tundra associations, and steppe halophilous plant formations.

Besides the paleopedogenetic features and the environmental evolution, it is possible to treat the paleopedocomplex as a direct indicator of environmental changes taken place at final stages of the Valday Glaciation. In this regard, the well-developed cryogenic deformations represented by deep fissures and wedges (Fig. 2) are of great importance, as the origin of the mantle loams of the upper layer of the paleocatena do as well.

The width of cryogenic wedges is restricted to the II (including the Bryansk Soil) and partly to the III lithological layers and belongs to the Vladimir stage (Velichko and Morozova, 1982). These wedges are filled in with the silty mantle loams accumulated during the Late Valday. According to our field study and also to the hypothesis put forward earlier (Rusakov and Korkka, 2004), we have assumed that the mantle loams covering the Bryansk fossil horizons display the subaqueous genesis which can be supported by the following evidences. These loams have a sharp boundary with the underlying moraine deposits (Fig. 4a), which are enriched with a small content of gravel and pebbles. At the bottom of this layer, the leached silty sands of strong subhorizontal orientation are present. The origin of these layers appears to be related not to pedogenic processes, but to sedimentation during a highstand (~160 m a.s.l.) of wide extraglacial lakes existing here during the maximum advancement of the Valday Glaciation. In this regard, the fissures and cracks developed throughout the thickness of the paleocatena from the upper part of the mantle layer (just below the E horizon of the modern soil) to the sandy moraine layer (Fig. 2) were developed between 10,000-15,000 yr BP during final cold stages of the Late Valday. On the right part of the paelocatena (Fig. 2), the right "shoulder" of the cryogenic wedge is clearly seen; this wedge is jammed between the 3AtGb horizon and mantle loams filling it. This "shoulder" is represented by a mixed layer, consisting of crushed fragments of paleohorizon and E and Bt horizons of the Holocene paleosol. We have assumed that this phenomenon reflects the really strong events of the Late Valday environment and can be considered the feature of specific glacial processes.

Now let us examine the problem of organization of the cley cutan complex, which is one of the main morphological features of the sequence, including the Holocene and Middle Valday paelopedocomplex. Well-developed argillans of the Bt horizon of the Umbric Albeluvisol are clearly seen on Fig. 4c. Our investigations of the modern soil of this paleocatena in the field have shown that the markedly thicker and more developed reddish and reddish brown argillans were common in the clay lenses sporadically distributed throughout mantle loams.

On the other hand, the well-developed cutan complex penetrated the thickness of thall the paleohorizons (Table 1, Figs. 3 and 4b,d,e). It is worth noting that argillans were more developed in the upper part of the Late Quaternary soil horizons and gradually decreased in the bottom part of the paleopedocomplex. Clay cutans cover a large quantity of coarse material of the Bryansk Soil, such as boulders and pebbles, and were markedly developed both on the surface of and within the mammoth shin-bone bone. Clay cutans often covered the walls of cryogenic cracks, which first appeared in the mantle loams and then expanded down the moraine loams.

Thus, the illuvial clay coating, which was developed within the Bt horizon of the Umbric Albeluvisol and on mantle loams and horizons of the Bryansk paleosol horizons developed on moraine deposits, was formed in the course of the Holocene pedogenesis, as "roots" of the illuvial part of the modern surface soil. This is also confirmed by the magnetic susceptibility analysis (Fig. 5). We have observed a considerable value of χ of the clay cutans covering wall peds of the paleosol and also in the illuvial part of the Holocene soil. This value allows us to assume the existence of a genetic relationship between the cutans developed in this part of strata and those of the overlain modern soil.

In this regard, we can draw a conclusion that the upper horizons of the paleopedocomplex, especially those restricted to the highest layers (2Atgb and 2Gtb horizons), could serve as illuvial part of the Holocene texturally differentiated soils as in a case of ordinary Umbric Albeluvisols formed on two-member deposits (the mantle loams underlain by the moraine). These soils were seen, for example, in the end-right part of the paleocatena.

Finally, we can conclude that during the Middle Valday Interstade the predominant individual pedogenic processes (IPP) are to be described by the following characteristic time (CT) (Targulian, 2005): 1) fast IPP, CT $- n$&middot10^1–10^2 yr:

gleyzation, aggregation and cracking; 2) medium-rate IPP, CT$-n$ &middot 10^2–10^{3-4} yr: humus formation. In the Holocene, the medium-rate IPP dominated, such as, lessivage and partluvation, podzolization, blocky and prismatic structuring and humus formation. Some of these processes overlapped with the Middle Valday pedogenesis, of which morphological features have been recorded in paleosol horizons. Despite the predominance of fast IPP during the formation of Bryansk paleopedocomplex, the result of these processes has been relatively stable and preserved in soil memory as a reflection of the Holocene pedogenesis.

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