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The Bryansk fossil soil of the extraglacial zone of the Valday glaciation as an indicator of landscape and soil forming processes in the center of the Russian Plain

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ABSTRACT

The morphologic-analytical features of the Bryansk fossil soil classified as Umbric Gley Soil formed in moraine loams and overlain by Upper Pleistocene moraine of the Valday (Würmian) glaciation are described. This paleosol, formed during the Dunaevo Interstadial of the upper Pleistocene and corresponding to the marine isotope stage 3, is confined to the extraglacial zone of the Valday glaciation. The paleosol marks the northernmost area of existence of the Bryansk soil cover in Europe. It is shown that the Bryansk fossil soil can serve as a direct indicator of landscape and soil forming processes in the center of the Russian Plain.

Key words: paleosol, Bryansk Soil, moraine deposits, Würmian glaciation, late Pleistocene, East-European Plain.

RESUMEN

Se describen las características analítico-morfológicas del suelo fósil Bryansk clasificado como Gleysol úmbrico formado en sedimentos morrénicos y sobreyacido por morrenas de la glaciación Valday (Würmian) del Pleistoceno superior. Este paleosuelo, formado durante el interestadial Dunaevo del Pleistoceno superior y correspondiente a la etapa isotópica marina 3, está confinado a la zona extraglacial del la glaciación Valday. El paleosuelo marca el área más al norte donde se presenta el suelo Bryansk en Europa. Se demuestra que este suelo fósil puede servir como indicador directo de los procesos formadores de paisaje y suelo en el centro de la Planicie Rusa.

Palabras clave: paleosuelo, Suelo Bryansk, depósitos de morrena, glaciación Würm, Pleistoceno tardío, Planicie del Este de Europa.

INTRODUCTION

The study of the Bryansk Soil, which formed during the Dunaevo interstadial of the Valday (Würmian) glaciation (marine isotope stage 3), is of key importance for reconstructing the paleolandscape and paleoclimatic conditions of the late Pleistocene. Meanwhile, diverse interpretations of this soil stratigraphic unit are reported in the literature. These different interpretations result from variations in profile characteristics within loess districts of the Russian plain (Morozova, 1981), incomplete study of these paleosols (Velichko and Morozova, 1972), an absence of likely analogues within Holocene soils of Europe (Velichko and Morozova, 1982) and cryogenic pedomorphism of the soil within the periglacial zone of the last glaciation (Velichko, 1982).

The great majority of descriptions of the Bryansk Soil are within loess belts that are relatively distant from the glacial boundary. No studies have investigated the Bryansk Soil formed in moraine deposits, or in the extraglacial zone of the Valday glaciation. Thus, we studied the Bryansk Soil formed in moraine deposits, and obtained results serving as direct indicators of landscape and soil forming processes in the center of the Russian Plain during the late Pleistocene.

METHODS

Particle-size distribution was determined by sieving and the pipette method, using $Na_4P_2O_7$ as a dispersant. Humus content was measured photometrically, pH_{water} was determined in water mixture (soil: water mixture 1:2.5). The radiocarbon data from humic acids were determined at the Institute of Geography of Saint-Petersburg State University. Thin sections were prepared from undisturbed blocks from paleosol horizons and studied under petrographic microscope; for the description, the terminology of Bullock *et al.* (1984) was used.

RESULTS

The basis of this research consists in our field measurement of soil cover structure and parent materials in the center of the Russian Plain (Vologodskaya oblast, Therepovetz district). This territory is confined to the northwest edge of the Sheksnin–Kostroma interfluve (Vologodskaya upland). The study area is located in the extraglacial zone of the Valday (Würmian) Glaciation (Figure 1). One of the important geomorphological features of this part of the Sheksnin–Kostroma interfluve is an absence of pronounced hummocky topography of end-moraine.

The geomorphology of the area consists of a series of terraces and terraced surfaces of different ages, rising as ledges from the Rybinsk water storage reservoir (110 m

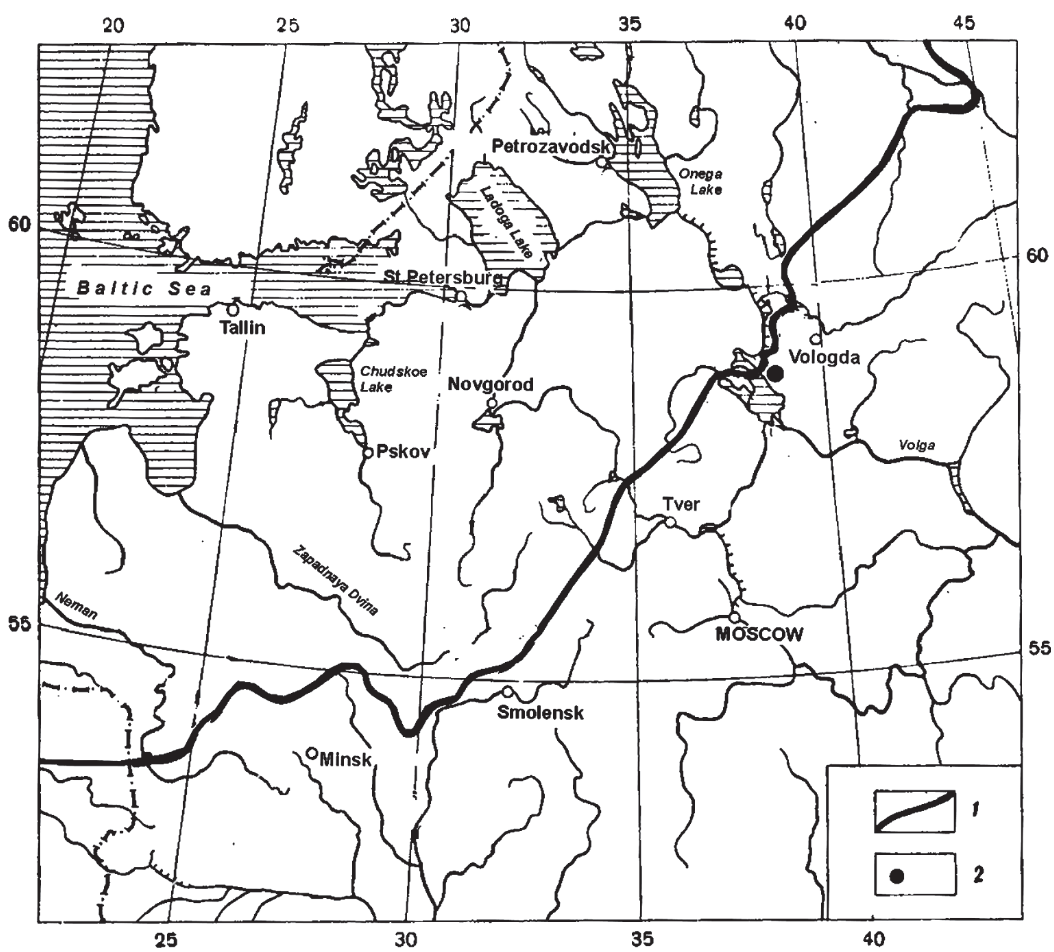


Figure 1. Boundary of the Valday (Würmian) glaciation in the East-European Plain (Chebotareva and Makarycheva, 1982) and location of the studied sequence. 1: Boundary of Valday (Wurmian) glaciation; 2: location of the sequence.

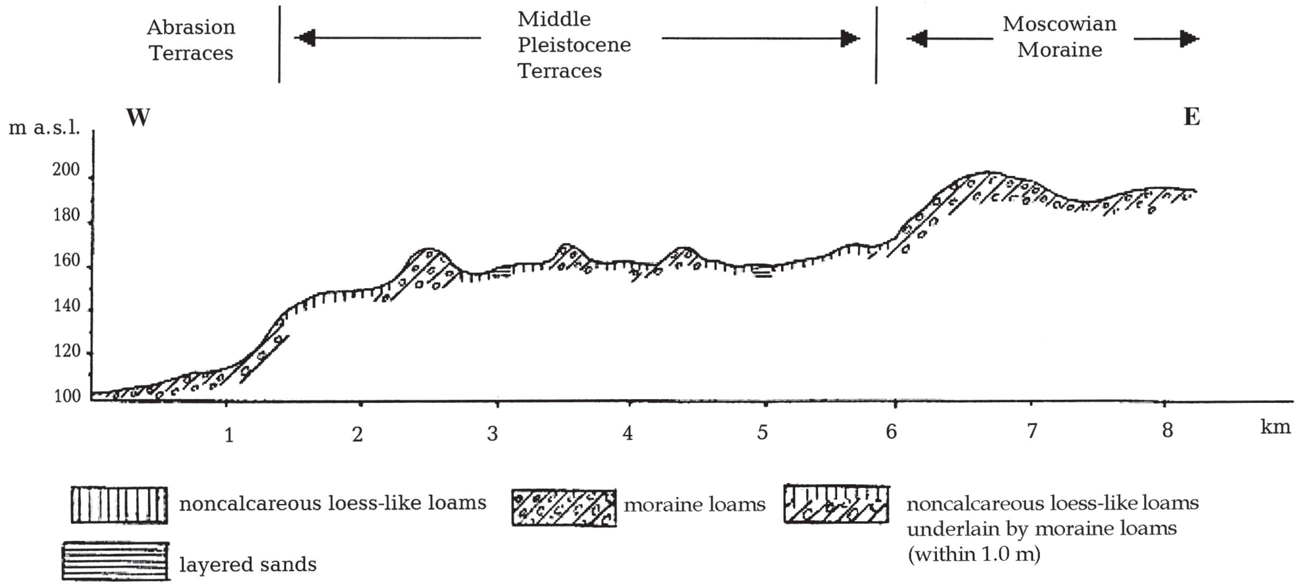


Figure 2. Relief and parent rocks of the northwest edge of the Sheksnin–Kostroma interfluve (Vologodskaya region).

a.s.l.), which is located in the tectonically conditioned Mologo–Sheksna lowland at the western branches of Vologodskaya upland (219 m a.s.l.) (Figure 2).

Traced at the lowest level of the topography (<120 m a.s.l.) are several steps of late Pleistocene lake abrasion terraces linked to ancient shorelines (Zarrina *et al.*, 1973; Markov, 1977). Parent materials covering this surface are abraded moraine deposits enriched with inclusions of boulders and to a lesser degree fluvioglacial deposits alternating with lacustrine loamy sands and loams.

Rising above the abrasion terraces is a steep (10°) abrasion moraine step to the middle Pleistocene terraced surface composed of the main Moscowian moraine (140–170 m a.s.l.), which occupies a large part of the study area (Figure 2). The surface of this level is characterized by flat plains topography with inclusion of individual hills with a relative height of up to 10–15 m. The topography of these hills is gentle, the tops of the hills are flat, and slopes are less than 5°. Soil forming materials that occur in this territory belong to different kinds of Quaternary deposits. Noncalcareous loess-like loams are restricted to the areas closest to the abrasion step and to flat areas between the hills. The noncalcareous loess-like loams are underlain by moraine loams at a depth of 1.0 m and are less widespread. These parent materials alternate with sporadic outcrops of layered glaciolacustrine sands. The elevated levels of topography within this surface (up to 170 m a.s.l.) are covered by moraine loams.

The surfaces of the highest levels (170–200 m a.s.l.) constitute the western end of the Vologodskaya upland and are composed of the main Moscow glaciation moraine. Gentle hilly relief is characteristic for this part of the study area. Moraine loams distinctly dominate the soil forming material of this territory.

Most of investigated area is plowed. Separate woodlands are confined to undrained wetlands between hills and automorphic position of hilltops within eastern parts of the upland. Swampy grasslands are developed on terraces of the lowland.

Holocene age Umbric albe luvisols and Umbric gleyic albe luvisols are developed on all these soil forming materials. Umbric gleyic soils are formed on flat surfaces of the Mologo–Sheksna lowland.

Close attention was paid to the study of the soil cover structure of the middle Pleistocene terraced surface. Here, the soil cover is complex and contains a heterochronous sequence that includes a buried Bryansk Soil. We studied a profile in a gravel quarry located 2.3 km to the north-east of the Rybinsk water reservoir (location 58º 49' N, 38º19' E; height 155 m a.s.l.). This profile, with a thickness of 2.0 m, consists of the following horizons: B↑↓-B2-2Bt-B3t-B4tg-Agb-Gb (Figure 3). Note that the upper part of the sequence, including the modern humus horizon and layers composed of noncalcareous loess-like loams, has been stripped off to enlarge the quarry. These deposits, which are underlain by moraine loams at a depth of 0.5–0.7 m, cover the nearest areas to the quarry.

The description of the whole profile, including the paleosol, is given below:

B↑↓ (0–15 cm). Natural horizon mixed by human impact. Variously colored: brown-yellowish (2.5Y 5/4) noncalcareous loess-like loam with reddish-gray fragments of moraine loam. Slightly moist, fine platy-granular structure, weakly compact. Many roots, small gravel and pebble. Abrupt transition, wavy boundary.

B2 (15–25 cm). Yellowish-brown (10YR 6/4),

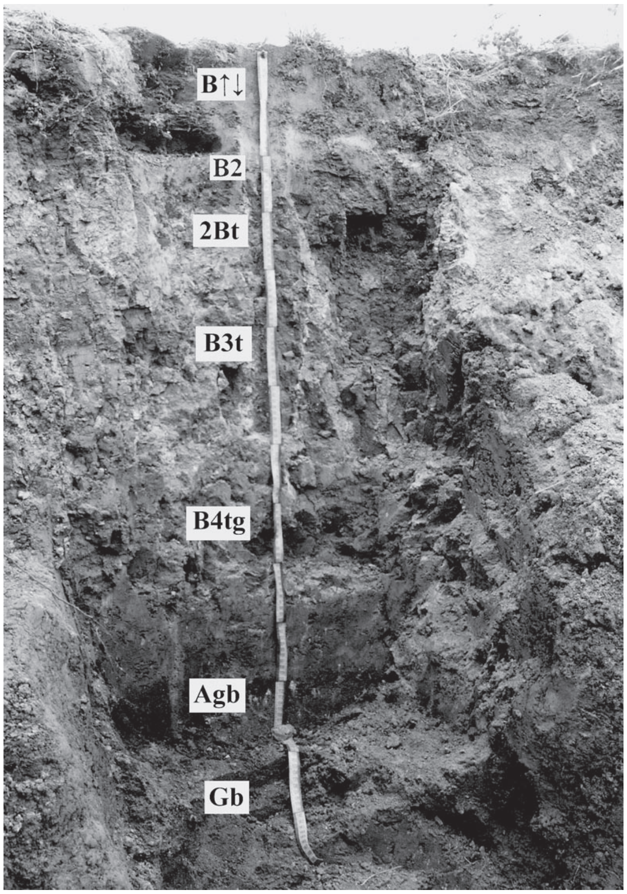


Figure 3. The complex organized heterochronous sequence including the Bryansk soil.

moderately moist, clay loam, fine granular-platy structure, rather compact. Weak skeletans on peds, many roots, small gravel, few roots. Abrupt transition, wavy boundary.

2Bt (25–42 cm). Brown-reddish with yellowish hue (10YR 5/4), moist, clayey, large nutty-blocky structure, compact, porous. Whitish skeletans and red-brownish films on ped faces. Small boulders, some grussified. Gradual transition, wavy boundary.

B3t (42–71 cm). Reddish-brown (10YR 6/4 + 7,5YR 4/4), moist, clayey, distinct large prismatic structure, very compact, porous. Abundant brown films on ped faces and along the walls of the pores in peds, sporadic gleyed smudges. Boulders, grusses. Distinct transition, wavy boundary.

B4tg (71–104 cm). Glaucous-olivaceous with rusty spots (5Y 7/2 + 7.5YR 6/8), moist, clayey, blocky structure, very compact, weakly porous. Gleyed smudges, boulders, some covered by Fe-coatings. Abrupt transition, tonguing boundary.

Agb (104–118 cm, with fragments having a thickness 104–148 cm). The thickness of the horizon varies from 14 to 25 cm. Brown-black with reddish hue (10YR 4/2), moist, clayey, cemented nutty-platy structure, very compact, porous. Discontinuous brown-reddish and iron-gray films on ped faces and along the walls of the pores in peds, rusty spots, gleyed smudges. Small boulders, grusses and wood coals. Abrupt transition, wavy boundary.

Gb (118–150 cm). Reddish-olivaceous with rusty spots (2,5Y 6/4), wet, loam, blocky structure, very compact, clammy. Gleyed smudges, grayish-brown films on ped faces, boulders, grusses.

Particle-size distribution data (Table 1) and macromorphological description of the profile shows that the layers of the sequence and paleosol developed from moraine loams. These deposits are poorly sorted, contain skeletal material (gravel and pebbles in upper horizons and more large material such boulders in the middle part and at the bottom of the sequence). Based on the particle size and morphological data, we subdivide this profile into three parts.

The upper (0–25 cm) horizons of the sequence are representative of mixed material and consist of moraine and noncalcareous loess-like loams. An occurrence of the latter deposits is shown in Figure 2. In the upper loamy and clay loam horizons there is a notably higher content of coarse sand and large silt fractions; the clay content in B2 horizon is higher.

The upper and lower intermediate layers (25–104 cm) consist of clayey Valday moraine. Granulometric composition shows a decrease in coarse sand content and an increase in fine sand content from 2Bt horizon to B4tg. The content of clay fractions and fractions <0.001 mm is relatively high within this part of the sequence (Table 1).

The third part of this profile is a well preserved upper Pleistocene paleosol having the profile Agb-Gb found at the bottom of the sequence formed, presumably in the Moscowian moraine. This soil is clay to sandy clay in texture. The content of fine sand fraction is relatively high.

Generally speaking, the fossil soil is distinguished from overlaying layers by markedly less content of coarse sand fraction and higher content of fine sand fraction. The content of loess-like fraction is higher in the 0–104 cm thick layer (Table 1). It might be explained by both the grinding effect during the glacier movement and the cryogenic comminution of the material.

The humus content in the upper (0–15 cm) horizon is 0.8 %, and in the upper and lower intermediate layers it varies from 0.3 to 0.4 %; in the Agb horizon, the content of humus reaches 1.0 %. All layers of this sequence are leached of carbonates: pH_{water} varies from 5.0 to 5.6 within the whole profile.

DISCUSSION

The radiocarbon data from humic acids obtained for the Agb horizon –33,200±2,000 ^{14}C yr BP (JIY-4600)– place the age of the formation of this paleosol to the early Bryansk (Dunaevo) Interstadial. This period of the upper Pleistocene

Table 1. Particle-size distribution and some chemical properties of the organized heterochronous sequence including the Bryansk Soil.

Horizon	Depth (cm)	Particle-size classes in mm (%)							pH_{water}	Humus (%)
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01		
B↑↓	0 –15	41	4	26	5	8	17	30	5.5	0.8
B2	15 – 25	28	3	24	8	6	31	45	5.2	0.3
2Bt	30 – 40	19	1	25	4	12	35	55	5.2	0.3
B3t	50 – 70	8	11	25	7	13	37	57	5.0	0.4
B4tg	80 – 100	7	10	29	4	13	37	54	5.3	0.4
Agb	104 – 118	5	23	19	7	13	34	54	5.6	1.0
Gb	120 – 150	7	43	15	5	11	19	34	5.5	0.3

(closing phase of the middle Valday) took place 31,000–25,000 BP (Chebotareva and Macarycheva, 1982; Borisova and Faustova, 1994) and corresponds to the marine isotope stage 3 (Shackleton *et al.*, 1991).

The formation of the late Pleistocene Bryansk Soil and the soil cover structure are linked to the thaw phase of the middle Valday in the periglacial zone of Europe. The Bryansk Soil and/or soils formed during the marine isotope stage 3 have been described in different parts of western and eastern Europe (Ruske and Wünshe, 1961; Haase, 1963; Lieberoth, 1964; Paepe, 1966; Ruske and Wünshe, 1968; Seppala, 1971; Velichko and Morozova, 1972, 1982; Jersak, 1973; Morozova, 1981; Zöller and Löscher, 1997). The sequences including the Bryansk Soil confined to the center of the East European Plain were widely presented at the V International Symposium on Paleopedology, Russia, Suzdal, 2000 (Velichko *et al.*, 2000; Alifanov *et al.*, 2000). All of the paleosols marked above formed only in loess and loess-like deposits.

According to our interpretation of the field and laboratory data, the paleosol formed probably in Moscowian (middle Pleistocene) moraine loams and was buried by Valday (upper Pleistocene) moraine loams. The Bryansk Soil is classified as an Umbric Gley soil. The profile we studied is cracked and turbated by cryogenic deformations of the Vladimir (Stillfried B) stage (Velichko and Morozova, 1982).

Aside from mesomorphological description of the sequence, the micromorphological features of the paleosol were also studied (Figure 4). We interpret planar voids, incomplete blocky pedality, charcoal microfragments and specific redoximorphic features (especially ferruginous infillings in the channels) as resulting from pedogenetic processes during the formation of the Bryansk Soil, whereas the illuvial clay coatings were formed in the course of the Holocene pedogenesis, as 'roots' of the illuvial part of the modern surface soil.

On the basis of the schematic map showing the Bryansk interstadial soil cover reconstruction of Europe made by Velichko and Morozova (1982), we can confirm that this paleosol, formed within the moraine sequence, marks the northernmost occurrence of the Bryansk Soil. The paleosol described above is situated in the territory for which the reconstruction of the soil cover of the marine isotope stage 3 is not yet completed. According to this map, the nearest estimated occurrence of the Bryansk Soil is situated about 300 km to the south of our study area. In that area, the soil cover was presented as Umbric Gley Cryogenic soils with calcareous B horizons having the profile A-(B)-Bca-Cg (Velichko and Morozova, 1982). These soils were also deformed by cryogenic turbation.

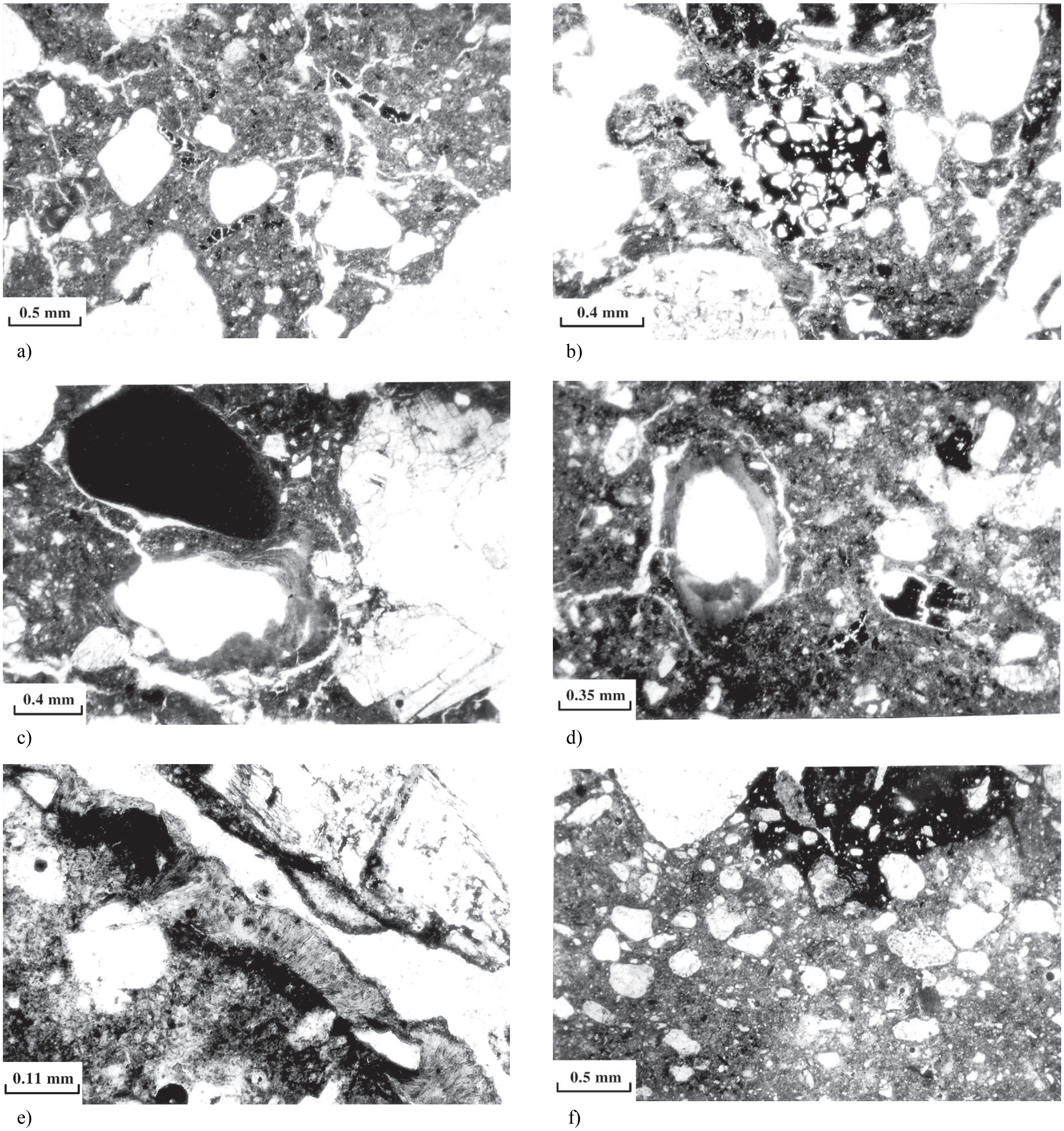
The humus matter content of the paleosols is relatively high (0.7–1.3 %) despite of light-colored A horizons (Velichko and Morozova, 1982). The modern analogues of the Bryansk Soil are Gelic Umbrisols developed in the central Yakutia (eastern part of Russia with a severe extra continental climate).

Next, we examine the demarcation of the late Pleistocene (Valday) glacial boundary within the study area, where the morphology of end-moraines is not pronounced. In this regard the soil stratigraphy may be used to demarcate the outer boundary of the former glacier. We interpret the upper (25–104 cm) clayey, very compact brown-reddish moraine, that is enriched by boulders and grusses, and is underlaid by the Bryansk Soil, as belonging to the Valday (Würmian) glacier deposits. The gentle plain character of the topography within the terraced surface eliminates the influence of sheet wash processes, we believe.

The distinct geomorphological confinement of the sequence, including the paleosol, also permits us to revise our understanding of the genesis of noncalcareous loess-like loams developed within the studied area. The literature has now accumulated abundant data on loess-like loams, but genesis of these deposits is still unclear and disputed.

The noncalcareous loess-like loams are restricted to the step of the Mologo–Sheksna lowland and to flat areas within the hills of the terraced surface (Figure 2). The loams have a sharp boundary with the underlying moraine and are enriched by small content in gravel (like 0–15 cm upper layer of the studied layer). Sometimes, these loams are characterized by inclusion of loamy sand layers. On this basis, the noncalcareous loess-like loams have a definite subaqueous genesis. Accumulation of the loamy sediments dates back to the cold stage following the Bryansk Interstadial.

The alternation of loess-like loams deposits with



Figue 4. Micromorphology of Bryansk soil. a–d: Ag horizon; e–f: G horizon. Plane polarized light. a) Planar voids, blocky structure, incomplete pedality, small charcoal particles in the groundmass. b) Ferruginous infilling in the channel. c) Clay coating in the channel. d) Larger clay coating; note charcoal fragments and ferruginous nodule incorporated in groundmass. e) Fibrous goethite coating in the void. f) Compact microfabric, coarse material of different size, note ferruginous nodule in the upper part.

outcrops of layered sands on the surface limited to 160 m a.s.l. indicate that the elevation of wide extraglacial lakes, that existed here during the maximum advancement of the Valday glaciation (Kvasov, 1974), may have exceed 160 m a.s.l.

CONCLUSIONS

We have established the northernmost occurrence of the Bryansk Soil formed during the last Dunaevo interstadial of the Valday (Würmian) glaciation (during marine isotope stage 3) in the extraglacial zone of the East European Plain. This paleosol is represented by Umbric Gley Soil formed presumably in Moscowian moraine and is overlain by Valday (upper Pleistocene) moraine. All of the paleosols having the same age and described in the literature were formed only in loess and loess-like deposits south of our study area.

The Bryansk Soil serves as a direct indicator of landscape and soil forming processes in the center of the Russian Plain. The noncalcareous loess-like loams of the study area definitely have a subaqueous genesis, we believe. Our data also shows the highstand (>160 m a.s.l.) of wide extraglacial lakes that existed here during the maximum advancement of the Valday glaciation.

Our research has shown that the glacier tongue could go forward along Mologo–Sheksna lowland covering close terraced surfaces with a low-energy sedimentary mantle. Thus, it is accepted that the Valday glacial boundary within the investigated area should be drawn a little further south.

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