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Stratigraphy and the small mammal fauna of the Late Pleistocene sections in the south of the middle reaches of the Volga River

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ABSTRACT

Two Pleistocene sections in the middle reaches of the Volga River – Spasskoe and Yagodnoe – have been described in details and analyzed, small mammal remains being recovered and identified. The fauna includes remains of open landscape species: *Eolagurus luteus* (Eremin and Moloskovsky, 1981), *Lagurus lagurus* Pallas, 1773, *Lasiopodomys (Stenocranius) gregalis* (Pallas, 1779) and others. Bone remains of a tundra species – collared lemming *Dicrostonyx* sp. were found in the Spasskoe section. No forest species are present in the sequence, nor remains of water vole *Arvicola*. The species richness of the faunas is rather low, which may be related to insufficient amount of material or to a specific climate. Such low species richness is typical of the periglacial faunas of the Pleistocene. The authors of recent article attribute the third Volga terrace to the Late Pleistocene refer usually to the 3rd terrace deposits in the lower reaches of the Volga where the Caspian Upper Khazarian (Hyrcanian) layers are found at the base of the sequence. The rodent molar morphology permits to date fauna to the beginning of the Late Pleistocene (to the early stages of the Valday glaciation) and to reconstruct periglacial steppes widely distributed in the Volga middle reaches at that time.

1. Introduction

The middle reaches of the Volga is a key region for the correlation between palaeogeographic events in the glaciated part of the Russian Plain and the areas inundated by the ancient transgressions of the Caspian Sea. The analysis of small mammal remains is of crucial importance in the stratigraphical and palaeogeographic correlations and reconstructions of the non-glaciated areas of the Russian Plain. Fossil remains of small mammals are a sensitive indicator of the past environments due to a quick response of those animals to the environmental changes.

In 1981 these sections were surveyed by the team of the Institute of Geography, Russian Academy of Sciences, headed by V.P. Udartsev. During the field survey the team performed the preliminary description of the sections and took samples from small mammal beds. The collected remains were studied by A.K. Markova. In 2003 the authors of the present paper revisited the Spasskoe and Yagodnoe sections. A more detailed description of the deposits of these sections has been done by A. A. Svitoch during this field work and the main units were identified.

The present paper summarizes results of the geological and palaeontological studies performed the two key sections of a high Volga terrace in the south of the Middle Volga region, near Spasskoe and Yagodnoe settlements (Fig. 1).

2. Regional setting

The territory under study is confined to the Middle Volga basin. It is located on the eastern Russian Platform and consists of several structural elements. The most extensive regional element is the Volga–Kama anticline that includes the Near Volga highlands, Trans-Volga highlands and Trans–Volga lowland. The Near Caspian syneclise is located to the south from the city of Saratov. Its structure is characterized by large slab deflections with thick sediment infillings. The territory under study represents the Volga River valley between the two uplands – the High Trans–Volga highlands on the east and the Near Volga highlands on the west (Fig. 1). The tectonic structure of the Trans-Volga highlands is heterogeneous. The gently undulating and often smoothed areas are characteristic for the High Trans-Volga highlands. The absolute heights are 40–150 m a.s.l., however, sometimes reaching up to 150–200 m. Tectonically, the Near Volga Upland is a syneclise, though it includes an anticlinal structural unit known as Zhiguli massif. The Near Volga Upland stretches along the right bank of the Volga River for more than 800

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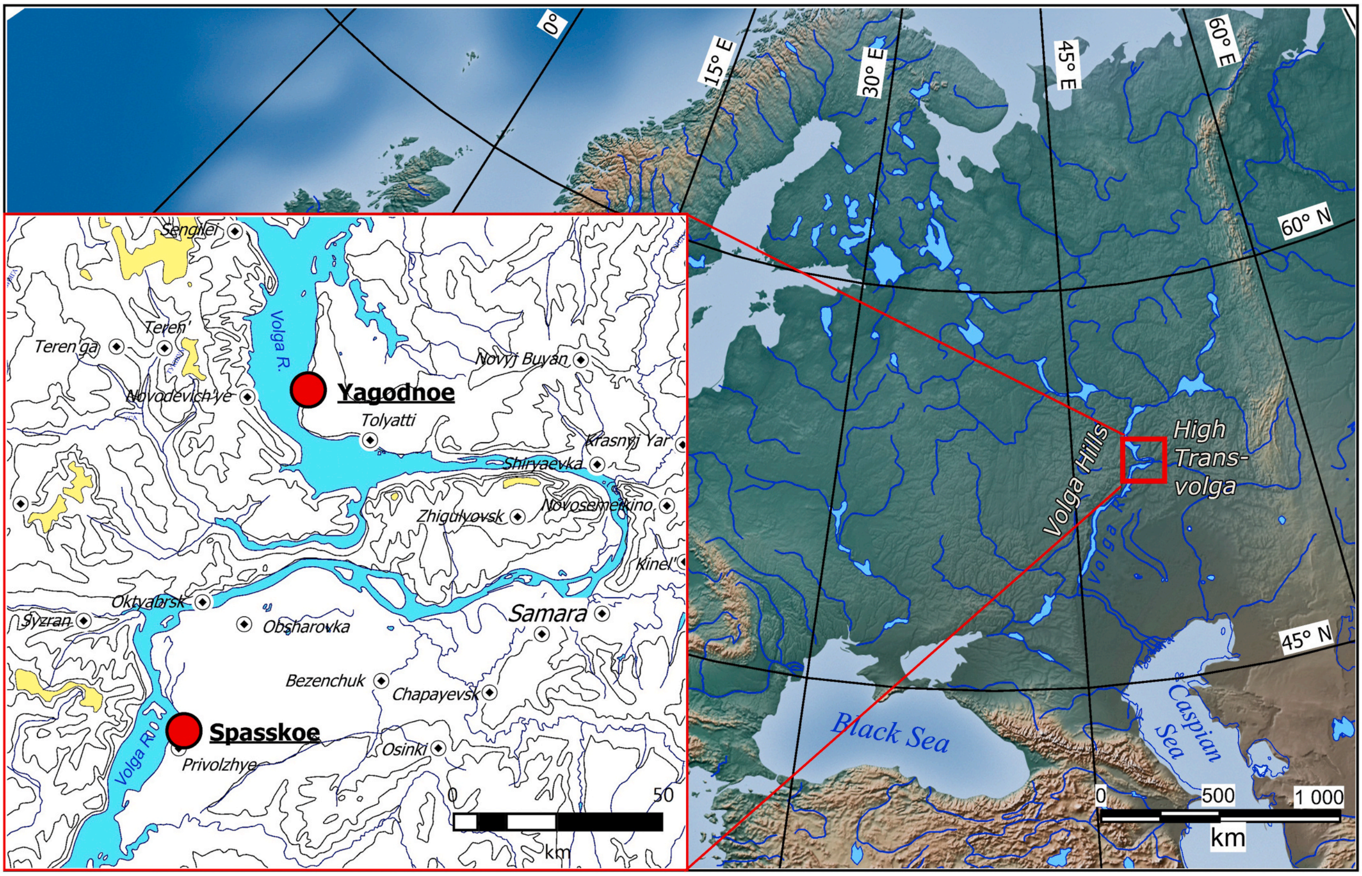

Fig. 1. Geographic position of the localities.

km. The territory under study encompasses the highest parts of the highlands averaging 250–270 m a.s.l. including the Zhiguli massif with the heights reaching 381 m (Chepikov, 1967). The Volga River bends around the upland forming a meander (Samarskaya Luka) (Dedkov, 1991).

The Neogene, Paleogene, Cretaceous, Jurassic, Permian and Upper Carboniferous sediments are exposed at the modern denudation surface of this territory. The Akchagylian (Upper Pliocene – Early Pleistocene) beds outcrop on both banks of the Volga River (Chepikov, 1967). The Quaternary deposits of different genesis are ubiquotous.

The valley is well developed, with a pronounced slope asymmetry. Its right side largely composed of solid rocks is higher (100–150 m) and steeper, while the left one is gently sloping. The alluvial-lake plain of the Pleistocene age is located on the left bank of the Volga River. The absolute heights of this surface are 90–115 m a.s.l.

With the river water level position at +28 m a.s.l., several Middle and Late Pleistocene terraces together with the modern floodplain are developed in the valley. The fragments of the highest forth terrace are found near Davydovka and Ekaterinovka villages at 60–81 m a.s.l. The terrace alluvium is represented by loam interbedded with fine-grained sands and less often with sandy loam (3–4 m thick). Sometimes the fossil soil horizon is present at the base of the terrace on top of the Akchagylian deposits. The age of this terrace is Bakunian (Middle Pleistocene) (Kirikov, 2017).

The third terrace (60–40 m a.s.l.) is widely distributed and consists of two sediment strata. The lower beds are represented by grey fine-grained and inequigranular quartz sands. Their thickness sometimes reaches 45–50 m. In the deepest parts of the paleo-Volga River valley the gravel beds composed of flint rock fragments lies on the eroded surface of the Akchagylian clay, Upper Jurassic clay and, rarely, Upper Carboniferous limestone. The upper layer is represented by alternating yellowish-grey loam and sandy loam (up to 16 m thick). These deposits are overlain by loess like loam with the thickness of 5–7 m. Although the third terrace is the most common feature among regional landforms, there is no agreement among the specialists regarding its age (the estimates vary from the Likhvin Interglacial to the beginning of Valdai Glaciation (Vasiliev, 1967; Dedkov, 1991; Kirikov, 2017).

The second terrace has the absolute height of 40–28 m. It is widely distributed on the left bank of the Volga River. In the region close to Spasskoe-Privol'noe settlement and to the south from it the terrace is composed of the so called "chocolate" clay with the thickness of 5–6 m. This clay was deposited in the former estuary of the Early Khvalynian transgressive Caspian Sea basin at the end of the Late Pleistocene. Up the river valley the alluvium is represented by yellowish brown, fine-grained, quartz sands with loamy interlayers. Their total thickness is 18 m. Most specialists attribute these beds to the Valday (Weichselian, =Vistulian) Glaciation – Early Khvalynian time (Vasiliev, 1967; Dedkov, 1991; Svitoch, Yanina, 1997; Svitoch, 2000; Kirikov, 2017). The first terrace is almost completely flooded by the waters of the reservoir.

The investigation of the geological position of the two new Spasskoe and Yagodnoe sections revealed their confinement to the third terrace of the Volga River.

The territory is located in a temperate continental climate, the main air flows come with the westerlies from the Atlantic. The average annual temperature is about +4°C. The total precipitation reaches 400–550 mm per year. Forest-steppe and steppe landscapes predominate, associations of herb-grass meadow steppes with pine and linden-oak forests are common. In the forest-steppe zone, grey forest soils were formed, as well as podzol soils, leached and typical chernozems. In the steppe zone, ordinary and southern chernozems and dark chestnut soils were formed (Kirikov, 2017).

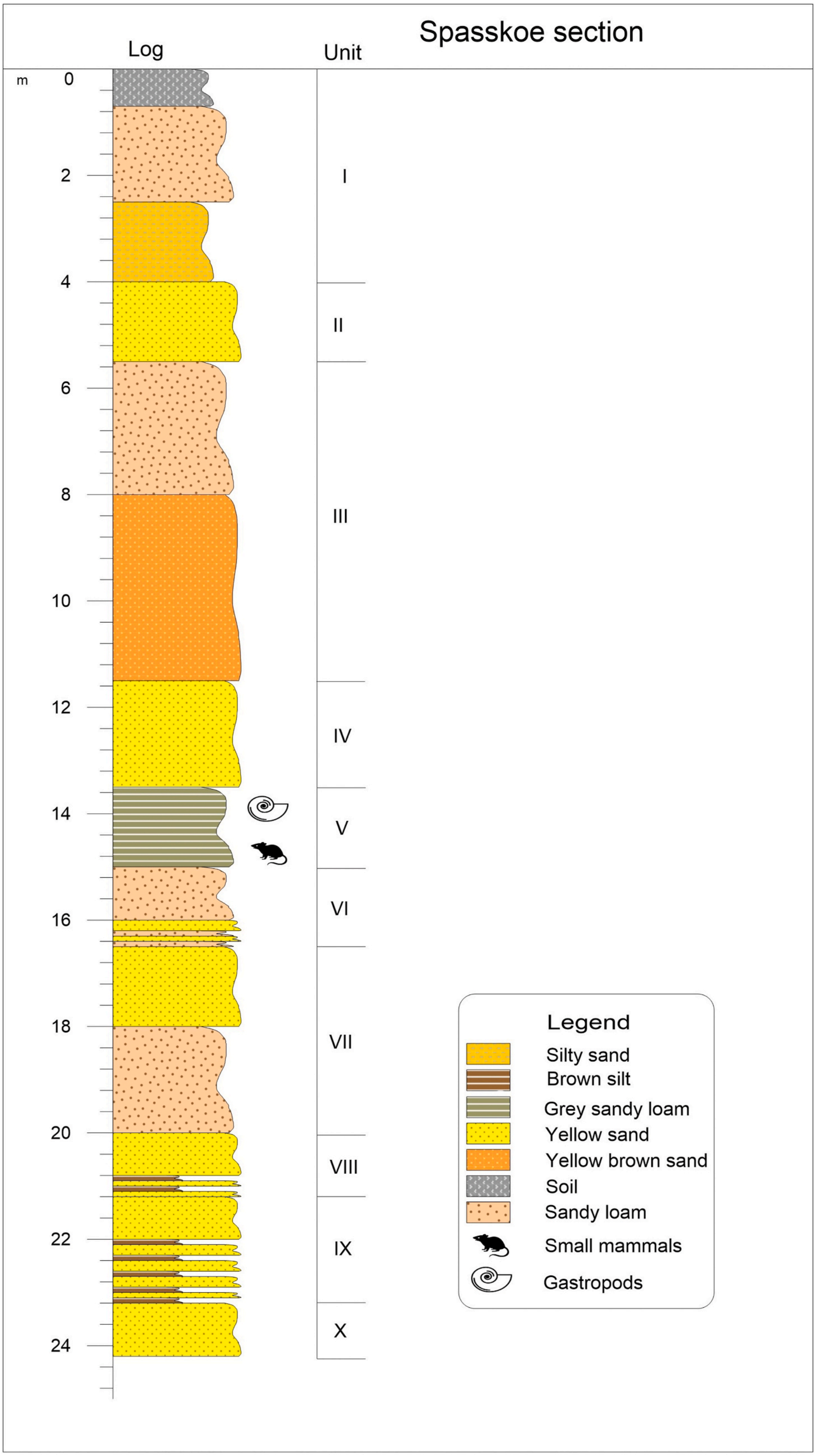

Fig. 2. The geological structure of Spasskoe locality.

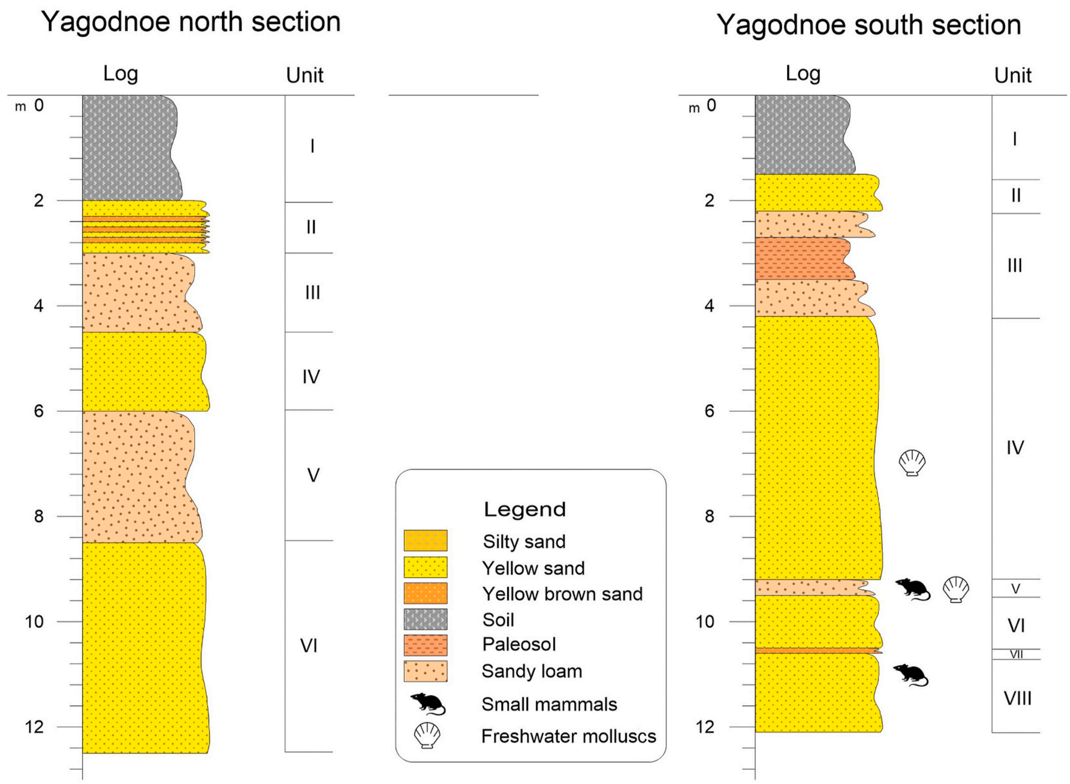

Fig. 3. The geological structure of Yagodnoe locality.

3. Methods and material

The description of the geological sections was done by A.A. Svitoch by the standard methodic. The deposits composition, colour, inclusions of the palaeontological remains and all other characteristics of the units in the Spasskoe and two Yagodnoe sections were described very detailed (see descriptions in next part of this paper and on Fig. 2 and Fig. 3). In addition, our study was accompanied by a drawing and photography of outcrops in order to perform a detailed stratigraphic scheme of the sections.

Stratigraphic subdivision of the sections is based on the sequence of the layers forming sedimentation cycles and their correlation with the neighbouring areas. We made the assumption on genesis of the described layers on the basis of lithologic composition and lamination of deposits. We have no absolute dates for the studied Spasskoe and Yagodnoe sections. There is one radiocarbon date (14 030 ± 250 yr BP, GIN-187) on a sample from the upper part (lower Khvalynian deposits) of the second terrace near Privolzhye settlement (Vasilyev, 1967). On the basis of the Calib 7.1 Program (Stuiver et al., 2017) and of the calibration scale IntCal13 (Reimer et al., 2013) we received age 16666–17405 (17036 ± 370) cal. yr. For confirmation of this date we used the published data for the lower Khvalynian deposits in the Lower Volga area (Svitoch, 2002; Yanina et al., 2017, 2019). We used the published datings for underlying deposits also (Shkatova et al., 1989; Shkatova, 2010; Yanina et al., 2017, 2018; Yanina, 2020; Kurbanov et al., 2018, and others).

The excavations and sampling for small mammal faunal investigations were executed according to standard methods (Gromov, 1957). The material was selected during the excavation with a help of washing through the sieve with 1.0 mm mesh cells. About 70 kg of sediments were washing in Spasskoe section and about 150 kg sediments from Yagodnoe section. The remaining material was dried under the sun and after that the bone remains were selected. The second stage includes the analysis of small-mammal bones under the microscope SMC 4, ASKANIA. This analysis includes the measuring of the bones under the microscope and the drawing the remains with the help of draw apparatus. The comparison with the fossil small-mammal materials from the collection of the Institute of Geography RAS has been done. The bone material from the sections has a good preservation. The angles of teeth weren't broken, some mandibles with teeth have been found. The bones have light yellow colour. About 800 small mammal remains were identified on the species level. The unidentified remains constitute about 1000 remains. The small mammal remains from Spasskoe and Yagodnoe are stored in the collection of the Institute of Geography RAS.

4. Results

4.1. Geology of the sections

4.1.1. Spasskoe section

The Spasskoe section (Fig. 2) is positioned on the left side of the Volga River valley at the northern margin of Spasskoe settlement (52°53′ N, 48°36′ E) (Figs. 1 and 2) and exposes the structure of the third terrace (of “Saale”, “Dnieper” or “Krasnoyarsk” age according to the European and Siberian stratigraphic schemes, respectively) 50–60 m a.s.l. or ~30 m above the river channel. The terrace surface is levelled, gently sloping northward; near the southern edge of the settlement it gives way gradually to a lower surface (~15 m above the river channel).

We have studied all the exposures of the terrace between Spasskoe and Privolzhye settlements. Fragments of the upper and lower portions of the sequence are exposed in the northern part of the terrace. At the lowermost part of the section there are clayey silt of estuarine type, chocolate-brown, horizontally bedded, or a thick series of grey cross-stratified sands (channel facies). The upper part of the section is different. It consists of a thick (more than 10 m) layer of sand (less common is sandy loam), yellow-brown or yellow-grey in colour, with thin horizontal or sub-horizontal bedding, seemingly deposited under conditions of quiet stream flow.

The most complete sequence was described in the exposure of the northern – highest – portion of the terrace as follows (from the top downwards) (Fig. 2):

I. Silty sand and sandy loam yellow and brownish-yellow (pale yellow on the weathered wall), dense, displaying vertical walls and columnar parting. The lower part of the unit is horizontally stratified, upwards the stratification becomes indistinct. There is a well developed soil of chernozem type at the top. The unit is 4 m thick, the transition to the underlying layer is gradual. *The unit was determined as floodplain deposits, heavily weathered in its upper part, seemingly overlain with thin deluvial apron.*
II. Fine-grained yellow-brown sand, well sorted, with indistinct thin bedding, 1.5 m thick. *Fluvial deposits of a steady stream flow.*
III. Sand and loamy sand, brown and brown-grey in colour, compact, with vertical walls. There is an indistinctly pronounced layering in the lower part; presumably, it is due either to the appearance of yellow sand interlayers, or to the carbonate enrichment. The lower boundary is indistinct. Thickness is 6.0 m. *Those probably are floodplain deposits, slightly affected by subaerial weathering.*
IV. Fine sand, yellow and yellow-brown, well sorted, indistinctly stratified. The deposits are similar in composition to the upperlying layer, though with a higher proportion of sand. The lower boundary is indistinct. The thickness is 2 m.
V. Sandy loam, greenish-grey, in the upper part – green, dense, with numerous small-sized shells of freshwater gastropods; transition to the underlying unit is gradual, the unit appeared to contain small mammal remains. The layer thickness is 1.5 m. *The layer presents the deposits of a stagnant oxbow lake.*
VI. Sandy loam grey-yellow, with ferruginized spots, locally with a considerable proportion of sand; the lower part displays horizontal layering (due to the presence of interlayers 2–6 cm thick of brown-grey sand). A fine horizontal stratification is noticeable within the layers. The lower boundary is clearly seen by the change in colour. The thickness is 1.5 m. *Alluvial deposits accumulated in quiet environments.*
VII. Sand and sandy loam compact, grey-brown and yellowish-brown indistinctly stratified, with large blocky-fragmentary partings, forming vertical walls in the scarp. Boundary is sharp. The unit is 4–4.5 m thick. *Deposits formed in a quiet sedimentation environments (in an oxbow lake on the floodplain or in a water hole); the uppermost part of the layer shows traces of subaerial weathering.*
VIII. Yellow and grey-yellow sand, thin-bedded or lenticular and banded, with interlayers of sandy brown-chocolate silt, occasionally ferruginous. Lower boundary is distinct. Thickness is 1.2 m. *Fluvial deposits of a floodplain or oxbow lake type.*
IX. Fine sand, grey and yellow-grey, well sorted, with thin horizontal and diagonal bedding (beds dipping downstream), with interlayers of sandy silt, brown (chocolate) in colour, often distorted and broken. Individual layers are distinct due to white salt efflorescence. The lower boundary is sharp. The unit is 2 m thick. *The material was seemingly deposited under conditions of shallow water and braided channels forming numerous branches.*
X. Light-grey sand, well sorted, cross-stratified, often with diagonal bedding; in the lower part of the horizon beds dip steeply downstream, the bedding is distinct due to alternating light grey and brown beds. The apparent thickness is 1 m. *Fluvial deposits of a highly dynamic stream.*

The total thickness of the exposed sequence is 24–25 m.

The described sequence permits to distinguish 3 major cycles of sedimentation.

Lower cycle (units X to VII) fine-grained and inequigranular quartz sands. Their thickness sometimes reaches more than 9 m thick begins with material deposited by a highly dynamic stream (unit X), changes to sediments of a quiet flow (units IX–VIII) and finally to deposits of a stagnant basin (unit VII).

Middle cycle (units VI–III) is thickest of all (11.0 m); it was found to contain remains of small mammals and molluscs, and obviously it represents the periglacial alluvial deposits of the ancient Volga R.

Upper cycle (units II–I) is thinnest (5.5 m). The layers are essentially changed by soil-forming processes. Quite possibly, the uppermost horizons belong to subaerial formations.

4.1.2. Yagodnoe section

The Yagodnoe section (Fig. 3) is on the left side of the Volga River 10 km to northwest from the city of Tolyatti (53° 36′ 47 ″N, 49° 02′ 43″ E) (Fig. 1). The section just north of Yagodnoe settlement exposes sediments of the 3rd terrace of the Volga 20–30 m high. The terrace surface is smooth, gently waving, slightly inclined towards north and south.

The most representative section of the terrace was found 1.5–2.5 km north of Yagodnoe settlement. In the upper part of the scarp the sequence is as follows (from top to the base of exposure):

I. Chernozem-like soil with well developed humus horizon (0.7–0.8 m thick) and carbonate horizon at a depth of 0.6–0.8 m. Transition to the parent rock is gradual, thickness – 2.0 m.
II. Alternating layers of gray and yellow sand, well washed, fine to medium-grained, with interbeds of brown clayey sand. The bedding is horizontal or wave-like, occasionally forming small-sized gentle crumples. Thickness is 1 m, the lower boundary is sharp. *Fluvial deposits, considerably changed by subaerial processes, particularly in the upper part.*
III. Loess-like sandy loam, pale yellow, with pseudo-mycelium, columnar structure. Thickness is 1.5 m. Sharp transition to the underlying layer. *The sediments were probably deposited in stagnant water and heavily reworked by subaerial processes; less probable is continental (eluvial-deluvial) genesis of the deposits.*
IV. Pale yellow and grey sand, fine-grained, well sorted, with thin horizontal bedding and fine banding. Thickness is 1.5 m. Lower boundary is sharp and distinct.
V. Sandy loam yellowish-brown at the top, yellowish-blue (or grey) in the middle part, and grayish-yellow in the lower part, with poorly pronounced horizontal bedding, 2.5 m thick, the lower boundary is lithologically distinct and sharp. *Deposits of a stagnant water basin (oxbow lake?).*
VI. Well sorted sand, yellow and grey-yellow, with lenses and interbeds of pale-grey to white sand (probably due to presence of salts), in the lower part changes to clayey brown material, indistinctly banded (due to the presence of loamy sand interbeds, often distorted). Apparent thickness is 4.0 m.

The sediments described as units V and VI present a single cycle of sedimentation, beginning from alluvial deposits left by highly dynamic streams at the base and changing gradually upward to facies of floodplain or stagnant lake; the cycle is easily traceable along the exposure. Up the section there are two more cycles of fluvial deposits separated by a subaerial break in sedimentation (top of unit III). Both cycles are similar in structure, with dynamic (channel) facies at the base changing upwards into quiet floodplain deposits. The base of the exposure down to the water level (10 m) is covered with debris.

The lower part of the terrace sequence is exposed in a deep ravine 1 km south of the above described exposure (clearing 3). The sequence exposed there is as follows:

I. Chernozem-like soil with well pronounced genetic horizons – dark brown loam coloured with humus and abounding with various carbonates in its lower part, 1.5 m thick. The lower boundary is distinct.
II. Yellowish-brown fine sand, well sorted, thinly and wavy bedded, with occasional lenses and interbeds of coarse sand; in the middle part of the horizon there are carbonate-rich interlayers. The boundary is sharp and irregular. The unit is 0.7 m thick. *Fluvial deposits formed in a dynamic stream.*

Species	Spasskoe	Yagodnoe		Species ecology
		Lower layer	Upper layer	
Eulipotyphla - Insectivores				
Crocidura sp. - белозубка		1	4	steppe, forest-steppe, semidesert
Lagomorpha - Lagomorpha				
Ochotona sp. – pika		8	42	steppe, semidesert
Rodentia - rodents				
Spermophilus sp. – ground squirrel	4		1	steppe, forest-steppe, semidesert
Pygeretmus pumilio Kerr - dwarf fat-tailed jerboa		1		open arid landscapes
Dicrostonyx sp. – collared lemming	2			tundra
Eolagurus luteus Eversm. – yellow steppe lemming	102	8		steppe, semidesert, periglacial steppe
Lagurus lagurus Pallas– steppe lemming	60	22	38	steppe, forest steppe, periglacial steppe
Lasiopodomys (Stenocranius) gregalis (Pallas) – narrow-skulled vole	18	6	22	steppe, forest steppe, periglacial tundra-steppe
Microtus (Pallasiinus) oeconomus Pallas – root vole	3	3	56	hydrogenous landscapes
Microtus sp. - vole	10	17	330	

Fig. 4. Species composition of small mammals from Spasskoe and Yagodnoe localities.

III. Loess-like loamy sand, compact, with columnar parting and abundant pseudo-mycelium. A light brown-red interlayer, probably corresponding to a buried soil, is found at a depth 0.5–0.6 m. The thickness is 2.0 m. The transition to the lower layer is gradual. *The deposits are seemingly subaerial accumulated during a long-term interval when alluvial deposition stopped.*

IV. Grey and yellow-grey sand, thinly horizontally laminated, with thin bands within; individual laminae are often broken or distorted. There are interbeds of ferruginous fine well sorted sand and lenses of coarse sand, including fragments of thin-valved mollusc shells. Thickness is 5.0 m; the lower boundary is sharp and irregular. *Fluvial channel deposits formed under highly dynamic conditions.* Probably, it belongs to the same sedimentation cycle as the overlying layer.

V. Silty sand, marly, light grey-greenish to white in colour, occasionally white lacustrine marl, with rusty spots and freshwater mollusc shells and rodent remains. Thickness is 0.3 m. The lower boundary is irregular, with large pockets due to convection. *Sediments of a stagnant water body (lake).*

VI. Sand, dirty yellow and yellow-grey in colour, with horizontal or wavy layering, thinly banded, with thin intercalations of loamy sand. Thickness is 1.0 m. The transition is sharp (traceable by a drastic change in lithology). *The unit is deposited by a highly dynamic stream and forms a single cycle with unit 5 deposits.*

VII. Loamy and silty sand, light brown, with salt efflorescence, 0.1 m thick. The boundary is irregular (with pockets). *Most probably, the unit was deposited in the lake (presumably on the floodplain).*

VIII. Sand, yellow-brown and dirty grey, fine-grained, well sorted, indistinctly layered. Small mammal remains were discovered in the upper part of the unit. The apparent thickness is 1.5 m.

Judging from the section, the lower part of the alluvial deposition cycle here (in common with the sequence exposed near Spasskoe settlement) consists of three series of deposits. Series II described in units III and IV may be used as the key horizon for correlation those two exposures.

4.2. Small mammal fauna

4.2.1. Spasskoe section

Unit V described in Spasskoe section yielded rodent bones identified as belonging to 6 species (Fig. 4).

The fauna is dominated by species of open landscapes, such as ground squirrel *Spermophilus* sp., yellow steppe lemming *Eolagurus luteus*, steppe lemming *Lagurus lagurus*, narrow-skulled vole *Lasiopodomys (Stenocranius) gregalis* (Fig. 4). Besides, there have been found remains of root vole *Microtus oeconomus* (Pospelova, 1989) living in moist meadows near water bodies and 2 M fragments of collared lemming (*Dicrostonyx* sp.) – typical tundra inhabitant. The fauna includes mostly inhabitants of open landscapes. Its species richness is rather low, which possibly reflects the low species richness of a cold environment rather than only small sample size. At present the region is inhabited by about 50 small mammal species including some Holocene invaders (Norway rat, black rat, muskrat). The low species richness of the Spasskoe fauna dominated by a few species (mostly *Eolagurus luteus*, and *Lagurus lagurus*) is characteristic of both modern tundra faunas and of periglacial faunas of glacial epochs. This consideration may be supported by reconstructions of the species richness in the Volga drainage basin at the Valday glacial time: the region south of 55° N was inhabited by 21–30 mammal species, while north of 55° N the number was reduced to 11–20 species (Markova et al., 1995). Therefore the cold environment at the time of accumulation of the fossil assemblage is not only responsible for the species composition, but also for the low species richness typical of the cold stage of the Pleistocene.

4.2.2. Yagodnoe section

The small mammal fauna identified in the Yagodnoe section includes 8 taxa (some of them are sp.) attributed to three orders (Fig. 4). Small mammals recovered from the lower and upper bone-bearing beds are similar in species composition to each other and consist exclusively of inhabitants of open landscapes.

Abundant remains of the narrow-skulled vole were described in the upper layer, though its presence in the lower layer was also recorded.

The lower layer (upper part of unit VIII) is dominated by steppe lemming (*Lagurus lagurus*), pika (*Ochotona* sp.), yellow steppe lemming (*Eolagurus luteus*), and narrow-skulled vole (*L. (S.) gregalis*). All those animals are characteristic of open and arid landscapes. They were widespread in both steppe landscapes of interglacial, but even more typical in periglacial landscapes of glacial epochs, including the Valday glacial. The only rodent indicative of a river presence in the vicinities is the root vole *Microtus oeconomus*. Both upper and lower layers yielded remains of white-toothed shrew *Crocidura* sp. At present an animal

Geochronology	Small mammal complexes	Localities of the Russian Plain	*Lagurus* morphotypes of m1, % "transiens" n	"transiens" %	"lagurus" n	"lagurus" %
Valday Glaciation (MIS 5a-d, MIS 4-2)	Sungirian	Luchki			28	100
		Arapovichi	2	12	16	88
		Spasskoe			4	100
		Yagodnoe (up.layer)	1	17	12	83
		Yagodnoe (lower layer)			3	100
Mikulino Interglacial (MIS 5e)	Shkurlatian	Gadiach	1	33	2	67
		Chernianka			1	100
		Shkurlat	5	17	24	83
Dnieper glaciation (MIS 6)						
		Pavlovka			1	100
		Igorevka	3	38	5	62
Romny Inter. (MIS 7)		Matveevka				
Cooling (MIS 8)						
Kamenka Interglacial (MIS 9)	Kamenkian	Priluki	7	44	9	56
Cooling (MIS 10)						
Likhvin Interglacial (MIS 11)	Gun'kovian	Gun'ki 2	29	58	23	42
		Chigirin	9	75	3	25

Fig. 5. Morphotypes of *Lagurus* molars from Pleistocene localities of the Russian Plain.

belonging to that genus – lesser white-toothed shrew C. *suaveolens* Pallas, 1811 occurs in the Volga basin, in the south of Eastern Europe, in the Northern Caucasus, in Kazakhstan and Central Asia. It inhabits steppe, forest-steppe and semidesert landscapes, and occurs in forbs and sedge meadows. It may be concluded that the presence of that animal remains also indicates the wide distribution of open landscapes.

5. Discussion

The Spasskoe terrace structure was repeatedly studied by many investigators (Shantcer and Trudy geol. Institute AN SSSR, 1951; Grishchenko and Kopteva, 1955; Moskvitin, 1962; Obedientova and Gubonina, 1962; Lavrushin, 1964; Goretskiy, 1966). Most of them distinguished two alluvial series in the terrace sequence though differ widely in their opinions as to the series age and environments of deposition. According to A.I. Moskvitin (1962), the sequence belongs to the forth terrace of the Volga; its lower series is dated to the early stage of the Dnieper glaciation on the Russian Plain (synchronous to the Early Khazarian transgression of the Caspian Sea), and the upper series formed in periglacial environments during the Dnieper long-lasting ice age. Similar to those are the views of Yu.A. Lavrushin (1964), except that he dated the lower boundary of the fluvial deposits to the end of the Likhvin interglacial epoch. According to G.I. Goretskiy (1966), the sequence belongs to the lower level of the 3rd periglacial terrace; the basal part of the series presents alluvial deposits of the upper Krivich suite (datable to the end of the Early Khazarian transgression) overlain by the periglacial alluvial layers (the Late Pleistocene beginning, Hyrcanian transgression of the Caspian Sea). Quite different views on the third terrace structure were stated by M.N. Grishchenko and A.M. Grishchenko and Kopteva (1955) who correlated the upper alluvial series with Khvalynian deposits of the Caspian Sea.

We distinguished three major cycles of sedimentation. Deposits of Middle cycle (units VI–III) contain remains of small mammals and considered to be datum horizon, best suited to the notion of Goretskiy (1966) and Moskvitin (1962) about the periglacial alluvial deposits of the ancient Volga River.

Summing up the information of the Spasskoe section, it should be noted that it exposes thick and well differentiated series of fluvial deposits formed mostly in quietly flowing stream or on the floodplain and including three cycles of sedimentation. All of them are similar in structure: channel deposits of undisturbed quiet flow at the base overlain with sandy loam deposited in estuary or on floodplain and affected by subaerial weathering or soil formation in the uppermost part. The entire sequence belongs to the upper alluvial member of the high (third) terrace. The lower alluvial member (Upper Krivich, according to G.I. Goretskiy, 1966) described earlier in the exposure is inaccessible to observation at present, as it is 7–10 m below water level of the Kuybyshev reservoir now. Its outcrops (a series of cross-stratified sands about 3 m thick apparently) occur at the base of the slope closely to the water level at some distance north.

The upper part of the section (presumably, two upper cycles) yielded pollen assemblage of definitely steppe type dominated by the grass and herb (*Artemisia*, Chenopodiaceae) pollen (78%). *Pinus, Betula, Alnus* are present in the AP group (Obedientova and Gubonina, 1962). As has been concluded by G.I. Goretskiy (1966), pollen assemblages recovered from the periglacial deposits of the Spasskoe section differ markedly from forest-type assemblages in the Khvalynian chocolate clays, in fluvial deposits of the second terrace of the Volga, and Upper Krivich suite at the base of the third terrace sequence.

The considered part of the Yagodnoe terrace (the northern part of the Samarskaya Luka bend) was investigated by A.I. Moskvitin (1962), G.I. Goretskiy (1966), G.V. Obedientova and Z.P. Gubonina, (1960). Judging from the section, the lower part of the alluvial deposition cycle here (in common with the sequence exposed near Spasskoe settlement) consists of three series of deposits. Series II described in units III and IV may be used as the key horizon for correlation those two exposures; in their composition and volume they are comparable with the periglacial alluvial series identified by G.I. Goretskiy (1966) in the third terrace sequence (the upper alluvial member). Quite possibly, it was from this series that the steppe pollen assemblages had been recovered and described by Z.P. Gubonina as typical of interglacial environments. The authors of the present article have a different idea of the climate situation during the accumulation of that series.

Unfortunately, we have not got absolute dates for Spasskoe and Yagodnoe sections. There is one radiocarbon date 14 030 ± 250 yr BP (GIN-187) from the upper part (lower Khvalynian deposits) of the second terrace near Privolzhye settlement (Vasiliev, 1967); calibrated age is 17 036 ± 370 cal. yr. The 3rd terrace is dated to the Middle Pleistocene – Early Khazarian time (Moskvitin, 1958; 1962; Lavrushin, 1964; Dedkov, 1991), or to the Late Pleistocene – (Mikulino-Kalinin – Late Khazarian-Atelian) (Vasiliev, 1967), or to Hyrcanian – Atelian interval (Goretskiy, 1966). The authors who attribute the third terrace to the Late Pleistocene refer usually to the third terrace deposits in the lower reaches of the Volga where the Caspian Upper Khazarian (Hyrcanian)

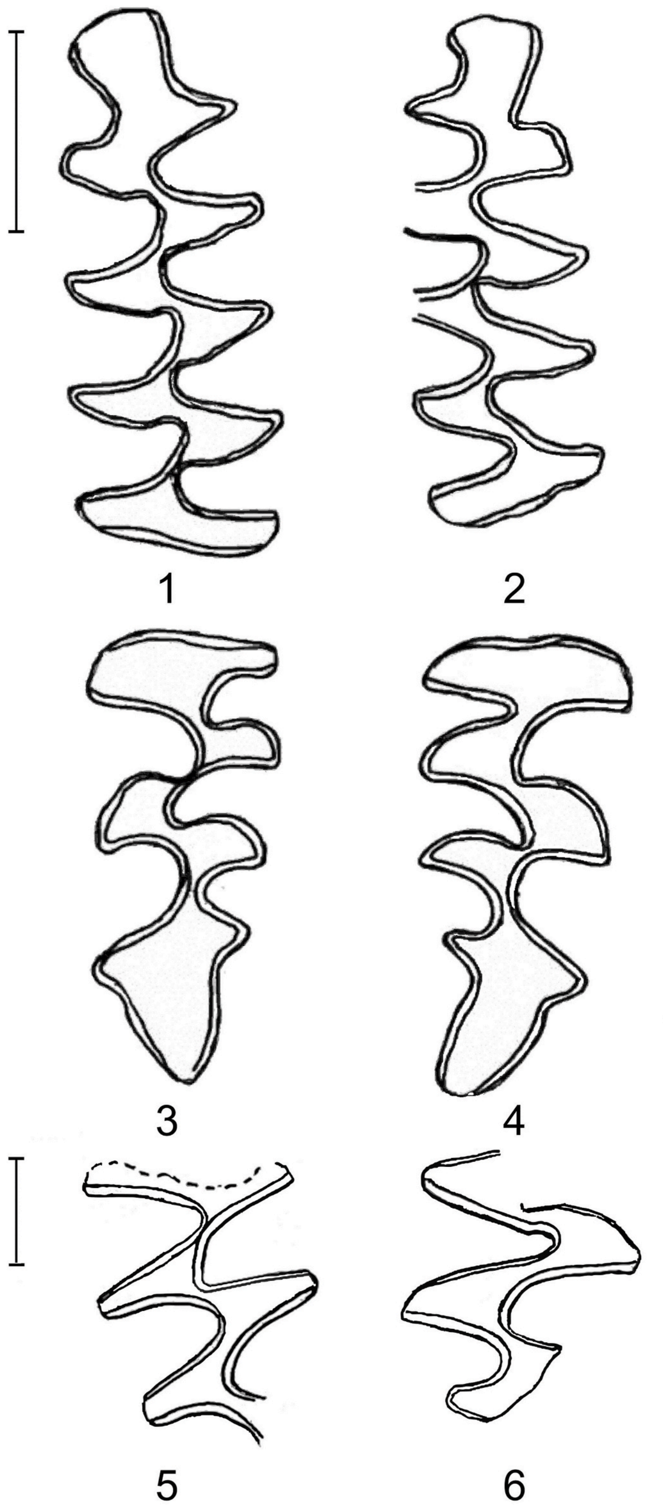

Fig. 6. Spasskoe, arvicoline molars: 1, 2 – m1 of *Lagurus lagurus*; 3, 4 – M3 of *L. lagurus*; 5 – fragment of M2 *Dicrostonyx* sp., fragment of M3 *Dicrostonyx* sp. Both scales are equal to 1 mm.

layers are found at the base of the sequence. Those layers are overlain with periglacial alluvial layers (described by G.I. Goretskiy under the name of the Akhtuba layers) deposited by the streams flowing into the regressing Hyrcanian basin. The sedimentation cycle of the third terrace was accomplished with Atelian continental deposits synchronous with the Caspian regression of the same name. All the units of said sequence are dated using the absolute geochronology methods.

Currently large number of absolute dates with various techniques has been applied to Middle and Late Pleistocene deposits of Volga River and Caspian Depression. A complex of absolute dating techniques has been applied to the Middle and Late Pleistocene deposits. The materials assorted and reviewed by A.A. Svitoch (2002) indicate that most reliable dates are those for the Late Khazarian (120–80 ka BP) and Khvalynian (20–10 ka BP) transgressions. Similar dates were provided by other authors studying deposits in the Caspian and Volga basins. Other examples show marine Lower Khazarian sediments were dated by Io/U technique to >300 ka BP and >250 ka BP, and by thermoluminescence (TL) method – at 148–174 ka BP (Shkatova et al., 1989; Baryshnikov et al., 1991). The Upper Khazarian sediments have been dated simultaneously using Io/U, ESR, and TL techniques, as well as paleomagnetic method; the dates thus obtained are in the range from 130 to 80 ka BP (Pospelova, 1989; Shkatova and Arslanov, 2004; Molodkov and Bolikhovskaya, 2002). The following dates are given in the paper by Shkatova (2010): TL dates – 127–89 ka BP; ^{230}Th/U – 122–87 ka BP; and Io/U – 127–91 ka BP. The age of the transgressive Late Khazarian phase was determined as 127–122 ka BP (Shkatova, 2010). Besides, the Blake paleomagnetic event was identified in the upper Khazarian deposits dated by calculation at 117–89 ka BP (Eremin and Molostovskiy, 1981; Shkatova and Arslanov, 2004). The continental layers exposed in the Srednyaya Akhtuba sections and corresponding to the Late Khazarian and Hyrcanian stages of the Caspian Sea history were dated by OSL (optically stimulated luminescence) and correlated with the entire MIS 5 stage (Yanina et al., 2017; Yanina, 2020). Another OSL date obtained on the Hyrcanian deposits is about 100 ka BP (Kurbanov et al., 2018).

All those data provide grounds for a reasonable correlation of the Upper Khazarian deposits with the Mikulino Interglacial (MIS 5e); the above lying Hyrcanian sediments may be correlated with the second (younger) half of MIS 5. That being so, the age of the well-known stratotypical mammal locality Cherny Yar confined to Upper Khazarian layers and dated formerly to the Middle Pleistocene (Gromov and Trudy GIN AN SSSR, 1948; Aleksandrova, 1976) had to be revised and is correlated with the Mikulino Interglacial at present. Another concept to be revised was a stratigraphic position of the Singilian faunal assemblage first described by V.I. Gromov, who dated it to Middle Pleistocene and considered it to be older than the Khazarian assemblage (also of the Middle Pleistocene age) (Gromov and Trudy GIN AN SSSR, 1948). According to the new data, the Singilian layers are younger and may be attributed between Lower and Upper Khazarian (Zastrozhnov et al., 2018, 2020).

The dates of the Atelian continental deposits obtained by TL method are in the range from 80 to 28 ka BP (Shakhovets and Shlyukov, 1987). The upper part of the sequence is dated by OSL at 48.68 ± 3.10 ka BP (Yanina et al., 2017); similar dates were obtained by radiocarbon (Bezrodnykh et al., 2017). It may be concluded that the subaerial Atelian formation was deposited in the early Valday time, namely in MIS 4, and in the first half of the interstadial warming MIS 3 (Yanina et al., 2018).

The TL dates obtained by TL measurements for Lower Khvalynian sediments fall within the interval from 76 to 16 ka BP, and for the Upper Khvalynian ones – to 30–16 ka BP (Shkatova and Arslanov, 2004). The authors of the present paper consider these dates doubtful. All the radiocarbon dates (67 altogether) available on the Lower Khvalynian deposits in the Volga region were systematized and calibrated by P.P. Makshaev (Yanina et al., 2019). All the 14C data fall within the interval 20 to 11 ka BP. Similar results were obtained by 230Th/234U method (Svitoch, 2002; Yanina, 2005; Arslanov et al., 2016) and OSL (Yanina et al., 2017, 2018) dating. The species is present in abundance in the Rybnaya Sloboda section at the Kama River mouth (at its entering the Volga R.) dated to the Likhvin Interglacial (Markova, 2007). The water vole remains are present in large quantities in the Cherny Yar locality dated recently to the Mikulino Interglacial (Aleksandrova, 1976; Kirillova and Svitoch, 1994; Kirillova and Tesakov, 2004; Shkatova, 2010).

Morphological characteristics of the rodent bone remains permit to make a guess about the fauna age, remains of steppe lemming and

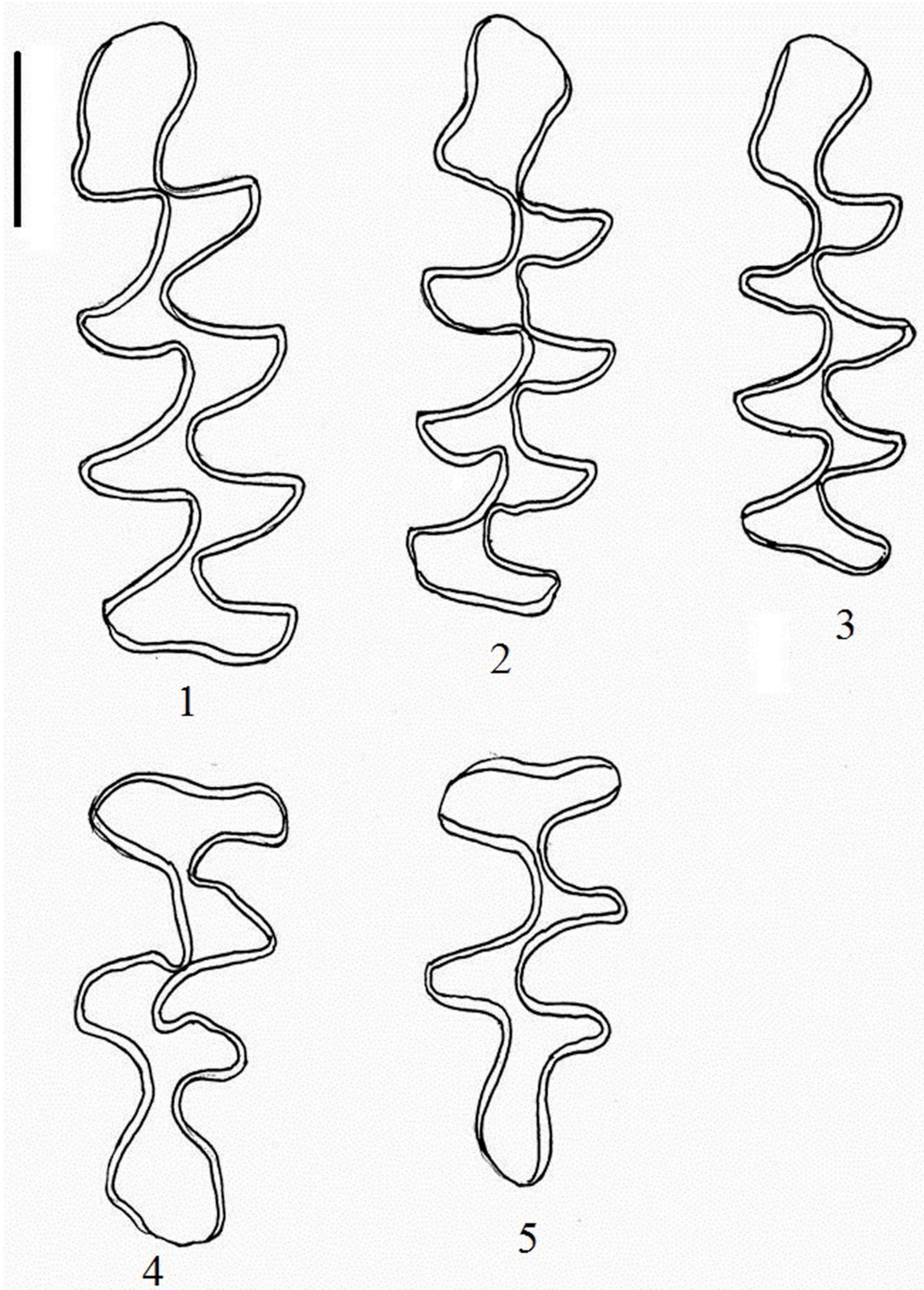

Fig. 7. Spasskoe: 1–3 – m1 of *Eolagurus luteus*; 4, 5 – M3 of *E. luteus.* Scale is equal to 1 mm.

yellow steppe lemming being most informative in this regard. The steppe lemming teeth found in the Spasskoe section are noted for a well differentiated anterior lobe of the anteroconid complex (ACC) of the first lower molar (Fig. 5; Fig. 6; *1,2*) and the posterior lobe of the upper third molar (Fig. 6; *3,4*).

Such morphology is typical for steppe lemmings since the end of the Middle Pleistocene and during the Late Pleistocene. In particular, the teeth are morphologically close to molars of the same species recovered from the Shkurlat locality dated to the 1st half of the Late Pleistocene (Mikulino Interglacial) (Markova, 1986) (see morphotype abundance in Fig. 5). They are also similar to scarce remains of lagurids present in the Pavlovka locality dated to the very end of the Middle Pleistocene (end of the Dnieper glaciation) (Agadjanyan and Glushankova, 1986; Agadjanian, 2009). *Lagurus* molars similar in morphology were recovered from the Arapovichi locality, in the Dnieper drainage basin (mole burrows in the Bryansk paleosol, MIS 3) (Markova, 1982). However, *Lagurus* molars found in the Spasskoe locality differ from teeth of steppe lemmings known from numerous localities dated to the Likhvin Interglacial, which are characterized by more primitive tooth structure (dominance of transiens morphotypes) and assigned to the ancestral form *Lagurus transiens* Yanossy, 1962 (Markova, 2004, 2006, 2007). The molars of *Lagurus* found in the Spasskoe are also more advanced compared with those from localities attributed to the Kamenka Interglacial (MIS 9) (Markova, 1982) and from localities related to the Dnieper glaciation (Fig. 5). Therefore, the tooth morphology of steppe lemmings permits to date the enclosing layers to a wide time interval –

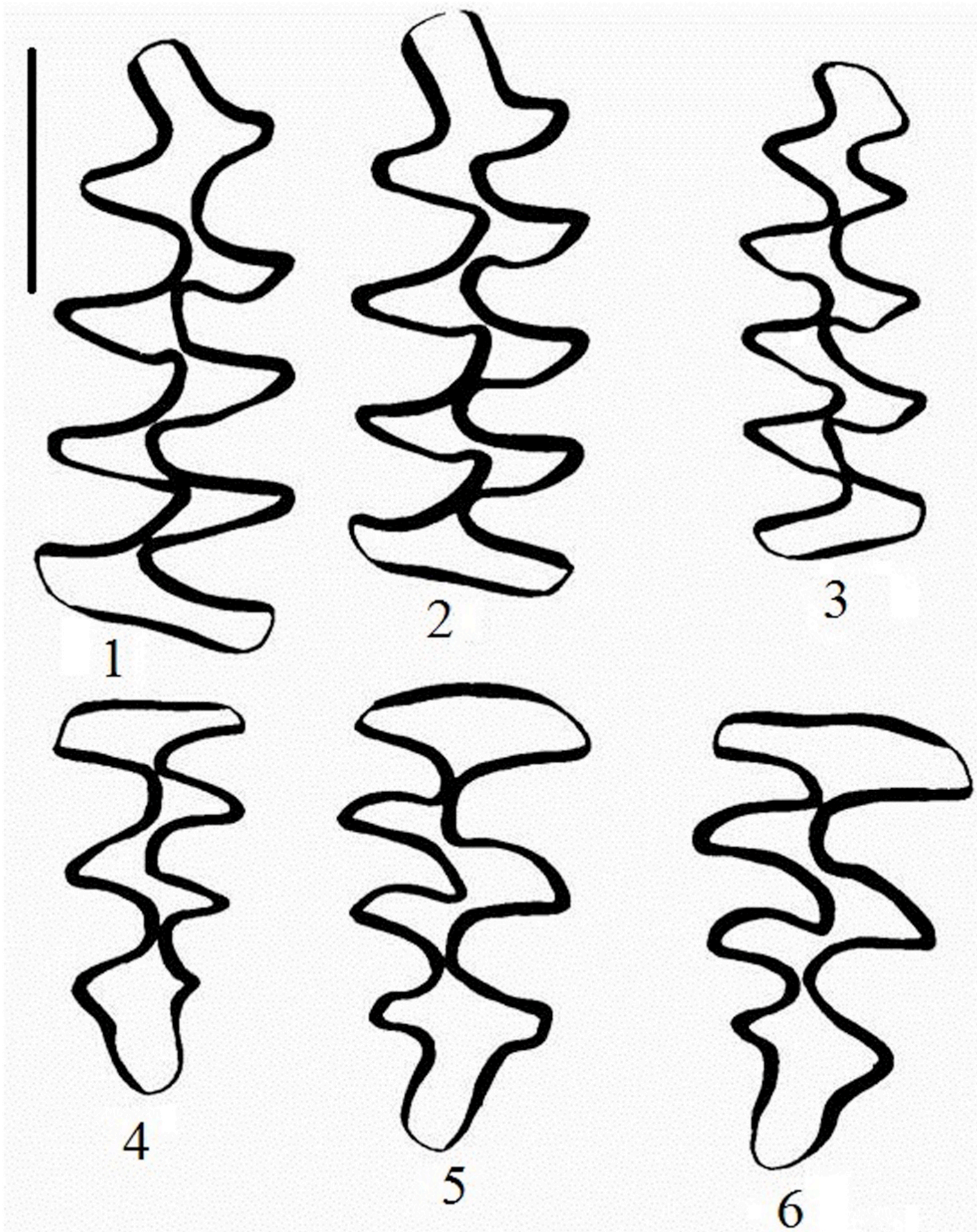

Fig. 8. 1–3 – Yagodnoe (lower unit): 1–3 – m1 of *Lagurus lagurus*; 4–6 – M3 of *L. lagurus*. Scale is equal to 1 mm.

from the end of Middle Pleistocene to the Late Pleistocene.

Numerous remains of yellow voles are similar in the molar morphology to the Late Pleistocene and recent *Eolagurus* (Agadjanian and Markova, 1983; Agadjanian, 2009) (Fig. 7).

Molar fragments of the collared lemming are slightly more primitive then modern ones and similar to *Dicrostonyx simplicior* Fejfar, 1966 (Fig. 6; *5, 6*). This species is very typical of the Middle Pleistocene, but it occurs occasionally in localities of the early Valday (Agadjanian, 1982; Motuzko, 1985). The fragmentary material from the Spasskoe prevents from specifying the age of the remains, so we described it as *Dicrostonyx* sp.

The molars of the narrow-skulled voles *Lasiopodomys (Stenocranius) gregalis* are morphologically close to the Late Pleistocene representatives of the species (Motuzko, 1992). In the Middle Pleistocene the structure of *L. gregalis* molars are more simple (Motuzko, 1992).

The small mammal fauna identified in the Yagodnoe section includes 8 taxa (some of them are sp.) attributed to three orders (Fig. 4). Small mammals recovered from the lower and upper bone-bearing beds are similar in species composition to each other and consist exclusively of inhabitants of open landscapes.

Abundant remains of the narrow-skulled vole were described in the upper layer, though its presence in the lower layer was also recorded.

The lower layer (upper part of unit VIII) is dominated by steppe lemming (*Lagurus lagurus*), pika (*Ochotona* sp.), yellow steppe lemming (*Eolagurus luteus*), and narrow-skulled vole (*L. (S.) gregalis*). All those animals are characteristic of open and arid landscapes. They were widespread in both steppe landscapes of interglacial, but even more typical in periglacial landscapes of glacial epochs, including the Valday glacial. The only rodent indicative of a river presence in the vicinities is the root vole *Microtus oeconomus*. Both upper and lower layers yielded remains of white-toothed shrew *Crocidura* sp. At present an animal belonging to that genus – lesser white-toothed shrew C. *suaveolens* Pallas, 1811 occurs in the Volga basin, in the south of Eastern Europe, in the Northern Caucasus, in Kazakhstan and Central Asia. It inhabits steppe, forest-steppe and semidesert landscapes, and occurs in forbs and sedge meadows. It may be concluded that the presence of that animal

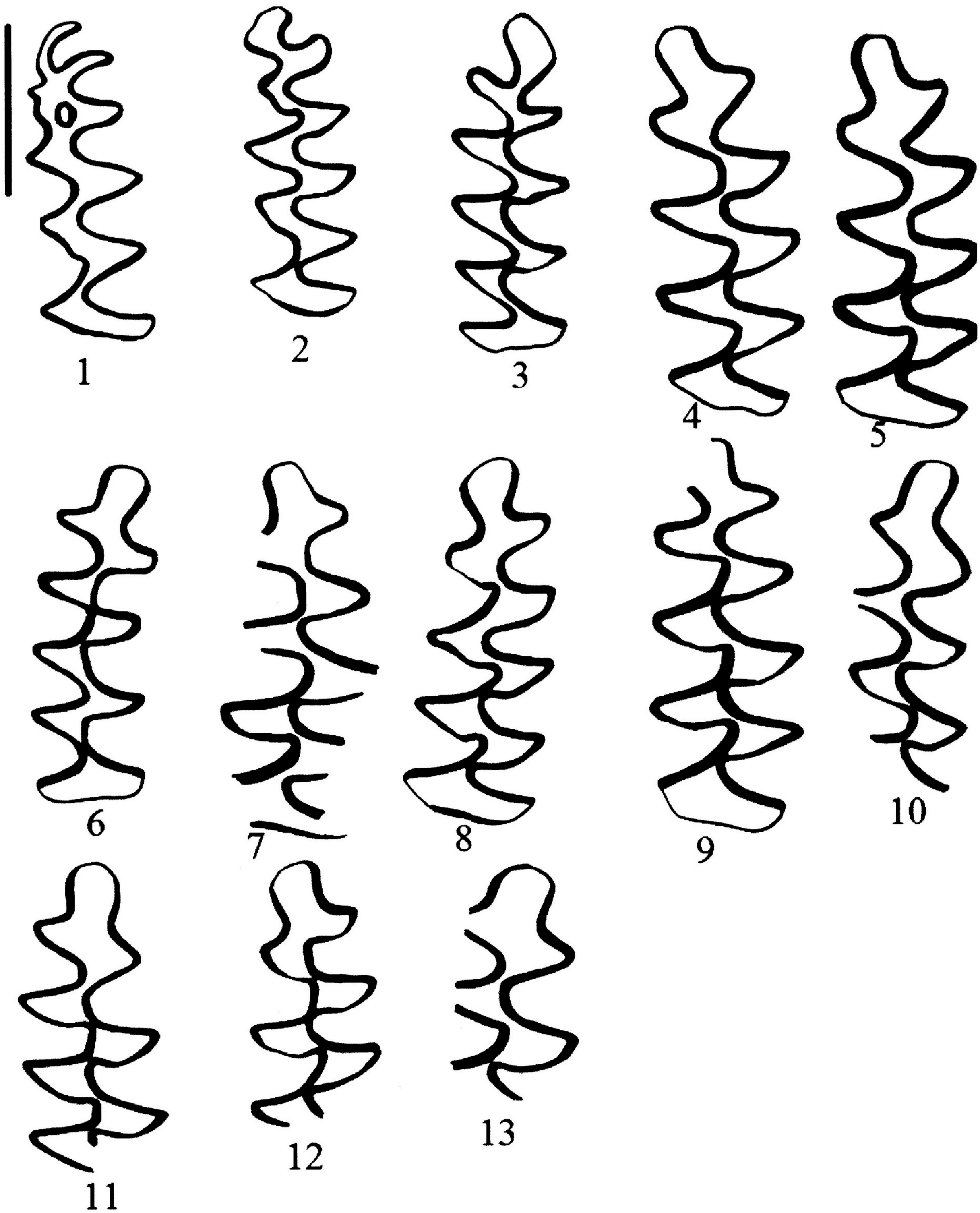

Fig. 9. 1–13 – Yagodnoe (upper unit): 1–13 – m1 of *Lagurus lagurus* from upper unit (1–3 – m1 of juvenile animals). Scale is equal to 1 mm.

remains also indicates the wide distribution of open landscapes.

The surprising thing is that water vole (*Arvicola amphibious* Linnaeus, 1758) remains are completely absent, which is probably evidence of arid, as well as cool, climatic conditions. Unlike the Spasskoe section, the root vole is present in both layers of Yagodnoe, being particularly abundant in the upper layer. No collared lemming remains was found in that section, nor bones of forest species. Both upper and lower bone-bearing layers yielded bones of pika (*Ochotona* sp.), particularly abundant in the upper layer. A single bone of the dwarf fat-tailed jerboa is found in the lower layer. There are abundant remains of steppe lemming (*Lagurus lagurus*), while yellow steppe lemming bones (*Eolagurus luteus*) occur in the lower layer only. The upper layer is completely devoid of dwarf fat-tailed jerboa and yellow steppe lemming. At present the named species occur not only in steppe landscapes, but in semideserts as well. The upper layer (unit V) is dominated by pika, steppe lemming, narrow-skulled vole and root vole. Quite possibly, the climate conditions were less arid at the time of this layer deposition than during the lower layer formation.

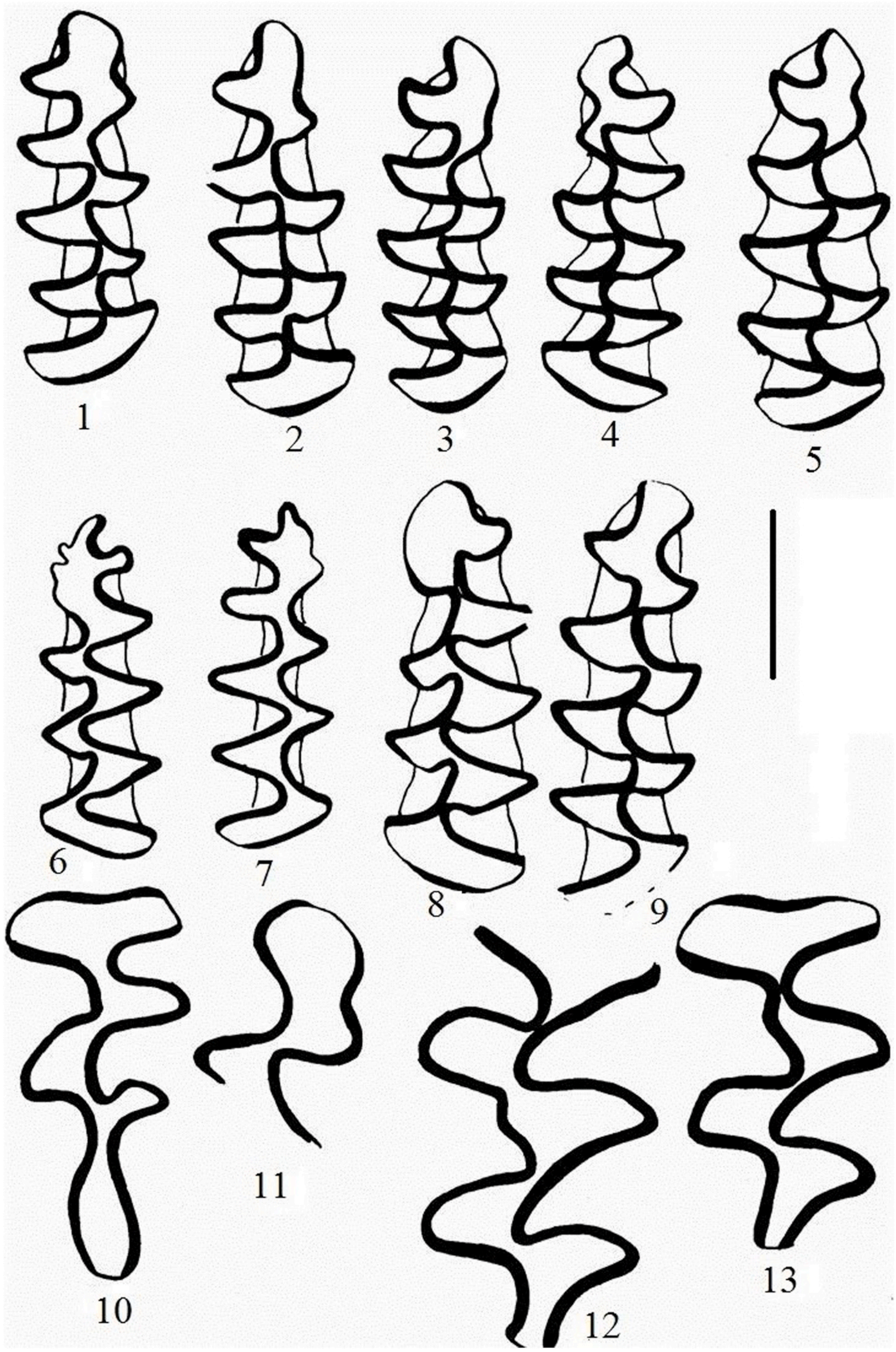

Fig. 10. Yagodnoe (upper unit), arvicoline molars: 1–9 – m1 of *Lasiopodomys (Stenocranius) gregalis* (6, 7 – m1 of juvenile animals); 10 – M3 of *Eolagurus luteus*; 11 – m1 of *E. luteus* (fragment); 12 – M1 of *E. luteus*; 13 – M2 of *E. luteus.* Scale is equal to 1 mm.

The exclusive occurrence of lagurus morphotypes (and lack of transiens morphotypes) in from Yagodnoe indicates the species *L. lagurus*. The m1 from the lower layer characterized by very advance morphotypes (IX and XI morphotypes, described Markova, 1982) typical to *L. lagurus* (Fig. 8). A large sample of steppe lemming remains extracted from the upper layer contains some juvenile teeth (Fig. 9; *1–3*), one of them with an enamel islet (Fig. 9; *1)*. Most of steppe lemming molars belong to morphotypes IX, X and XI typical of the Late Pleistocene *Lagurus* (Fig. 6; *4–13*) (Markova, 1974, 1982).

The tooth morphology of narrow-skulled voles *L. gregalis* obtained from the Yagodnoe does not show any archaic traits; they are noted for a strong dissection of the anterior lobe of m1 (Fig. 10). The sample included m1 of both mature (Fig. 10; *1–5, 8, 9*) and young animals (Fig. 10; *6, 7*).

In common with Spasskoe section, bone-bearing beds of Yagodnoe locality do not contain remains of water voles – a typical semi-aquatic species found in abundance in other localities along the Volga R., including the Likhvin locality 'Rybnaya Sloboda' (Markova, 2004, 2006). This might be evidence of rather cool (probably, glacial) conditions at the time of fluvial deposition in Spasskoe and Yagodnoe localities. The same environments can be implied for the presence of collared lemming (*Dicrostonyx* sp.) in Spasskoe locality and numerous remains of the narrow-skulled vole – a typical inhabitant of open landscapes, including periglacial tundra-steppe and steppe (Markova et al., 1995,

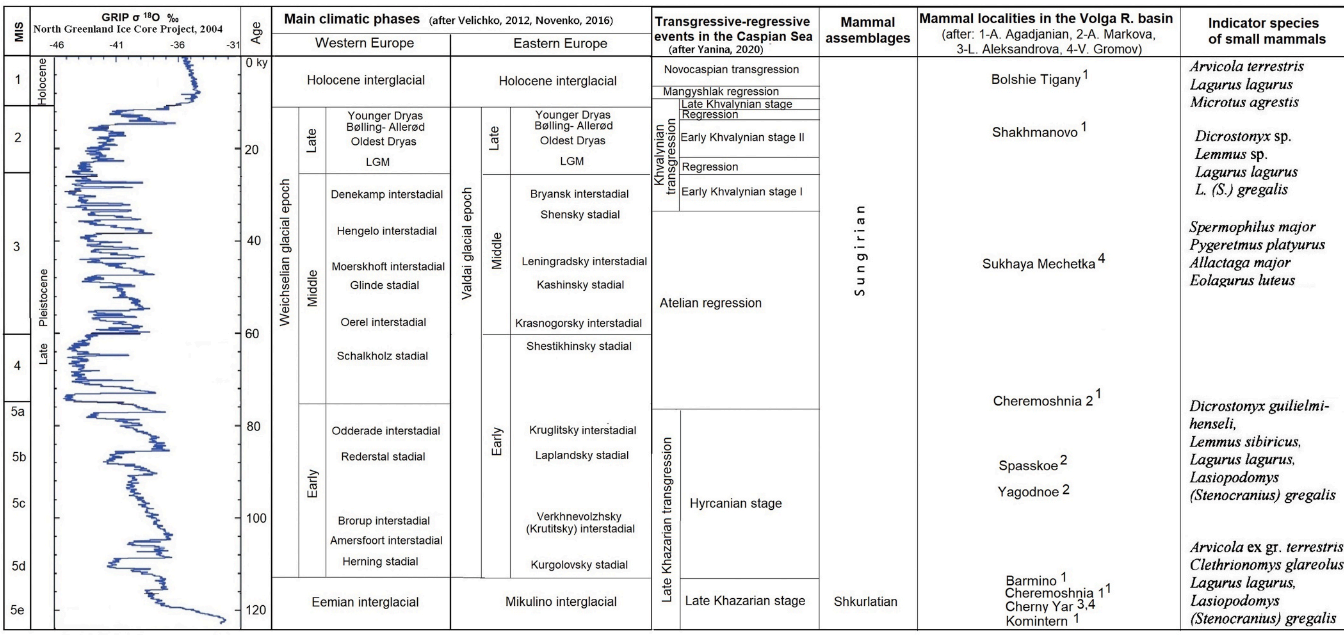

Fig. 11. Chronostratigraphic scheme of the Late Pleistocene of Volga-Caspian basin based on geological and small mammal data (Marine isotope stages, stratigraphic units and transgressive-regressive events of the Caspian Sea are given according North Greenland Ice Core Project members, 2004; Novenko, 2016; Velichko, 2012; Yanina, 2020).

2019). A considerable number of open space dwellers (such as steppe lemming and yellow steppe lemming, ground squirrels, pika, dwarf fat-tailed jerboa) suggest a wide occurrence of open landscapes, most probably those of periglacial steppe. Morphological characteristics of molars of steppe lemming, collared lemming, and narrow-skulled vole make possible a correlation of the Spasskoe and Yagodnoe faunas with cold phases either of the very end of the Middle Pleistocene (possibly, with final phases of the Dnieper glaciation), or with the beginning of the Valday glacial age. According to the theriological and geological data, the fossil small mammal remains belong most probably to the beginning of the Valday glacial age.

The analyze of the geological structure of the Spasskoe and Yagodnoe sections and the morphological characteristics of small mammal remains extracted from alluvial layer in Spasskoe and Yagodnoe sections permits to correlate these deposits and faunas with the beginning of the last glacial time. The absence of paleosols in the upper horizons may be indicative of a relatively young age of the sequences. For example, paleosols of the Mezin paleosol complex (corresponding to the Mikulino Interglacial) are commonly found in the drainage basins of Dnieper, Dniester, Don and many other rivers of the Russian Plain (Velichko et al., 1987, 1992). Their presence is usually considered as an indicator of an older age of the underlying deposits. The Spasskoe and Yagodnoe sections have no that soil complex, nor any other fossil soil horizons. That is indirect evidence that the alluvial series was deposited later than the Mikulino Interglacial.

The ecological characteristics of the faunas suggest cool and dry conditions of their existence. The faunas are dominated by species of open biotopes. Remains of collared lemming – a typical tundra inhabitant – are present in the Spasskoe faunal assemblage. The species richness of both Spasskoe and Yagodnoe faunas is rather low, which may be ascribed either to insufficient amount of material or to a harsh climate. The poor composition of the mammal faunas dominated by a few species is characteristic of the Pleistocene periglacial faunas. The absence of water vole remains also suggests rather inhospitable environments. The species is commonly found on river banks in various natural zones, and its absence from the Volga alluvial deposits suggests its range being shifted southwards. The tooth morphology of rodents belonging to several phylogenetic lines suggests the Late Pleistocene age of the faunas. The species composition of small mammals recovered from the Spasskoe and Yagodnoe sections is indicative of the open periglacial landscapes, most probably of the periglacial steppe type. Most probably, they should be correlated with the beginning of the Valday glaciation. That agrees well with the conclusion by Goretskiy (1966) on the periglacial type of alluvial layers exposed in the Spasskoe section; in his opinion, the lower alluvial member is correlatable with final episodes of the Khazarian transgressive epoch, while the thick upper series (which the faunal finds are confined to) – with the early Valday epoch (marked by a gradual lowering of the Hyrcanian basin and the Atelian regression of the Caspian).

Palynological data indicate widely distributed steppe vegetation at the time of deposition of two uppermost alluvial cycles exposed in the Spasskoe section (Obedientova and Gubonina, 1962). The pollen data confirm the conclusion about the open landscape dominance when the upper fluvial series of the Spasskoe section was deposited. Such a dating does not contradict to the geology of the sequences (Fig. 11).

So the analysis of the two new small mammal faunas recovered from newly described localities in the middle reaches of the Volga, together with detailed investigations of the localities' geological structure, permitted reconstructing the history of the environmental evolution in this key region through the Late Pleistocene.

6. Conclusion

Pleistocene sections Spasskoe and Yagodnoe in the middle reaches of the Volga River exposes thick and well differentiated series of fluvial deposits formed mostly in quietly flowing stream or on the floodplain. Three cycles of sedimentation are established. Deposits of middle cycle (periglacial alluvial deposits of the ancient Volga River) contain remains of small mammals. The sequence belongs to the upper alluvial member of the high (third) terrace.

The species composition of small mammals is indicative of the open periglacial landscapes, most probably of the periglacial steppe type. The ecological characteristics of the faunas suggest cool and dry conditions of their existence. The faunas are dominated by species of open biotopes. Remains of collared lemming – a typical tundra inhabitant – are present in the Spasskoe faunal assemblage. The poor composition of the mammal faunas dominated by a few species is characteristic of the Pleistocene periglacial faunas. The absence of water vole remains also suggests rather inhospitable environments.

The tooth morphology of rodents belonging to several phylogenetic lines suggests the Late Pleistocene age of the faunas.

The analyze of the morphological characteristics of small mammal remains extracted from alluvial layer in Spasskoe and Yagodnoe sections permits to correlate these deposits and faunas with the beginning of the last glacial time.

According to the geological and theriological data, the fossil small mammal remains belong most probably to the beginning of the Valday glacial age.

Therefore, the analysis of the two new small mammal faunas recovered from newly described localities in the middle reaches of the Volga, together with detailed investigations of the localities' geological structure, permitted reconstructing the history of the environmental evolution in this key region through the Late Pleistocene.

Data availability

The small mammal remains from Spasskoe and Yagodnoe are stored in the collection of the Institute of Geography RAS.

Authors contributions

A. Svitoch conducted field work, executed description of the deposits and identified the main units in the sections; A. Markova conducted field work, collected and processed the palaeontological material, identified the species, executed the stratigraphical and palaeogeographic conclusions; T. Yanina took part in the discussion and in writing of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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