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ALEKSANDROV QUARRY. LATE PLEISTOCENE–HOLOCENE. COVER COMPLEX: SOILS, LOESSES, BURIED BALKA

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Abstract. Erosion network formed during the Mikulino–Valdai (Eem–Würm) Interglacial, which is now buried under recent deposits, is the best object of Quaternary geology. One can see its exposures in the Aleksandrov quarry on the Central Russian Upland. The Mikulino–Valdai erosion network certainly needs to be protected as a natural monument. Buried Mikulino balkas (wide flat-bottomed gullies) are unique natural objects, which represent a complete erosion cycle from the surface dissection to its stabilisation, palaeosol formation, and surface levelling as a result of denudation of watersheds and infilling or burying of depressions. On the basis of profiles studied along and across Mikulino balkas, it is possible to trace gradual and catastrophic changes of palaeolandscapes and reconstruct the development stages of topographical forms and soils, associated with climate change within the interglacial–glacial cycle. Over the balka bottom, one can observe the Valdai soil — lithogenic series having no analogues with such a precise and complete stratigraphy within the whole Russian Plain. Besides Mikulino Interglacial palaeosol, there are four buried soils of Valdai interstadial period: Kukuevka, Streletskaya, Aleksandrovka, and Bryansk palaeosols (33,140 ±230 BP, Ki-8211). Such a complete set of Late Pleistocene palaeosols is very rare on the East European Plain. In the studied profile we have also found fragments of bones of furred rhinoceros and a prehistoric horse (39,710 ±580, Ki-9362).

Key words: Buried balka, climatic and erosional cycle, palaeosol, loess, palaeolandscape, Russian Plain.

Abstrakt. Sieć rynien erozyjnych, utworzona podczas intreglacjału Mikulino-Wałdajskiego (Eems–Würm), pokryta współczesnymi osadami, jest doskonałym obiektem geologii czwartorzędowej. Jej odsłonięcia widoczne są w kamieniołomie Aleksandrov, w Centralnej Wysoczyźnie Rosyjskiej. Erozyjna sieć Mikulino-Wałdajska powinna być chroniona jako pomnik przyrody. Pogrzebane bałki (szerokie płaskodenne kanały/rynny) Mikulino są unikatowymi obiektami, reprezentującymi pełny cykl erozyjny, od rozcięcia powierzchniowego do jego stabilizacji, powstania paleogleby, wyrównania powierzchni w wyniku denudacji działów wodnych oraz wypełnienia lub pogrzebania obniżeń. Na podstawie profili przebadanych wzdłuż i w poprzek rynien (bałk) Mikulino było możliwe prześledzenie stopniowych i gwałtownych zmian paleokrajobrazu oraz zrekonstruowanie etapów rozwoju form topograficznych i gleb, związanych ze zmianami klimatu w cyklu interglacjał–glacjał. Na dnie bałk występuje gleba wałdajska — seria litologiczna, z punktu widzenia precyzyjnego i pełnego podziału stratygraficznego niemająca odpowiedników na całej Nizinie Rosyjskiej. Poza paleoglebą interglacjału Mikulino występują tam jeszcze cztery pogrzebane gleby wałdajskich okresów interstadialnych: paleogleby Kukujevka, Streletskaya, Aleksandrovka i Bryansk (33 140 ±230 BP, Ki-8211). Taki kompletny zespół późnoplejstoceńskich paleogleb jest rzadkością na Niżu Wschodnioeuropejskim. W przebadanych profilach znaleziono również fragmenty kości długowłosych nosorożców oraz prehistorycznego konia (39 710 ±580, Ki-9362).

Słowa kluczowe: pogrzebane rynny (bałki), cykl klimatyczny i erozyjny, paleogleba, less, paleokrajobraz, Nizina Rosyjska.

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INTRODUCTION

The buried balka system, structure of which reflects the late Pleistocene history of landscapes, soils, and mesotopography forms, is exposed in the Aleksandrov quarry. The previous Mikulino–Valdai climatic and erosional cycle is illustrated by the structure of the late Quaternary deposits in the Aleksandrov quarry section.

The quarry is located 10 km south of Kursk on the watershed of the Seim and Mlodat' rivers. The quarry occupies the watershed area between two branches of the Kukuev Log balka with the absolute height of 230–240 m (Fig. 1). In this area, the recent late Valdai–Holocene erosional mesoform of topography does not inherit the Mikulino one; it is displaced to the west.

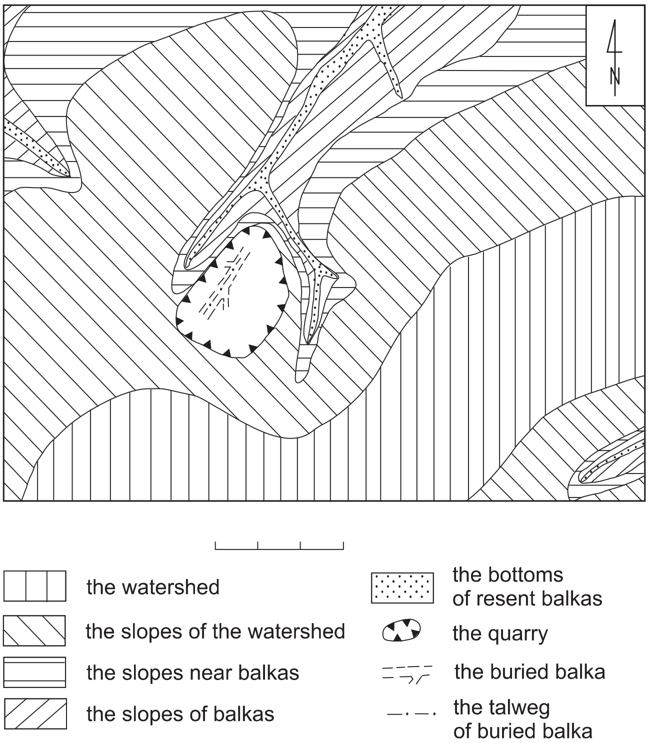

Fig. 1. The map of Aleksandrov quarry in resent relief

The geological structure of Pleistocene sediments in the environs of the quarry is typical for watersheds of the Central Russian Uplands (Velichko *et al.*, 1992; Sycheva, 1994, 1996, 1997, 2003, etc.). The Holocene soils are represented by leached and typical chernozems developed at the Valdai brown-yellow loess-like loam. At a depth of 2–3 m it is underlain by pale--yellow Dnieper loess-like loam 4–5 m thick. Depending on the position in the palaeotopography and on different manifestation of the Valdai slope processes, the following palaeosols occur at the boundary of the loesses: the more commonly conserved Bryansk soil and the Mezin complex found only in ancient depressions. They are separated by early and middle Valdai deluvial-solifluction and deluvial-eolian loams. In the pale-yellow Dnieper loess sequence, the poorly developed soddy-gley Kursk soil occurs which subdivide it into the Dnieper and Moscow stages. The Dnieper loess is underlain by the middle Pleistocene Romenka palaeosol of forest steppe genesis.

The buried erosional form is recorded in the section by the development in its bottom and slopes of interglacial forest soil and of a cup-like form filled with the deluvial-solifluction and eolian loams — pedosediments — alternating with buried interstadial soils formed in situ (Figs. 2, 3). The interglacial soil developed in the bottom and slopes of the palaeoform is of Mikulino age and has all typical diagnostic features permitting its correlation with the analogous Salyn' soil of the Mezin complex from the Mezin section and other late Pleistocene reference sections of the Russian Plain. It is an important strati-

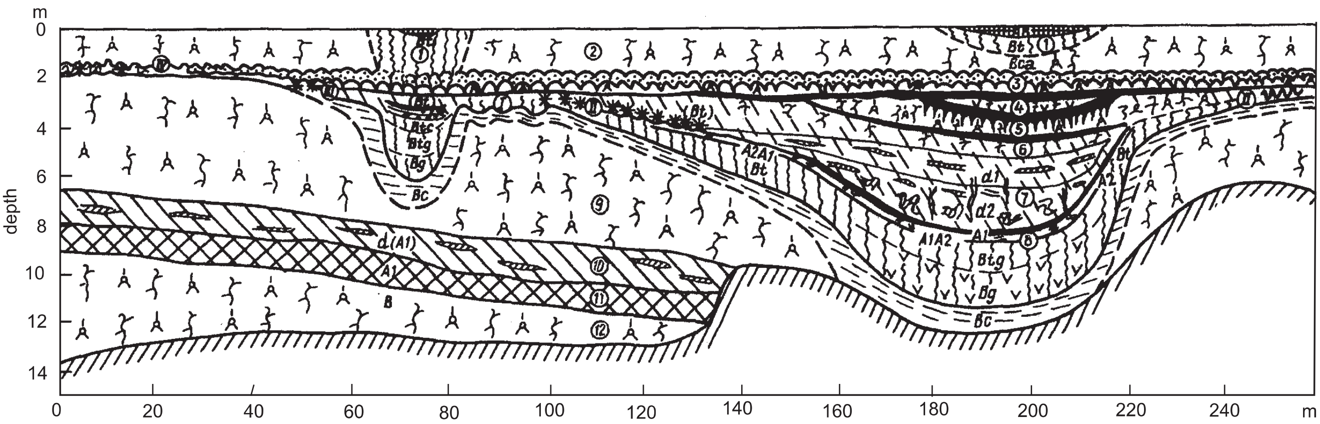

Fig. 2. The cross sections over the buried Mikulino–Valdai erosional system exposed on the walls of the Aleksandrov quarry open-cut mine in 1988

Fig. 3. Mikulino–Valdai buried erosional system in Aleksandrov quarry in 2000 year

graphical marker. The underlying pale-yellow loess with cryogenical and erosional features may be assigned to the Dnieper glaciation. The sediments and soils above the Mikulino soil are referred to the next Valdai glaciation.

The described section differs from the late Pleistocene reference sections of the Russian Plain in that the Mezin complex includes there three early Valdai soils in addition to the interglacial Mikulino soil.

THE MIKULINO–VALDAI PALAEOFORM AND ITS PALAEOSOILS AND DEPOSITS

In the Section 88-7 that exposes the balka's bottom, the following beds occur from the top downward (Fig. 4):

Bed 1. The Holocene soil, leached chernozem.

Al horizon was destroyed by excavations.

A1B horizon, 0.45 m thick. Brown-grey clay loam, finely porous, containing a lot of coprolites, disrupted by shrew passage-ways, with a finely prismatic structure.

B horizon is 0.35 m thick. Pale-yellow-brown loam of prismatic structure. Prism particles are pelliculated. The transition is gradual, expressed by the carbonate appearance and in colour.

Bed 2. The Valdai loess transformed in its upper part by the Holocene soil formation.

Bca horizon, 1.2 m thick. Brownish-pale-yellow clay loam with abundant carbonate pseudomycelium and coarsely prismatic structure. Rare cutans along large pores occur. Colour transition is gradual.

Bed 3. The Bryansk soil (33,140 ±230, Ki-8211).

Al horizon is 0.3 m thick. Brown clay loam, dense, coarsely porous, with ooidal microstructure and abundant fossil coprolites. The ortstein and amount of dot stains are greater. The Al horizon fills the cryogenic funnel-shaped structures.

Bca horizon, 0.7 m thick. Brownish-pale-yellow sandy clay loam, carbonate, with large pores and a lot of black Mn-stains. Carbonates are represented by pseudomycelium and farinaceous spots.

Bed 4. The Aleksandrovka soil. Depth is 3.0 m.

Al horizon is 0.25 m thick. Brownish-grey loam, heterogeneous, humidified, with alternated brown and dark grey material, and a cell-imbricate structure. Scales are covered with mat pellets. The included bulk is darker than the general background of the horizon. The most gluey spots, stains, and microortsteins is associated with the upper boundary of the Al horizon.

B horizon, 0.45 m thick. Dark brown sandy clay loam, heterogeneous, porous, not structured, bearing Mn-ortsteins. It is broken by fissures filled with carbonate dolls. The boundary is pocket- and fissure-shaped, inclined to the balka valley. The bone of horse was find in the B horizon (39,710 ±580, Ki-9362).

Bed 5. The Streletskaya soil. Depth is 3.7 m.

Alg horizon, 0.2 m thick. Brownish-grey bluish loam.

Al horizon is 0.1 m thick. Brownish-grey loam, not structured, more heterogeneous in the upper part owing to spots of bluish gluey and darker humidified loam, with black dot stains and carbonate pseudomycelium. The lower boundary is disrupted by large fissures filled with gluey brownish-light-grey humidified loam. The width of fissures is 15–20 cm in the upper part; they penetrate at a depth of 1.0 m terminating by a series of small veins. The fissures resemble humic tongues of the Al horizon of the Mezin complex developed in reference sections on the Russian Plain.

Bca horizon, 0.8 m thick. Brownish-pale-yellow loam, not structured, porous, with abundant carbonate pipes along pores, with dolls, and pseudomycelium. The colour transition is sharp. The plane boundary is disrupted by fissures from the Al horizon. The Bca horizon and the Al horizon of the underlying interstadial soil are dug up by passage-ways of ancient shrews.

Bed 6. The Kukuevka soil. Depth is 4.8 m.

Al horizon, 0.2 m thick. Dark grey loam, finely porous, of granular structure. The upper boundary is unconformable; sometimes the horizon is overlain by a bed of brownish-grey

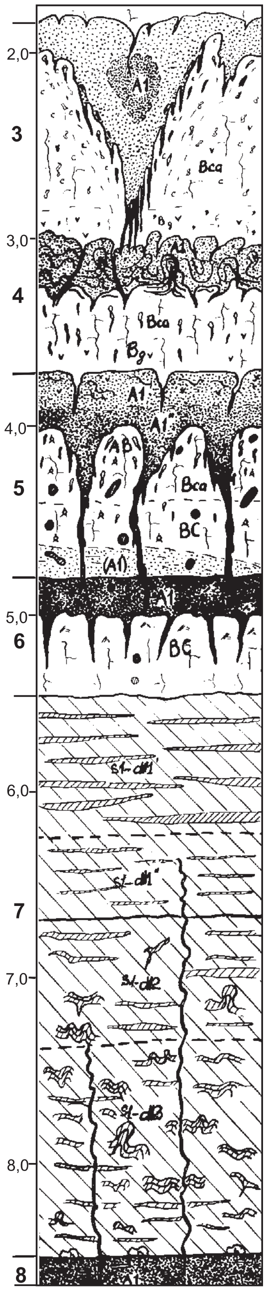

Fig. 4. The Late Pleistocene palaesols and deposits in section 88-7 (Aleksandrov quarry)

3 — Bryansk palaeosol, *4* — Aleksandrovka palaeosol, *5* — Streleskaya palaeosol, *6* — Kukuevska palaeosol, *7* — Early Valdai deluvial-solifluction pedosediments, *8* — Mikulino palaeosol

gluey loam, up to 4 cm thick, that represents the Alg horizon. The lower boundary is sharp and disrupted by small veins. Humic stains penetrate to a depth of 30–40 cm.

B layer, 0.5 m thick. Brownish-pale-yellow loam, non bedded, carbonate free, with cellular texture and whitish silicic powder in the upper part.

Bed 6a is 0.6 m thick and is formed by solifluction from the reworked material of the Bt horizon of the Mezin complex. It is represented by non bedded, brown sandy clay loam, without the nutty structure characteristic of the illuvial horizon.

Bed 7. 5.4–7.6 m thick.

Within the solifluction and deluvial deposits, three subhorizons may be distinguished: the sl-dll subhorizon — the sandy clay loam formed by the illuvial horizon reworking; the sl-dl2 subhorizon — the sandy loam bearing light layers (the material of the A2 horizon); and the dl3 subhorizon. The sl-dll subhorizon includes layers of 2–3 mm sized loamy sand. The light-yellow sandy layers from 1 mm to 1 cm thick occur in the upper part of the member. As a whole, it is a heterogeneous horizontally bedded sequence of a loamy composition and brownish colour. It is microheterogeneous and includes round forms different in colour and composition (microcharriages and ooids) up to 1 mm sized. Thin layers of humidified greyish-brown and whitish-pale-yellow loam with a horizontal parting form a tabular structure. Ooids are densely packed, and the non aggregated bulk is almost missing.

Bed 8. The Mikulino soil. Depth is 8.0–10.0 m.

Ao horizon is 0.05 m thick. The clay loamy sooty member, bearing small coal pieces and spots of red annealed loam.

Al horizon, 0.15 m thick. Brownish-grey silty clay loam, microporous, bearing a lot of 0.5–2 cm sized coals, and spots of whitish powder and baked red loam. The transition is sharp. The boundary is wavy and intermittent, with lenses of darker and light-grey loam.

A2g horizon, 0.3 m thick. Whitish-grey loam with bluish tint and abundant powder responsible for the general background of the horizon. It is characterised by finely nutty structure. The intraped bulk is darker, brownish-light grey. Coals, spots, and microortsteins are still abundant. The transition is expressed by colour and structure.

A2Bt horizon, 0.2 m thick. Sandy clay loam, bright brown with whitish tint owing to the abundant powder, of tabular-nutty structure. Gradual transition is expressed by structure.

Btl horizon, 0.6 m thick. The most bright brown loam with nutty structure and glossy pellets on sides. Thin hair-like layers forming a net (postschlieren texture), are recorded. The transition is gradual.

Bt2 horizon, 0.5 m thick. Brownish-pale-yellow loam with the admixture of fine sand. The structure is prismatic with thick clayey cutans along large fissures. The brown cutans are clayey, and the black ones are humic clayey. The postschlieren texture is more distinctly expressed. The bluish gluey spots, rusty dots and black stains appear in the lower part. The transition is gradual, expressed in colour.

BC horizon, 0.2 m thick. Heterogeneous loam, whitish-pale-yellow with lenses of whitish loamy sand. Sandy loam with sand admixture and numerous stains of brown, rusty, and black colour.

PALAEOPEDOLOGICAL AND GEOMORPHOLOGICAL RECONSTRUCTION

The Mikulino soil that developed at the bottom and on slopes of the balka and its branches, forms different palaeocatenas in various cross sections. The accumulation and, partly, transit-accumulation sectors are the most fully conserved in palaeocatenas. Eluvial sectors were destroyed by subsequent denudation.

The slopes of the balka are occupied by sharply differentiated soddy podzolic and light grey forest soils (Fig. 5), whereas its bottom — by grey forest superficial-gluey peaty soils with the profile Ao-Al-A2g-A2Bt-Bt-BC, and with traces of a large fire (Fig. 6). The evolution of the Mikulino soil included the following stages: the primary differentiation of rock to horizons Al-A2-Bt, the formation of soddy podzolic and light grey forest soils, and finally, the formation of peaty and gluey soils.

The interglacial Mikulino soil stopped its development because of a strong forest fire, which traces, namely numerous coals, spots of baked red loam, and sooty layers, are recorded in the sections. In two or three seasons, it was buried under deluvial loam dl 3" (Alg) on the balka bottom and slopes. On the watershed slopes and most likely on watersheds, the soil was eroded to the variable degree. The deluvium that caused the primary burial of the Mikulino soil, is similar in properties to the Al horizon from which it was formed, but contains considerably less humus amount, is more muddy and gluey.

The strong forest fire that initiated the quickened natural erosion produced by subsequent cloud-bursts, fell within the terminal interglacial, which was characterised by unstable climate. The strong smoke-cloud caused a sharp temperature decrease and, along with the general cooling trend, led to the appearance of cryogenic processes. Their traces are manifested in the following plastic deformations of the top of the Mikulino soil: in cryoturbation folds and involutions in the Al horizon at the balka bottom, and in solifluction loops and excrescences on its slopes.

The described type of deformations associated in the reference sections of the Mezin complex of the Russian Plain with the contact between the Salyn' and Krutik phases, is of great stratigraphical significance, as it corresponds to the boundary between the Mikulino interglacial and Valdai glaciation (namely, the Smolensk cryogenic horizon, the "a" phase) (Velichko, Morozova, 1985; Velichko *et al*., 1992; Morozova, 1981). This stage is correlated with the beginning of the Valdai glaciation and initiates another trend in the Mikulino palaeoform and Mezin complex development: the repeated infilling of the depression with deposits, which was interrupted by the formation of interstadial forest-steppe soils of a meadow series.

The filling sequence is composed of the reworked material of different horizons of the interglacial Mikulino soil. It includes three loam beds formed during the first early Valdai stade. The filling loams occur inversely with respect to the interglacial soil horizons, from which they were formed. This reflects the succession of washing down and redeposition of material of slope soils and then of watershed soils: at the 1st stage — the Ao, Al, A2, A2A1, A2A1 horizons; at the 2nd stage — also the A2Bt, BtA2, and Btl horizons; and at the 3rd stage — the material of the Bt horizon, finally mixed with the Moscow loess.

The whole loam sequence is characterised by cryogenic deformations. In the contact zone with the Mikulino soil (in the dl-sl 3), they are represented by the described above plastic deformations. In the dl-sl 2 horizon, the small thin sinuous fissures (elementary veins) appear, which penetrate through the underlying dl-sl 3 sequence and the Mikulino soil to a depth of

Fig. 5. Mikulino palaeosol in the slope

Fig. 6. Mikulino palaeosol in the bottom

Fig. 7. The Holocene soil and 4 Valdai interstadial palaeosols

2–3 m. The thickness of slope deposits markedly decreases towards the margins of the palaeoform. The solifluction folds and tongues of subhorizontal extension, in the form of small excrescences, are distinctly expressed there.

The characteristic of the beds cited above enables the consideration that they were formed mainly by the sheetflood erosion and by the shift of water-saturated soil ground clamped between two frozen beds. The denudation of the interglacial soil on the slopes and its burial on the balka bottom began with the sheet erosion as a result of strong cloud-bursts after the fire.

Then the solifluction, a new instrument of redeposition of soil horizons, was added. During the glaciation, as the aridity of the climate raised, the role of solifluction processes in the accumulation of slope deposits decreased, and the sheetflood erosion became leading again. The linear erosion, namely the formation of gulches in the upper reaches of the balka system, most likely occurred together with the reworking of earlier accumulated sediments by temporary water flows on the balka bottom, which was manifested in some sorting of the deluvial and solifluction material of dl-sl 1 (balka alluvium).

The cryomorpholithogenic processes described above resulted in the rearrangement of the balka system into a less deep dell with symmetrical slopes and subsequently, as it will be shown below, into a chain of closed forms (padings) along the valley of the former linear form. The palaeoform changed in a short time. The accumulation rates were high, and soils *in situ* had no time to be formed. The inner heterogeneity of mixed material, namely small layers and lenses composed of fragments of different soil horizons, is preserved.

Three interstadial soils, developed on bottoms of secondary palaeoforms, occur above the described deluvial-solifluction loams (Fig. 7). The soils reflect a considerably long periods of stable surface, when the soil formation rate exceeded that of morpholithogenic processes. The soils were formed during three warmings, which may be assigned to the following interstades: the Amersfoort, Brorup, and Odderade of Western Europe or the Upper Volga, Chermenino, and Berezai interstades of the Russian Plain (Bolikhovskaya, 1987, 1995).

Each of the soils is formed as non bedded loam of eolian--deluvial-solifluction origin and has its peculiar features that distinguish it from other soils and permit the inference of the soil forming conditions. The early Valdai interstadial soil profiles are less thick (0.5–1.2 m) and differentiated, compared to that of the interglacial Mikulino soil which resulted mainly from the shorter period of their evolution. The humus accumulation together with other processes was the leading mechanism for all three soils. The content of organic matter (0.6–1.3%) and thickness of the humus horizon (20–25 cm) suggest that humus reserves in each of the early Valdai soils were higher than in the Mikulino forest soil (Fig. 7).

The lower interstadial soil, named by us the Kukuevka soil, has a profile of the Al–B type, partly formed of the reworked material of lower horizons of the Mikulino soil. The intrasoil weathering and superficial gleization at the terminal stages of development, in addition to the humus formation, were the leading processes for this soil. They resulted in the accumulation of humus and other compounds in the Al horizon compared to the B horizon. The group composition of humus of the Al horizon of the Kukuevka soil is humatic (Cha:Cfa = 2.2). This permits to consider the Kukuevka soil as the forest-steppe meadow soil that developed in conditions of the seasonal (spring) over moistening and of considerable summer drying up in the forest-steppe of more continental type than the modern forest-steppe of the Central Russian Uplands.

The middle of the early Valdai soils, the Streletskaya soil, is characterised by the most differentiated profile Al–ABca–BC. The soil is distinguished by the humus content. The ratio Cha to Cfa slightly changes along the profile and is equal to 1, which is typical for forest-steppe soils. The humus and the intermediate horizons are characterised by the accumulation of SiO_2, CaO, and MgO with some washing out of R_2O_3, especially of Al_2O_3, from the Al horizon. The MgO content has two maximums: in the Al horizon (diagenetic) and in the BC horizon, possibly genetic, suggesting the accumulation of highly soluble salts in the lower part of the Streletskaya soil profile.

The soil characteristics permit its reference to the meadow, or chernozem-meadow soils that was developing longer and in less continental conditions than the Kukuevka soil. Not only the profile of highly soluble salts, but also the carbonate one have managed to form. The humus fissures are substantially larger than the deformations at the lower boundary of the Al horizon of the Kukuevka soil, which suggests more severe conditions of terminal stages of the soil formation in passing to the third early Valdai stade. Chernozems of the forest-steppe of more continental type than the modern one, but of more humid than in the first interstade, were formed on flat watersheds during the second warming.

The Aleksandrovka soil is the least thick and humidified. The Alg horizon is cryoturbated and crumpled in folds and loops which is characteristic for over moistened frozen grounds. The deformations are of stratigraphical significance in the reference sections indicating the Smolensk cryogenic horizon, phase "b" {Velichko, Morozova, 1985; Velichko *et al*.,1992; Morozova, 1981). The organic matter content is not large in the Aleksandrovka soil. The humus is of humatic type. The humus horizon of the Aleksandrovka soil, as of other early Valdai palaeosols, is marked by the increased content of mud fraction and sesquioxides, probably owing to the intrasoil and cryogenic weathering. A strong disruption of the profile by cryogenic processes, gleization, and the lack of differentiation suggest its assignment to humid-meadow cryogenic soils that were formed in padding in the colder forest-steppe than formerly.

All the soils, especially the Kukuevka soil, are slightly eroded at the upper boundary of humus horizons and glued. They are locally distributed and better preserved above the bottom of the Mikulino balka. Towards its sides, the early Valdai soils are superimposed and merged reflecting the process of infilling of the primary depression and down wearing of the topography.

As the sediments accumulated, the palaeoform lost a shape of the balka with asymmetrical combined sides and already in the first stade was transformed into a less deep dell with symmetrical slopes. The local base level of erosion was elevated, and the energy of the sediment transportation along the talweg weakened. As a result, in certain periods of strengthening of the linear erosion in the upper reaches of the branches, the bottom was in some places partitioned off by alluvial fans, and the balka was most likely separated into isolated closed forms that composed a chain of paddings on the covered bottom. A lot of examples confirming this process may be seen at modern large-scale maps.

As the secondary paddings in the upper reaches of different balka systems adjoining the watershed surface were filled, and the latter was denudated by wind and sheet erosion and solifluction, they merged and formed a larger closed form, a flat-bottom depression, that occurred in the Bryansk interstade.

Unlike the early Valdai soils, the Bryansk palaeosol is preserved not only above the bottom of the filled Mikulino balka, but also on watershed slopes in all studied cross sections. It was destroyed by denudation in the most uplifted areas only, as was the Mezin complex. In the studied section, the soil of the middle Valdai warming is characterised by all morphotype features that permit its correlation with the analogous Bryansk interstade soils from the sections with established ^{14}C age, for instance, from the Bryansk and Zheleznogorsk sections (Morozova, 1981). The following most pronounced characteristics of the soil as the Al–Bca–Bca,g profile, the wedge-shaped boundary of the humus horizon, its ooidal structure, farinaceous carbonates in the Bca horizon, and others, enable its assignment to forest-steppe meadow soils. They underwent a long evolution, at the terminal stage probably experienced the cryogenic processes, and became the cryogenic-carbonate soils.

During the Bryansk interstade, a shallow closed depression, considerably larger than the early Valdai paddings, still occurred. This flat-bottom depression is recognised by the lenslike occurrence of the markedly expressed carbonate horizon of the Bryansk soil, which overlies the bottom of the Mikulino palaeosol. The complete burial of the palaeoform took place during the rearrangement of the watershed topography in the second half of the Valdai glaciation.

CONCLUSION

Buried Mikulino balka exposed in the Aleksandrov quarry is a unique natural object. It is currently used as a training site for students (geographers, geologists, and pedologists), particularly as the object for their coarse papers and diplomas. It was many times demonstrated in course of International Conferences, for example, it was among the three objects for studying the soil polygenesis by participants of the International Expedition from four countries: Austria, Germany, Mexico and Russia (the ICSU project). Undoubtedly, buried Mikulino balka with the most complete set of Late Pleistocene palaeosols and deposits, should be conserved.

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