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GEOGRAPHY

Chronostratigraphy of the Cheremoshnik Key Section (Yaroslavl Volga Region) Based on New Geochronological, Palynological, and Paleosol Data

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Abstract—According to radiochemical and biostratigraphic studies of the buried peat layer in the Cheremoshnik key section on the East European plain, the first age dating of this peat was obtained and its assignment to the Mikulino interglacial was confirmed. The Th/U isotope age data obtained for the peat horizon allow us to state with confidence that it was formed during the MIS5e. It was found that a variety of signs, including the lithological characteristics of dated layers and climatic indexes, is evidence that the Cheremoshnik site and Borisoglebsk upland occurred in the periglacial zone during MIS3–MIS2.

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The Cheremoshnik key section, considered to be one of the most important key sections of Quaternary sediments in the central part of European Russia, is located in the eastern part Borisoglebsk upland (Yaroslavl Volga region). Although this section has been studied by geologists and experts in allied disciplines for more than 60 years, there are still some debatable problems ([1, 2], etc.). Among them are the autochthonous position of the Mikulino horizon at the base of the section due to a lack of absolute age datings and the genesis and age of the overlying series of fine-grained and clastic sediments. Here, the thick soil-sedimentary stratum in the middle and upper parts of the section has not been studied previously.

On the basis of comprehensive study of the recently reopened (2008–2014) Cheremoshnik key section [3] (57.16632° N, 39.2886° E) and adjacent sections using new methods and approaches, new data have been obtained to answer the topical questions. For this purpose a clearing (depth, ≈7 m; upper width, 6.5 m; bottom width, up to 3 m) was made on the terrace of a right ravine tributary of the Cheremoshnik ravine.

The stratigraphy and absolute geochronology of paleosols and pedosediments, lithology, and the main signs of the complex soil-sediment strata of the key section are schematically shown in the figure. In total, five lithologically different "layers" (I–V) with six pedostratigraphic complexes ("units") were distinguished following the methodology in [6]. In our work, we used the classification of soils given in [4] and the indexes of the soil horizon are given in accordance with the WRB in [5].

At the base of the section (layer V) (the flat bottom of the ravine, 6.3 m deep from the edge of the ravine), boulder loam (Moscovian moraine deposits) crops out; in the upper part, loam is highly weathered. The composition of the debris and pebbles is as follows: 70% sedimentary rocks (mostly limestone), 23% igneous rocks (mostly gabbro, granite), and up to 7% metamorphic rocks (quartzite dominates). On the moraine loam throughout the clearing above the bottom of the ravine, an underdeveloped peat (humus)—dark humus gley paleosol (horizons of Hb/Tb and Agb are about 3 cm thick), overlain by a strata of humous varved clays with interlayers of peaty material of 5–10 cm formed. In this area, the early stage of the interglacial pedogenesis (Marine Isotope Stage 5 (MIS5)), later interrupted sharply by the accumulation of subaqueous lacustrine sediments of the early Mikulino age, was revealed for the first time. The palynological

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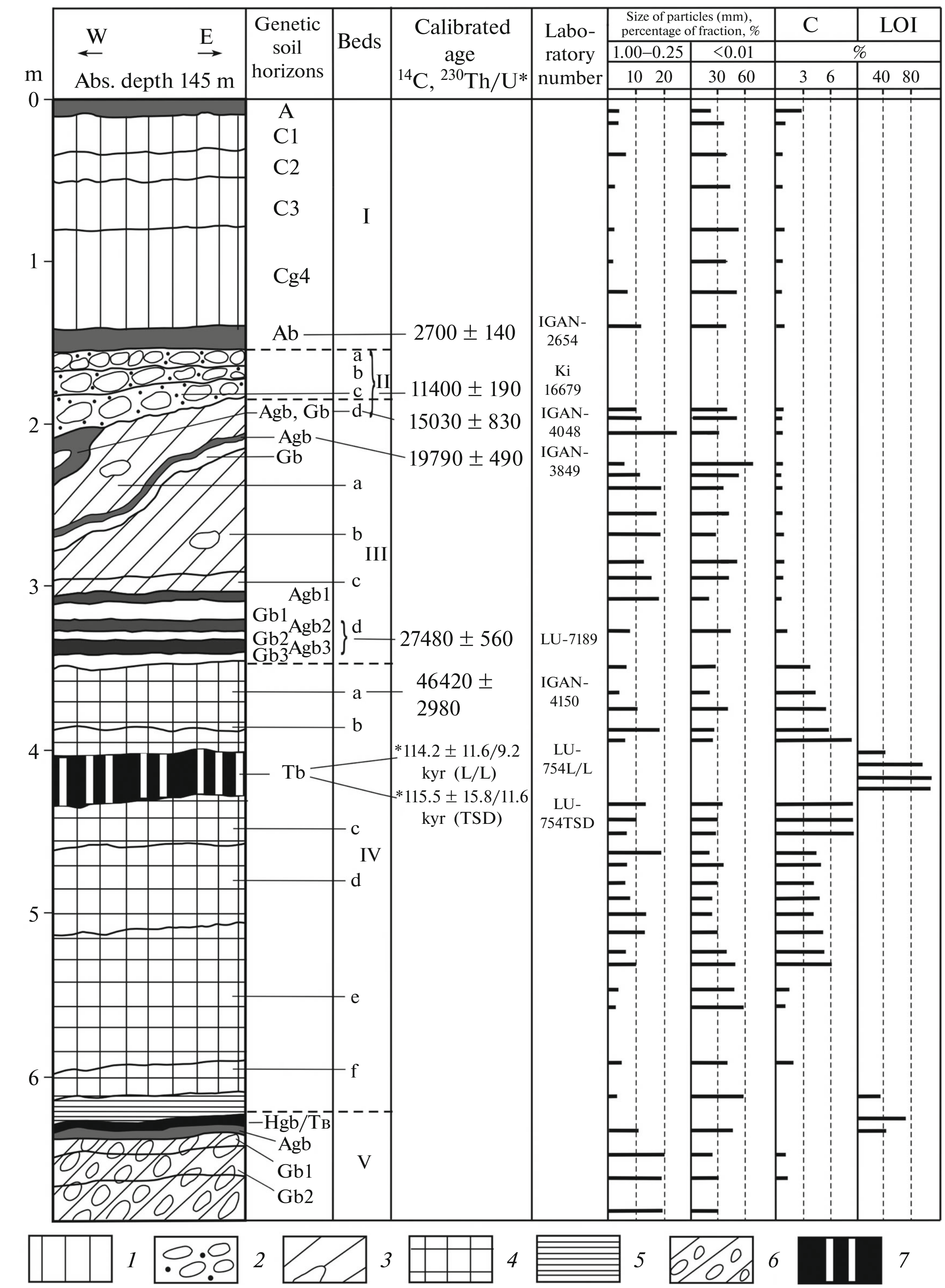

Fig. 1. The structure of Late Pleistocene sediments and paleosols in the Cheremoshnik key section. (*1*) Loesslike noncalcareous loams, (*2*) gravel–pebble deposits, (*3*) loam with single boulders, (*4*) gyttja peat, (*5*) varved clay, (*6*) Moscow moraine, (*7*) Mikulino peat (P); A–Ab, soil horizons of the stratozem; buried soil horizons: Agb, humus-accumulative; Gb, gley; Hgb, histic; Tb, peaty.

analysis (PA) indicates the formation of these sediments under the predominance of the forest and forest–tundra vegetation types with elements of periglacial flora. In addition, a short-term phase of the occurrence of dark coniferous taiga (spruce forest phase of the Mikulino interglacial), water logging, and development of a shallow-water reservoir is recorded in the section.

A large part of the studied section at a depth of 6.25–3.50 m is represented by gyttja layers (layer IV), subdivided by us into zones IVe–IVf, according to their granulometric composition and organic carbon content (figure). Gyttja layers have clearly visible subhorizontal bedding (unconformable in the upper units: zones IVa, IVb). In addition, there are fragments of peat sublayers, macroremains of marsh plants, and an abundance of quartz grains. According to the palynological data, gyttja layers were formed under conditions of universal development of forest vegetation with the change of several phases (from bottom upward): (1) spruce forests indicating a relatively cool and humid climate; (2) the development of pine forests indicating a cool and dry climate; (3) pine and birch–pine forests with broad-leaved trees, indicating a relatively warm and dry climate; (4) broad-leaved forests with alder and hazel indicating a relatively warm and humid climate. The peat horizon is distinctly observable throughout the clearing at a depth range of ≈4.3–4.0 m; the central part of the horizon has a high content of organic matter LOI up to 80% or more). Given the increase in the carbon content in the underlying and overlying gyttja layers and the lateral continuity of the peat layer, one can suggest a relatively calm accumulation of sediments, likely autochthonous. The ^{230}Th/U age dating of Middle and Late Neopleistocene continental buried organogenic sediments in the peat horizon was performed by authors using two analytical techniques of separation of the U and Th isotopes from samples: leaching (L/L) and the complete dissolution of the sample (TSD) [7]. The absolute age datings obtained (114.2 ± 11.6/9.2 kyr (L/L) and 115.5 ± 15.8/11.6 kyr) are referred to the MIS5e phase and are in good agreement with the palynological data.

Despite the belonging of the upper gyttja layer (a) to the Mikulino interglacial (figure), as evidenced by the palynological data as well, the radiocarbon (RC) age of the 5 cm upper gyttja layer appears to be Middle Valdai 46200 ± 2980 cal. kyr BP (IGAN-4150). Judging by the sharp change in the spore-pollen spectra with a high content of alder and hazel pollen grains by the spectra with the dominance of dwarf birch and alder, it is possible to assume the occurrence of a long-term hiatus of ~60 kyr in the sedimentation. In addition, the final phases of the development of vegetation at the end of the Mikulino interglacial (M7 zone, M8, [8]) are missed in the studied section.

The upper loamy stratum (layer III, depth int. 2.0–3.5 m), overlapping the Mikulino layers, is subdivided in zones IIIa–IIId mainly based on the change in color (reddish brown, bluish reddish, etc.). In the lower zone IIId (depth int. 3.0–3.5 m), the Middle Valdai dark humus–gley paleosol described as the pedocomplex Agb–Gb was studied in detail (figure). The soil is formed in morainelike loamy strata (ravine alluvium) with rare boulders redeposited from watersheds. It was formed under the conditions of predominance of dwarf birch and alder in the composition of vegetation. Three rhythms of ephemeral soil genesis, similar in morphological and genetic peculiarities, were distinguished. The thin humous (up to 5 cm) horizons Agb of all three rhythms are darker in coloring (darker) and lumpy-granular in structure. Horizons Gb (up to 12 cm thick) are more clayey, lumpy with small boulders, grayish-bluish. Each rhythm of the pedogenesis recording the stabilization of the initial surface was overlapped by new sediments, which, in turn, began to form a new soil layer, morphologically similar to the previous one. The radiocarbon age of the lower strata of the pedocomplex (Agb2 and Agb3 horizons) is 22920 ± 470 (27630 ± 560 cal. kyr BP (LU-7189)), which corresponds to the Bryansk interval of the MIS3 stage. Thus, the series of ephemeral paleosols of the MIS3 stage formed under the dynamic development of a network of gullies and ravines records short-term climatic changes in the morphology in contrast to the soils from the watersheds. It was revealed that there is a morphological similarity between paleosols of the stage MIS3 in the Cheremoshnik section and the Middle Valdai paleosols in key sections of the upper Volga River [9, 10].

In the upper part of layer III (depth int. 2.1–2.7 m), another, clearly observable, thin dark humus–gley paleosol (Agb–Gb profile) was identified. Based on the age dating (19790 ± 490/560 cal. kyr BP, IGAN 3849), it is defined as Trubchevsk paleosol. This paleosol layer clearly separates layers IIIa and IIIb composed of ravine deposits. Despite having a curved boundary, the paleosol horizon stretches without breaks that is, it marks the buried ground surface (paleoslope). This paleosol horizon formed as a result of weak pedogenesis under the harsh climatic conditions of the Late MIS2. The find of the Trubchevsk paleosol is evidence of a new soil, the northernmost point of the spread at this time, in the central East European plain.

At the depth interval of 1.5–1.7 to 2.1 m (layer II), dense gravel–pebble filling, consisting of four distinct units IIa–IId along a paleochannel in the ravine, was identified (figure). According to all indications, these units of layers of clastic deposits differ from moraine and solifluction formations, as well as between each other. There are variations in the petrographic composition of clastic material as well: a decrease in the percentage of the clastic of sedimentary rocks up though the section and an increase of that of igneous and metamorphic rocks. All of these features identified point to the deposition of each layer by temporary water streams of varying intensity within the extended trough, signs of which are preserved in the current topography.

A pocked structure IId, filled with sediments, at the base of a local lowering of layer II contains redeposited fragments of pedosediments (segments of the profile across the thin dark humus–gley paleosol layer, RC 15030 ± 830 cal. kyr BP, IGAN-4048). The palynospectra of this soil indicates the development of the birch woodlands with herbaceous vegetation, green mosses, and ferns.

The gravel filling contains coalified stipiform fragments of marsh vegetation (sedges, rushes), captured by water streams. For example, a reliable age dating (11400 ± 190 cal. kyr BP, Ki-16679) of the time of the occurrence of the ravine and the duration of its filling with sediments was obtained owing to the analysis of plant remains. Judging by the three age datings available, the period of development of the ravine from the filling with sediments and the subsequent overlie by loess deposits lasted from ~15 300 to 12 400 ± 560 cal. kyr BP.

The upper part of the Cheremoshnik key section (0–1.6 m) is made of Middle and Late Holocene stratosoil (2700 ± 140 cal. kyr BP, IGAN-2654), namely, synlithogenic soil developed on noncalcareous surface loesslike loams redeposited from a surface watershed.

CONCLUSIONS

(1) The analysis of the factual material confirms the status of the recently studied Cheremoshnik section as a key section of the periglacial zone of the East European plain. The section was recently comprehensively characterized in terms of chronostratigraphy and evolution of landscapes recorded in the sedimentary strata of the soil (MIS5–MIS1).

(2) In the Cheremoshnik key section of Late Neopleistocene sediments, paleosol series (MIS5–MIS2), including Early Mikulino, Bryansk (3 rhythms of the pedogenesis), and Trubchevsk paleosols, were studied, characterized, classified, and dated for the first time. An ensemble of paleosols developed and preserved in heterochronous, complexly structured strata of the Cheremoshnik section appeared to be the northernmost area of distribution of Late Pleistocene soils in Europe. The major soil-forming processes were gleyzation, cryogenic aggregation, and humus and peat formation.

(3) According to many features, the regionally distributed upper loams with a minimum content of clastic material (layer III) are correlated with continental and basin sediments, but not glacial sediments accumulated during the period of the Last Glacial Maximum. The overlying regional series of layers of clastic sediments (often recognized as morainelike and/or solifluction sediments) is reliably correlated with the activity of temporary water streams in a local ravine in the period of 15–12 cal. kyr BP.

(4) According to the radiochemical and biostratigraphic studies of the buried peat collected from the Late Pleistocene Cheremoshnik key section, the age of its accumulation was established for the first time, and it was confirmed that it belongs to the Mikulino interglacial. The U–Th isochrone age datings obtained for the peat horizon allow us reliably to assign the time of its formation to the stage MIS5e. The age dating is consistent with the palynological data available (M1–M6 zones [8]).

(5) Several of the features revealed, including the lithological characteristics of dated layers and the corresponding climatic indexes, allow us to state with confidence that the Cheremoshnik area and Borisoglebsk upland occurred in the periglacial zone during MIS3–MIS2.

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