



## EARLY PLIOCENE BIOTIC LOCALITY NOVAYA LIVENKA IN SOUTH OF WESTERN SIBERIA (RUSSIA): PALYNOLOGY, PLANT MACROFOSSILS, MOLLUSCS, SMALL MAMMALS, AND BIOCHRONOLOGY

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**Abstract:** Fluvial deposits of the Krutaya Gorka regional formation host a new locality of Early Pliocene continental biota from southern Western Siberia. The Novaya Livenka site provides important data on palynology, paleocarpology, molluscs, fishes, and small mammals, mostly coming from a single fossiliferous bed. This study is the first successful insight into regional Early Pliocene palynology reliably controlled by the stage of mammalian evolution. The micromammal association is dominated by remains of pika *Ochotona* sp. and the primitive brachyodont vole *Promimomys*. Important biochronological and paleoecological elements of the fauna also include a shrew *Parasoriculus*, a hazel dormouse *Muscardinus*, a small beaver *Trogontherium* and other forms. The vole *P. cf. davakosi* characterizes a regional phyletic stage of Arvicolinae between a more brachyodont *P. antiquus* of earlier Ruscinian and forms of the vole radiation event of the late Ruscinian. Synthetic biotic data enable a reconstruction of a smaller water body with a slow current fringed by patches of broad-leaved and conifer forest, and meadow and steppe-like open landscapes under a humid and warm temperate climate. Biochronologic signals of mammals and palynology imply the Early Pliocene age of the biota and its correlation with late early Ruscinian ELMA (MN 14) and mid-Zanclan between ca. 4.5 and 4.3 Ma.

**Key words:** palynology, plant macrofossils, molluscs, fishes, small mammals, biostratigraphy, biochronology, Early Pliocene, West Siberia, Russia

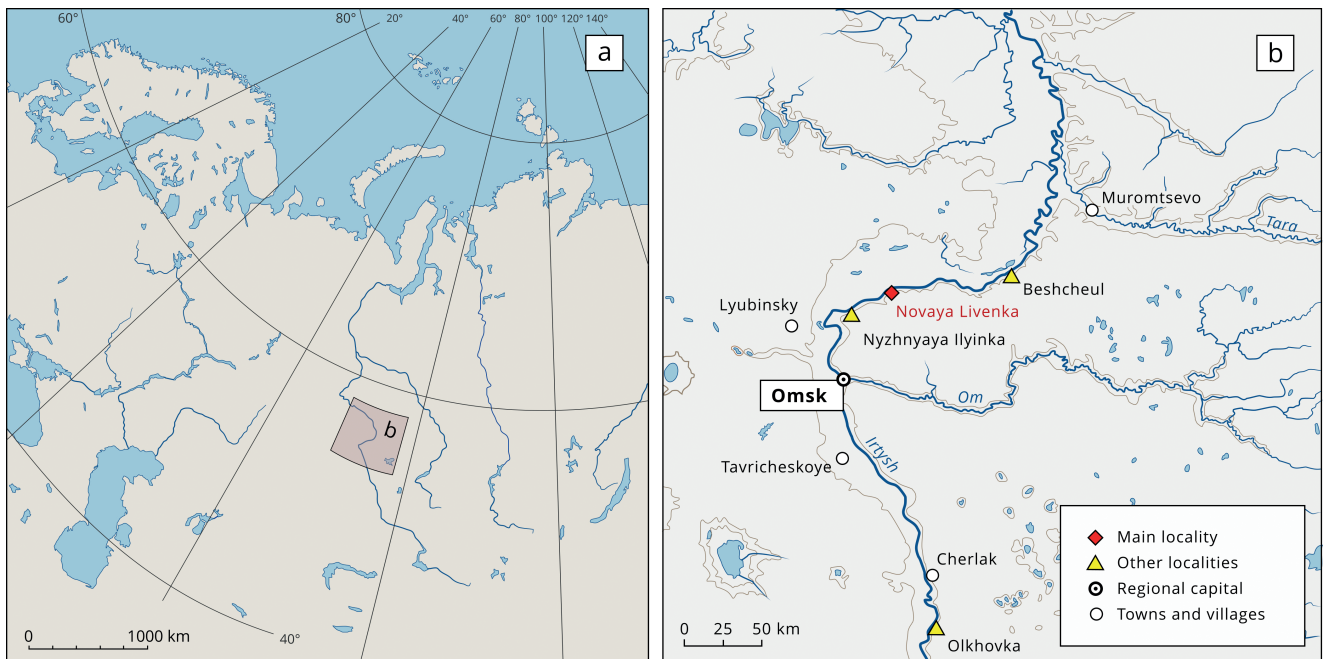
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### Introduction

The southern part of Western Siberia (Text-fig. 1a) is famous for its excellent record of late Cenozoic deposits (Zykin 2012). The large West Siberian alluvial plain preserves a representative archive of Tertiary and Quaternary continental deposits rich in remains of plants and animals. Numerous exposures of these deposits along the right bank of the north-flowing great Irtysh River and its tributaries provide a solid geological background for

studies in stratigraphy and paleontology (Nikolaev 1968, Arkhipov et al. 1993, Volkova et al. 2002, Zykin 2012). It was this region where important contributions to the knowledge of land plants based on seed assemblages and leaf imprint fossils were obtained in the 20<sup>th</sup> century (Nikitin 1961, Gorbunov 1962, Dorofeev 1963). During this period, palynological studies of extensive material from boreholes and natural exposures helped create a general understanding of the sequence of palynological floras in the late Neogene of the region (Volkova and Panova 1975, Volkova and



**Text-fig. 1. Geographic position of Novaya Livenka locality, and other reference sections of Krutaya Gorka Formation in Omsk Region.**

Kulkova 1984). These studies included definitions of vegetation zones, recognition of biochronological levels with drastic floral turnovers, and quantitative estimates of climatic variation during the Neogene (Kuzmina et al. 2017). Palynologists L. A. Panova, V. S. Volkova, I. A. Kulkova, G. F. Bukreeva and some others contributed to the study of the Cenozoic of the West Siberian Plain (Volkova et al. 2002). The data obtained were summarized and included in regional stratigraphic schemes (Gurari et al. 2001).

The peculiar Pliocene molluscan faunas of the Omsk Region, especially rich in unionid bivalves, were the focus of consecutive studies in the 19<sup>th</sup> and 20<sup>th</sup> centuries (Martens 1864, Bogachev 1908, 1924, 1961, Lindholm 1932, Maderni 1968, Zykina 1979, etc.). The introduction of screening techniques for extracting microvertebrate remains from continental deposits in the late 1960s provided a sound basis for a new regional stratigraphy, drastically changing the concept of chronology and regional stratigraphic subdivision. The accumulated data on molluscan and small mammal faunas make it possible to put forward a renewed sequence of Late Miocene and Pliocene regional formations, based on irreversible stages of biotic evolution (Zazhigin and Zykina 1984). Following early studies of the last century (Bogachev 1908, Sytchevskaya 1966, Zazhigin 1980, etc.), several important contributions on fossil vertebrates published in recent years shed more light on the still insufficiently-studied faunal history of Western Siberia in the late Neogene (Storch and Zazhigin 1996, Zazhigin et al. 2002, Zykina and Zazhigin 2004, Zazhigin and Lopatin 2005, Vasilyan et al. 2017, Zazhigin and Voyta 2019, Tesakov and Bondarev 2022, etc.).

Discovered in 2021, the site Novaya Livenka and its geological structure and fossil materials were studied in 2021–2024 by the joint team of the Geological Institute of the Russian Academy of Sciences and Omsk regional branch of the Russian Geographic Society, with participation of colleagues from other scientific institutions. Preliminary results of the study were reported earlier this year

(Ivanova and Sizov 2024, Tesakov et al. 2024). The goal of this communication is a short account of the new rich microvertebrate locality Novaya Livenka in the south of Western Siberia, with special reference to paleobotanical (pollen and plant macroremains) and paleozoological (molluscs, fishes, small mammals) data, in order to create a benchmark for further refinement of the regional biochronology, stratigraphy, and paleontology.

## Material and methods

The palynological samples from Novaya Livenka were processed following the standard technique accepted at the Laboratory of Quaternary Stratigraphy of the Geological Institute, Russian Academy of Sciences, Moscow, Russia (GIN). The technique included (a) dissolving carbonates treated with cold HCl (10%), (b) removal of clay particles with aqueous solution of Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub>, (c) extraction of palynomorphs by centrifuging the sediment with cadmium heavy liquid (2.25 g/cm<sup>3</sup>), (d) dissolving silica elements with HF (70%) and (e) screening of dried sediment on temporary slides (in glycerol) for further study under a microscope. In order to determine the taxonomy of palynomorphs and their count, a Saik digital biological light microscope was used. Temporary slides of palynomorphs were studied at 400× magnification. Microphotography of preparations was performed with the same microscope, equipped with a digital camera. Pollen grains were counted on temporary slides – up to 400–600 slides in case of good saturation; for poorly saturated cases, only one slide was studied (2 × 2 cm). The minimum slide count was 100 for samples containing non-pollen palynomorphs only. All slides are stored in GIN (Moscow). To assess the participation of different groups in the palynological spectra, the sum of all palynomorphs (pollen, spores, freshwater algae) was taken as 100 percentages. Shares of the individual taxa were calculated from the total sum of determined pollen grains. Tilia 2.6.1

software (Grimm, E. C. 2004: Tgview. Version 2.0.2. Illinois State Museum, Research and Collections Center, Springfield) was used for the calculation of percentages and for drawing the final diagram. Boundaries of pollen zones were delineated based on visual analysis of spectra and constrained incremental sum of squares (CONISS) cluster analysis integrated into the Tilia software.

Plant macroremains (seeds) were extracted from a rock sample of ca. 10 kg from the fossiliferous bed by wet-screening (mesh size 0.2 mm) and flotation, according to the standard technique (Nikitin 1969). The initial volume of the sample was reduced by the process to ca. 200 g of dry concentrate, which was then sorted in the laboratory.

Small vertebrate samples were collected by wet screen-washing (mesh size 0.7–1 mm) of about 600 kg of sediments from the fossiliferous bed. Animal remains were extracted from the concentrate in the laboratory. Microphotographs of vole molars were taken with SEM equipment of Geological and Paleontological institutes, RAS (Moscow).

Terminology of vole morphological features follows standard usage of van der Meulen (1973) for occlusal elements, Rabeder (1981) for dentine tracts, von Koenigswald (1980) for enamel microstructure (Schemelmuster). Abbreviations used in tables of measurements are: L, length; W, width; A, length of anteroconid; A/L, index of anteroconid; H, crown height; H/L, index of crown height; dentine tracts: ASD – anterosinuid; HSD – hyposinuid; HSLD – hyposinulid; HH-index;  $\Sigma$ \_tract, sum of tracts;  $\Sigma$ \_tract/L, index of sum of tracts. HH-index is the square root of the sum of heights of dentine tracts of hypoconid and hypoconulid in lower molars (Rabeder 1981). Enamel differentiation quotient BTQ (= SDQ3) is the mean thickness of the anterior wall of occlusal triangle in relation to that of the posterior wall calculated in percent (Tesakov 1998).

Samples of molluscs and small vertebrates are stored in the Laboratory of Quaternary Stratigraphy of the Geological Institute of the Russian Academy of Sciences (GIN), in the collection GIN-1189.

Contributions of the authors to the study and preparation of the publications were as follows: all authors except PF and SK participated in field studies and sampling. All authors took part in the discussion of the obtained results. AT supervised and coordinated the study and manuscript production and conducted the study of small mammals; AB coordinated the field campaign and contributed to the laboratory preparation of paleontological materials, and in the general stratigraphy of the regional biotic sequence. AI processed palynological samples and made palynological analysis; AVS was in charge of the field stratigraphy and geological logging, and illustrated the structure of the section; AY studied fossil voles and their enamel microstructure; ST studied fossil seeds; PF, molluscs; SK, fishes; AD contributed to the sorting of the microvertebrate concentrate in the laboratory; ADS provided important technical services in the field.

## Geological settings

The locality Novaya Livenka is situated 3 km north of the Oktyabrskoe settlement and 2 km north-east of the abandoned village Livenka, Omsk Region, Russia (Text-fig.

1b). A small gully cutting through the upper part of the right bank escarpment of the Irtysh River exposes in its right side a 16 m deep section of Pliocene and Quaternary deposits (Text-figs 2, 3).

Three sedimentary cycles can be recognized in the section. The lowest member (1), with an observed thickness of 10 m, is represented by lacustrine-fluviatile light yellow parallel and wavy bedded clays and sandy siltstones with interbeds of clays and sands (Text-fig. 3: 2). In the middle part of member 1, there is a well-defined interbed of chocolate-brown cross-bedded micaceous sands with plant detritus, shells of molluscs, and bones of small vertebrates (Text-fig. 3: 3). The fossiliferous bed wedges and disappears up the ravine. The cross-bedding is also characteristic for the upper silty part of the member. The cross-bedded series show monotonous westward dip, indicating the paleocurrent direction parallel to the inclination of the thalweg of the modern gully, i.e., towards Irtysh River. The age of this member is Early Pliocene, as inferred by the age of the mammalian fauna from the fossiliferous bed.

Upsection, a member (2) of greenish-brown clays, ca. 3 m thick, occurs on the eroded surface of member 1. The base of member 2 is formed by a well-defined interbed of pelitomorphic limestones of paleosol origin. The surface of this interbed is wavy. The upper part of the member shows vertical carbonate structures. Clays are usually sandy and strongly carbonatized in the upper part. The assumable Late Pliocene age of this member is based on the high stratigraphic position and lithological similarity of its clays with deposits of the near-by Nizhny Rozovsky section, characterized by early Late Pliocene assemblage of small mammals (Tesakov and Bondarev 2022).

The section is crowned by Late Pleistocene sandy loessic carbonated siltstones with columnar jointing, and the modern soil with the total thickness of ca. 2 m. This top member (3) of the section occurs on the eroded surface of carbonatized clays of member 2.

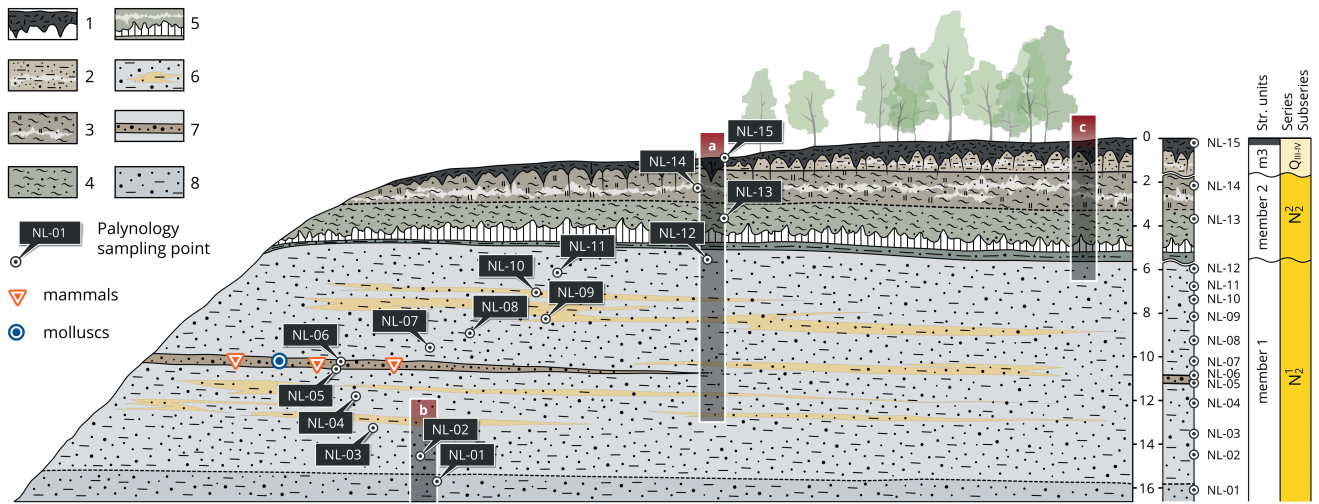
The deposits of member 1 in the studied section, which are in the focus of our study, can be correlated with the Krutaya Gorka Formation, defined in the mid Early Pliocene in the sequence of Neogene continental formations in the south of Western Siberia (Zazhigin and Zykin 1984, Zykin 2012). Two main correlation criteria are relevant here. First is the paleontological one, based on the stage of evolutionary development of the vole *Promimomys* cf. *davakosi* and other forms of the biotic assemblage. Second is the geological position of the deposits in the upper part of the Neogene sequence, below dark clays locally dated to the Late Pliocene (Tesakov and Bondarev 2022).

## Biotic records

### Palynology

A total of 15 palynological samples (including a surface one) were collected from all members of the section (Text-fig. 2). After laboratory processing and analysis, the following results were obtained.

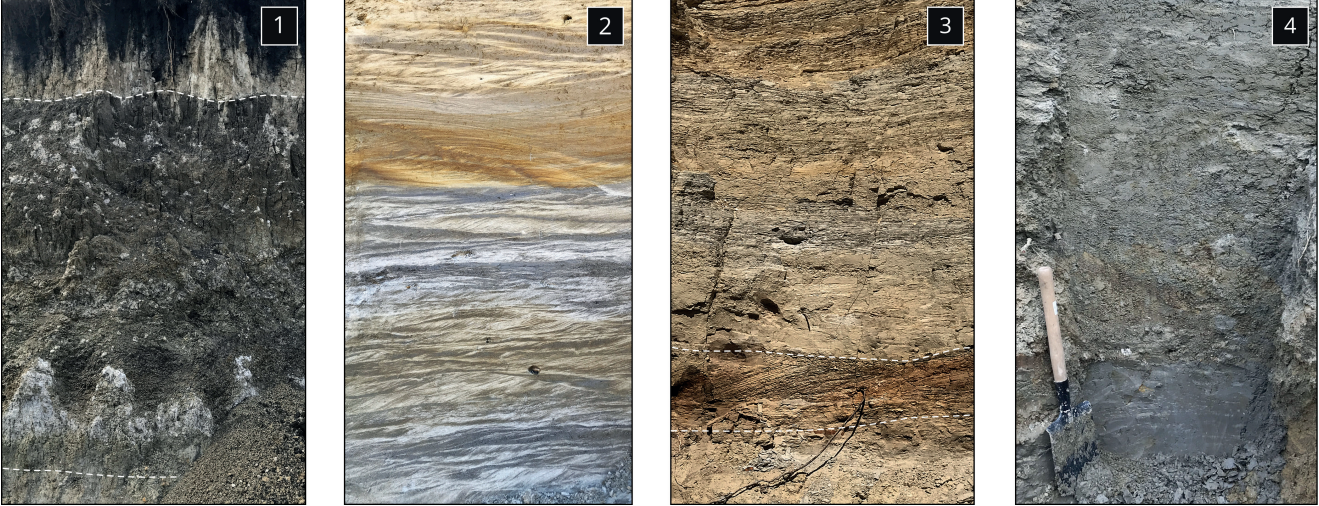
Data are presented on a pollen diagram (Text-fig. 4); palynomorphs are illustrated in Text-figs 5, 6. Microphytoplankton (Chlorophyta and Zygnematales) was



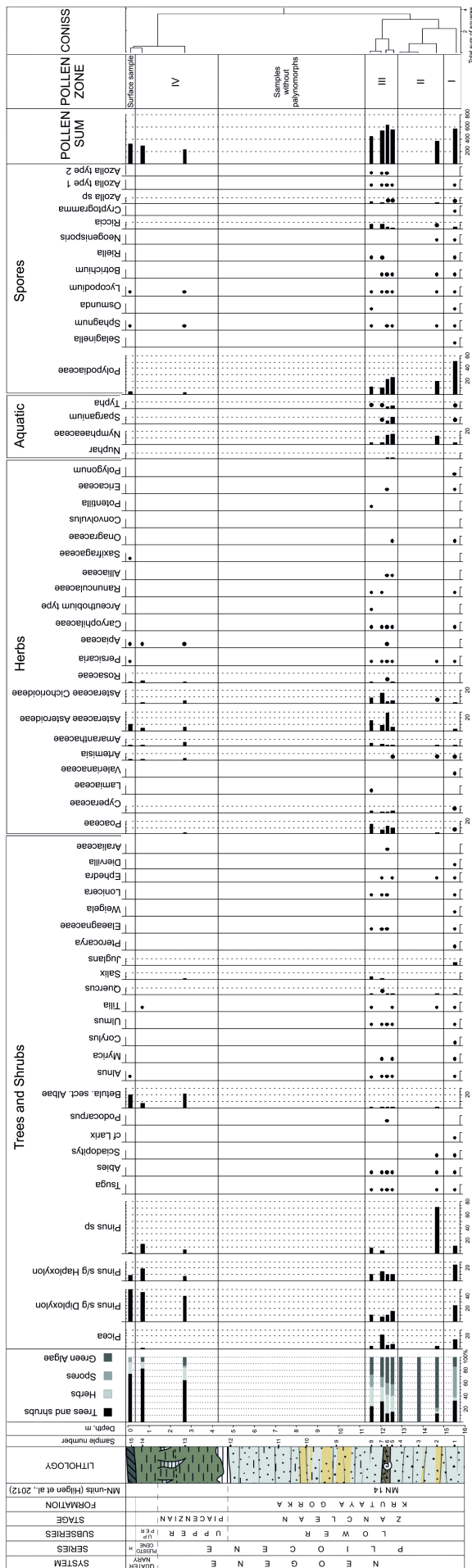
**Text-fig. 2. Geological section of Novaya Livenka locality. 1 – modern soil; 2 – carbonatized silts; 3 – greenish-brown carbonatized sandy clays; 4 – greenish sandy clays; 5 – soil limestone bed; 6 – silts; 7 – sands; 8 – clayey silts and silty clays.**

studied in the same samples selected for spores and pollen. Four pollen zones were identified and described, differing in taxonomic composition and structure. Pollen zones I–III are associated with the Krutaya Gorka Formation.

Pollen zone I *Pinus-Picea*-Polypodiaceae was identified from the bottom of the grey undulating sand horizon (15.4–15.0 m). The arboreal group is mainly represented by gymnosperm plants: *Pinus* sbg. *Haploxylon* and *Pinus*



**Text-fig. 3. Overview of Novaya Livenka geological section (top) and details of members of section (bottom). a, b, c – trenches; 1–4 – close-up details of trenches.**

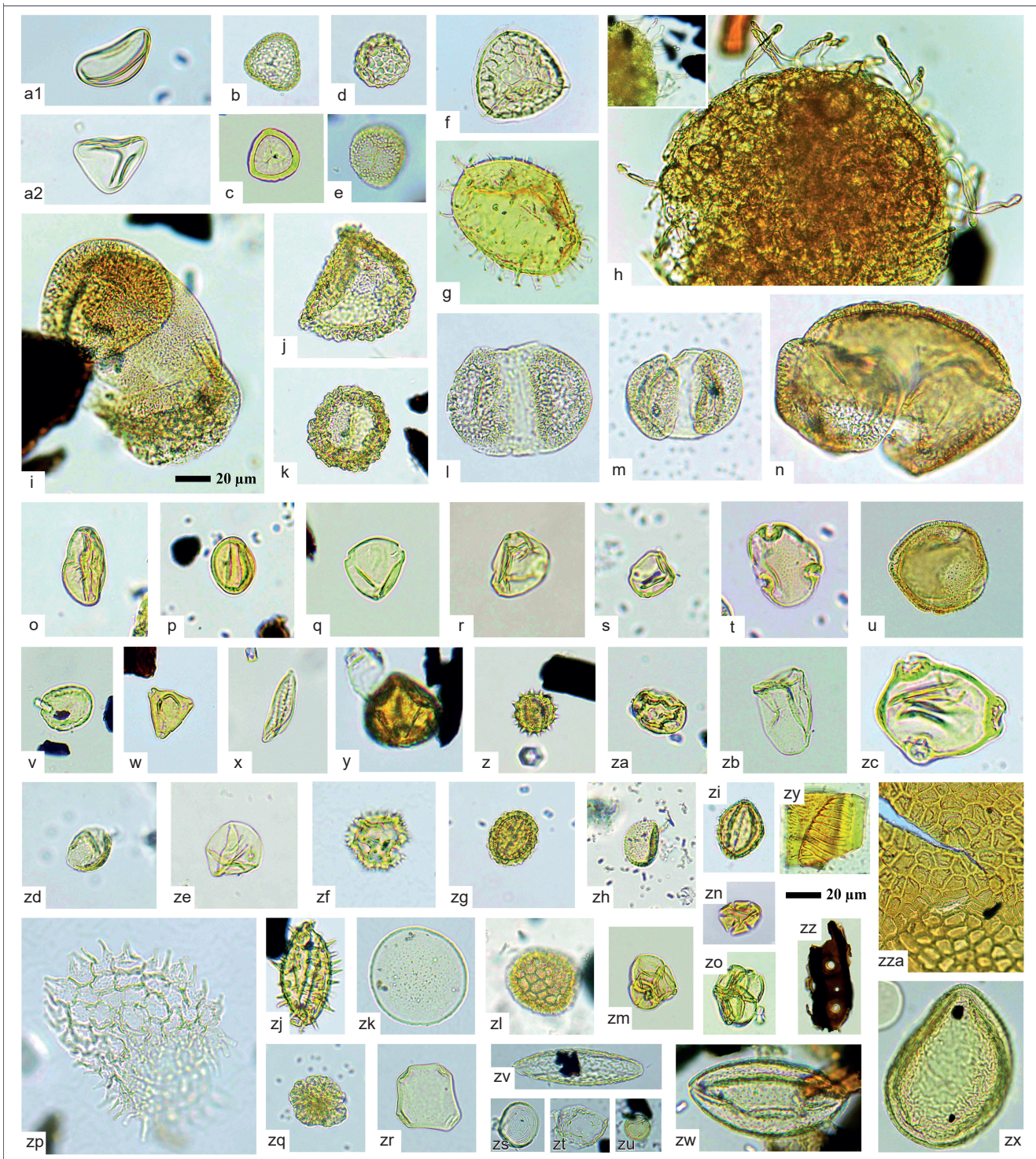


Text-fig. 4. Pollen diagram of Novaya Livenka section.

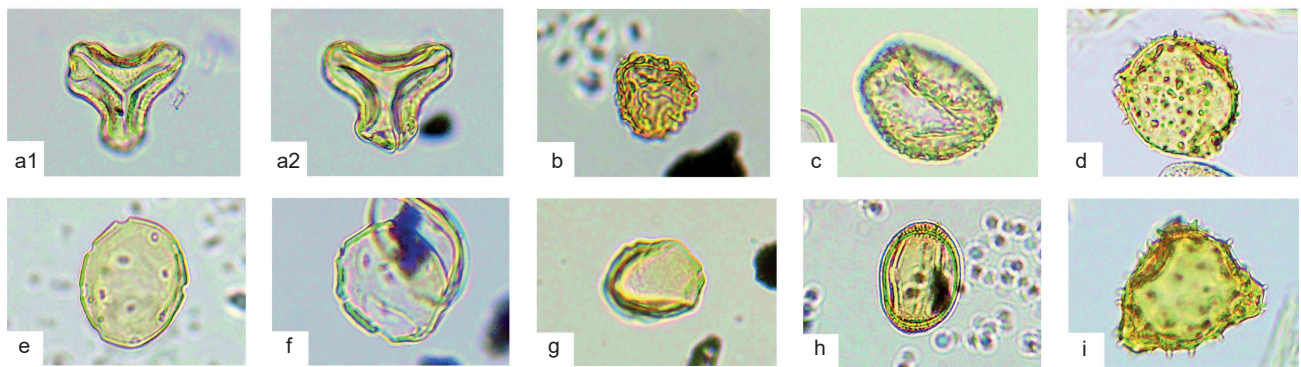
sbg. *Diploxylon* (up to 25 %), *Picea*, less frequently, *Tsuga* (several types), *Abies*, *Ephedra*, *Sciadopitys*, cf. *Larix*. Small-leaved (*Betula* sect. *Albae*, *Alnus*, *Salix*), broad-leaved (*Quercus*, *Ulmus*, *Tilia*, *Corylus*) and other species (*Elaeagnaceae*, *Myrica*, *Diervilla*, *Weigela*, *Lonicera*) are present in insignificant numbers. The presence of pollen of nut genera *Juglans* (up to 5 %) and *Pterocarya* is noteworthy. The non-arboreal group is small in quantity, but diverse: pollen of Asteraceae of subfamilies Asteroideae and Cichorioideae, families Ericaceae, Poaceae, Cyperaceae, Onagraceae, Amaranthaceae, Caryophyllaceae, Valerianaceae, Ranunculaceae, genera *Persicaria*, *Polygonum* and *Artemisia* was recorded. Pollen of aquatic vegetation, Nymphaeaceae, *Sparganium*, and *Typha*, is common. Spores of ferns make up to 55 % of the complex. In addition to Polypodiaceae, spores of *Riccia* (several types), *Azolla* (several types), *Botrichium*, *Osmunda*, *Sphagnum*, *Lycopodium*, *Riella*, *Neogenisporis* sp. are also present. Non-pollen palynomorphs are represented by freshwater green algae *Botryococcus braunii* KÜTZ., *Pediastrum boryanum* (TURPIN) MENEGH., *Spirogyra*, *Zygnema*, *Sigmopolis*.

Pollen zone II with *Botryococcus*, *Sigmopolis*, and *Pinus* is established higher in the section, in the same grey silty sands in the interval 12.7–15.0 m. This palynological zone is characterized by extremely high participation of microphytoplankton – *Botryococcus* (up to 80 %), *Sigmopolis* (up to 40 %), and *Pediastrum* sp. Most spores belong to the Polypodiaceae family; *Lycopodium*, *Azolla*, *Botrichium*, *Sphagnum*, *Neogenisporis* sp., and *Riccia* are less frequently observed. Pollen grains of *Pinus* spp. are present, much less frequently of *Picea*, *Tsuga*, *Abies*, *Sciadopitys*, *Ephedra*, *Betula* sect. *Albae*, *Quercus*, *Tilia*. Pollen of herbaceous plants is almost completely absent, except for fragments of grains of Nymphaeaceae and single grains of Poaceae, Amaranthaceae, Asteraceae, *Persicaria*. The preservation of the overwhelming number of palynomorphs can be characterized as rather poor (pollen grains are deformed and broken; colonial algae are represented only by small fragments). This could be due to taphonomic (active hydrodynamic conditions?) and ecological reasons.

Pollen zone III with *Pinus*, Asteraceae, Polypodiaceae, *Botryococcus* corresponds to the interval of 11.2–12.6 m, which includes a fossil-rich bed consisting of medium-grained brown sand and grey silt-sands. The tree group is represented by pollen of *Pinus* s/g *Haploxylon* and s/g *Diploxylon* (up to 24 %), *Picea* (up to 14 %), *Tsuga* (several types), *Abies*, *Elaeagnaceae*, *Ephedra*, *Lonicera*, *Myrica*, *Araliaceae*, cf. *Podocarpus*; small-leaved *Betula* sect. *Albae*, *Alnus*, *Salix*. Pollen of broad-leaved species *Quercus*, *Ulmus* and *Tilia* occurs in insignificant quantities. Compared to the previous complexes, the role of herbaceous vegetation increases, primarily due to representatives of Asteraceae and Poaceae. Other representatives of this group are Cyperaceae, Alliaceae, Rosaceae (including *Potentilla*), Amaranthaceae, Caryophyllaceae, Apiaceae, Lamiaceae, Ranunculaceae, *Persicaria*, *Arceuthobium* type. A distinctive feature of these samples is a noticeable quantity of aquatic plant pollen: Nymphaeaceae and genera *Nuphar*, *Typha*, and *Sparganium*. Among spore plants, the percentage of which varies within 20–30 %, Polypodiaceae, *Riccia*, *Azolla*,



**Text-fig. 5.** Palynomorphs from Pollen Zone III, Novaya Livenka section. a–zo: pollen and spores; zp–zx: microphytoplankton; zy–zza: plant remains; magnification 400×. a1, a2: Polypodiaceae; b: *Cryptogramma* sp.; c: *Sphagnum* sp.; d: *Botrichium* sp.; e: *Osmunda* sp.; f: *Riccia* sp.; g: *Riella* sp.; h: *Azolla* type 1; i: *Picea* sec. *Eupicea* WILLK.; j: *Tsuga* type “piccolo”; k: *Tsuga diversifolia* (MAXIM.) MAST.; l: *Pinus* sbg. *Haploxylon* (KOEHNE) PILG.; m: *Pinus* sbg. *Diploxylon* (KOEHNE) PILG.; n: *Abies* sp.; o: *Quercoidites henrici* (R.POTONIÉ) R.POTONIÉ, P.W.THOMSON et THIERG. (*Quercus* type 1); p: *Quercus* type 2; q: *Myrica* sp.; r: *Betula* sect. *Albae* REGEL; s: *Alnus* sp.; t: *Tilia* sp.; u: *Lonicera* sp.; v: *Ulmus* sp.; w: *Elaeagnaceae*; x: *Ephedra* sp.; y: *Araliaceoipollenites* sp. (affiliation: *Araliaceae*), possibly reworked; z: *Asteraceae*: *Asteroidae*; za: *Caryophyllaceae*; zb: *Cyperaceae*; zc: *Onagraceae*; zd: *Amaranthaceae*; ze: *Poaceae*; zf: *Asteraceae*: *Cichorioideae*; zg: *Asteraceae*: *Centaurea* type; zh: *Sparganium* sp.; zi: *Spinulaepollis arceuthobioides* KRUTZSCH (*Arceuthobium* type); zj: *Nuphar* sp.; zk: operculum of zygospore *Diagonalites diagonalis* KRUTZSCH et PACLOTOVÁ (affiliation: *Mougeotia*); zl: *Persicaria* sp.; zm: *Ericaceae*; zn: *Lamiaceae*; zo: *Typha* sp.; zp: *Pediastrum boryanum* (TURPIN) MENEGH.; zq: *Botryococcus braunii* KÜTZ.; zr: *Tetrapidites* sp. (affiliation: *Mougeotia*); zs: *Chomotriletes* s.l. (affiliation: *Euglenophyceae*?) sensu van der Schootbrugge et al. (2024); zt: *Zygnema* sp.; zu: *Signopollis laevigatoides* KRUTZSCH et PACLOTOVÁ; zv: *Ovoidites ligneolus* (R.POTONIÉ) R.POTONIÉ (affiliation: *Spirogyra*); zw: *Spirogyra* type 1; zx: *Spirogyra* type 2; zy: fragment of scalariform perforation plate; zz: tracheid fragment from conifer wood, with torus-margo pits; zza: leaf epidermis fragment.



**Text-fig. 6.** Palynomorphs from Pollen Zone I, Novaya Livenka section. a–i, pollen and spores; magnification 400×. a1, a2: *Neogenisporis* sp. (affiliation: Gleicheniaceae); b: *Selaginella* sp.; c: *Sciadopitys* sp.; d: *Diervilla* type; e: *Juglans* sp.; f: *Pterocarya* sp.; g: *Corylus* sp.; h: *Polygonum* sp.; i: *Weigela floridiformis* ILIENOK nom. nud. (Shirokova 1964).

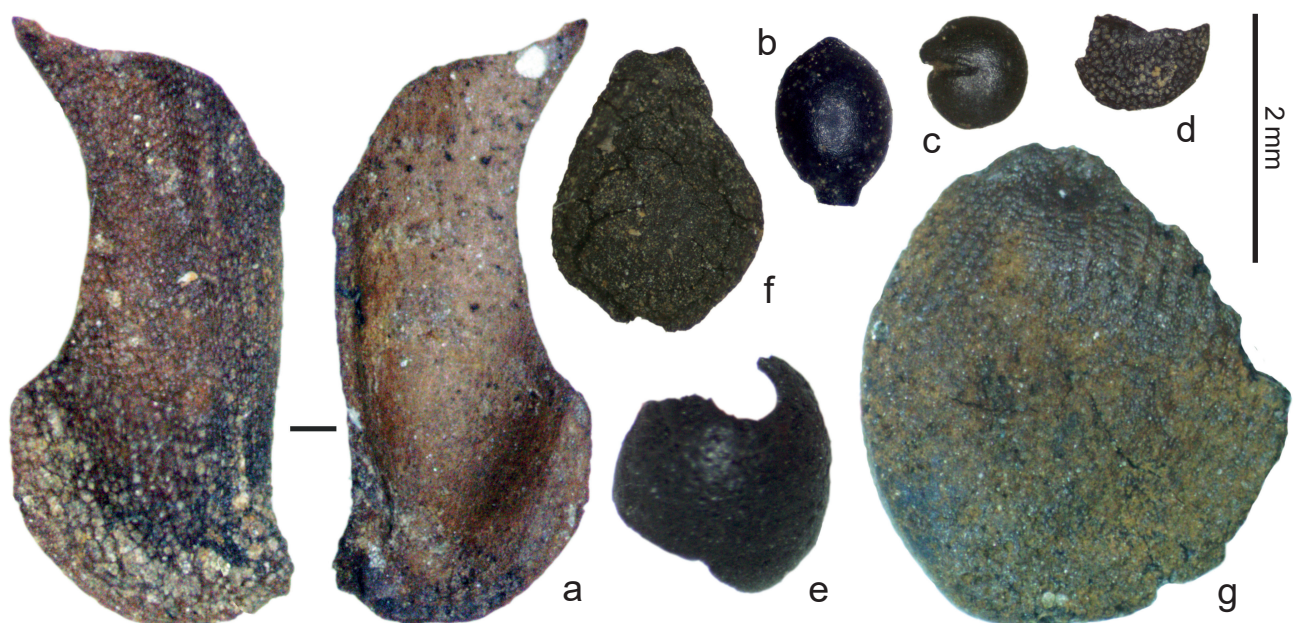
*Osmunda*, *Botrichium*, *Lycopodium*, *Sphagnum*, *Riella*, and *Cryptogramma* are noted. Green algae are still numerous (*Mougeotia* and *Chomotriletes* s.l. appear), but their role in the spectra begins to gradually decrease. In addition, Pollen Zone III includes non-pollen palynomorphs, such as fragments of scalariform perforation plates of xylem vessels, guard cells, and other fragments of plant tissues. Isolated palynomorphs were extracted from sediments in the interval 11.2–3.0 m; no spores or pollen were found.

#### Plant macrofossils

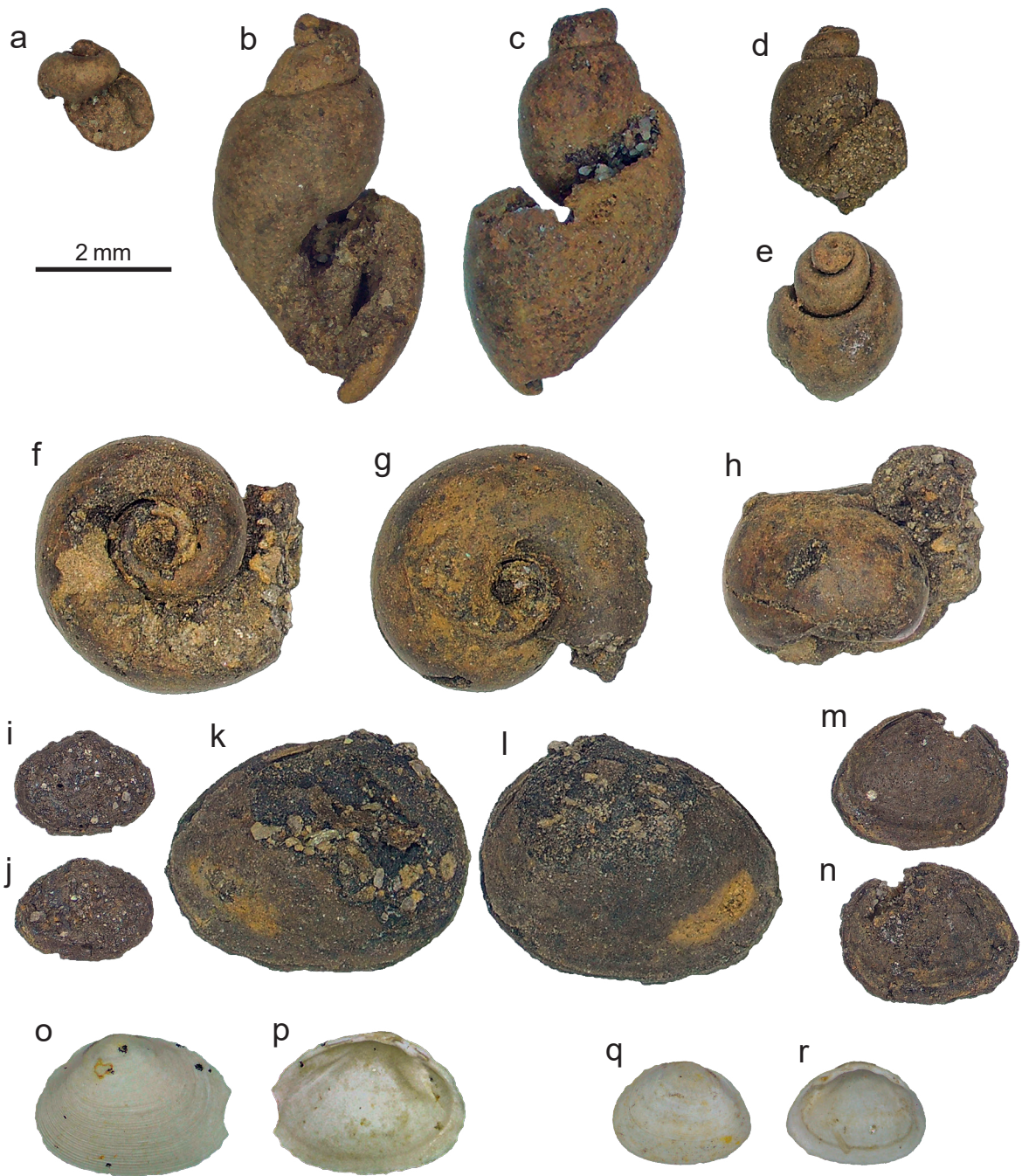
The small assemblage of fossil carpoids collected from the fossiliferous bed of member 1 (Text-fig. 2) includes (Text-fig. 7) *Aldrovanda* cf. *eleanorae* P.A. NIKITIN (n = 2), *Brasenia* sp. (1), *Chenopodium hybridum* L. (1), *Chenopodium* sp. (2), *Hartziella rosenkjaeri* (HARTZ) SZAFER (11), *Nymphaea* sp. (1), *Sparganium* sp. (2) and *Stratiotes* cf. *intermedius* (HARTZ) M. CHANDLER (1). Most of the collected specimens

are fragmentary seeds of herbaceous plants. The remains of aquatic (*Brasenia*, *Aldrovanda*, *Stratiotes*, *Nymphaea*) and shallow-water species (*Sparganium*) predominate in the material. The presence of *Brasenia* and *Aldrovanda* suggests the formation of the studied sediments in a warm water body. Terrestrial vegetation is represented by *Chenopodium*, a plant common on disturbed soils.

*Aldrovanda* cf. *eleanorae*, a free-floating insectivorous plant, is an extinct species that was widespread in Western Siberia from the Oligocene to the Pliocene (Nikitin 2006). It is known from the Isakovka and Lezhanka reference sections in the Omsk region, previously dated to the Miocene (Dorofeev 1963), but currently can be considered as Pliocene (Zykin 2012). A fragmented seed of the aquatic plant water soldiers, *Stratiotes* with an almost smooth outer surface is similar to two closely related species: the extinct *Stratiotes intermedius* (HARTZ) M. CHANDLER and the modern *S. aloides* L., but appears closer in morphology to



**Text-fig. 7.** Plant macrofossils found in Novaya Livenka section. a: *Stratiotes* cf. *intermedius* (HARTZ) M. CHANDLER; seed fragment. b: *Aldrovanda* cf. *eleanorae* P.A. NIKITIN, seed. c: *Chenopodium* sp., seed. d: *Chenopodium hybridum* L., seed fragment. e: *Brasenia* sp., seed fragment. f: *Sparganium* sp., fruit. g: *Nymphaea* sp., seed fragment.



Text-fig. 8. Molluscs from the Novaya Livenka section. a: *Valvata* sp., GIN-1189/501; b–e: *?Oncomelania* sp., GIN-1189/502-503. f–h: *Planorbarius* sp. i, g: *Sphaeriinae* indet. k, l: *Pisidiinae* indet. m–r: *Euglesinae* indet. a–n: internal casts. o–r: shells.

*S. intermedius*. This plant was geographically widespread in the Pliocene, but probably did not survive into the Pleistocene (Velichkevich 1982). In Western Siberia, this species has been common since the Middle Miocene (Nikitin 2006). The morphologically modern species *S. aloides* apparently appears in Western Siberia in the Early Pleistocene as an evolutionary replacement of *S. intermedius*. *S. aloides* was previously found in the Pleistocene (formerly “Late Pliocene”) deposits of the village of Chernoluchye near Omsk (Dorofeev 1963). The morphological features of *Stratiotes intermedius* and *Aldrovanda eleanorae* are well expressed in large, representative samples, so our definitions

are necessarily preliminary. *Chenopodium hybridum* L., a modern species recorded in Western Siberia since the Pliocene (Nikitin 2006), is also present. The extinct species *Hartziella rosenkjaeri* (HARTZ) SZAFER ex ERW.KNOBLOCH. had a long time range, from the Oligocene to the Pliocene (Dorofeev 1963). The upper time limit of this species in Western Siberia is recorded in the Early Pleistocene previously dated to the Late Pliocene, from sections near the town of Barnaul (Nikitin 1961). In our sample, all endocarps of *Hartziella rosenkjaeri* are fragmented and bear signs of fossilization, so we do not exclude their redeposition. The studied association has a general Pliocene appearance.

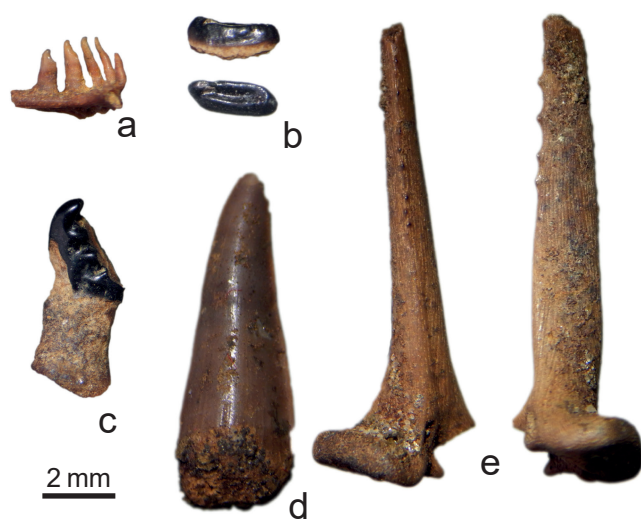


## Molluscs

Samples collected from the fossiliferous bed produced a poor assemblage of molluscs, represented mainly by the internal casts of bivalves and gastropods, and occasionally shells (Text-fig. 8). In four years of collecting, only a few complete shells have been found. Among gastropods, only the following genera have been identified: *Valvata* sp. (Text-fig. 8a), *?Oncomelania* sp. (Text-fig. 8b–e), *Planorbarius* sp. (Text-fig. 8f–h) and two damaged shells of terrestrial *Vallonia* sp. Internal casts that possibly belong to *Oncomelania* GREDLER, 1881 may also belong to the Lymnaeidae family (i.e., the genus *Galba* SCHRANK, 1803). According to data of Zykin (2012), the mollusc association of the Krutaya Gorka Formation consists of 22 species of 16 genera. This assemblage does not contain representatives of the Lymnaeidae family, but does contain *Oncomelania* aff. *bogatshevi* (LINDHOLM, 1932). In our view, this form is the closest match for our internal casts. Most of the studied association consists of small bivalve molluscs of the Sphaeriidae family. One form has a central umbo and is probably referable to the Sphaeriinae subfamily (Text-fig. 8i, j). Relatively large internal casts with a displaced umbo, up to 5 mm in size, most likely belong to the Pisidiinae subfamily (Text-fig. 8k, l). Most of these internal casts resemble representatives of the Euglesinae subfamily (Text-fig. 8m, n), due to their small size and slightly displaced umbo. Two well-preserved shells also belong to this subfamily (Text-fig. 8o–r).

## Fishes

The fish association (Text-fig. 9) from the locality is represented by: Tincidae: *Tinca* sp. (3 pharyngeal teeth), Leuciscidae: *Rutilus* sp. (3 pharyngeal teeth), *Scardinius* sp. (3 pharyngeal teeth), *Leuciscus* sp. (2 ossa pharyngea inferior), Leuciscine gen. indet. (2 ossa pharyngea inferior, 2 pharyngeal teeth), Siluridae: *Silurus* sp. (2



**Text-fig. 9.** Fisches from Novaya Livenka section. a: *Leuciscus* sp., left pharyngeal bone, GIN-1189/561. b: *Tinca* sp., isolated pharyngeal tooth in occlusal and lateral views, GIN-1189/562. c: *Scardinius* sp., isolated pharyngeal tooth, GIN-1189/563. d: *Esox* sp., tooth, GIN-1189/564. e: *Silurus* sp., pectoral fin spine in lateral and dorsal views, GIN-1189/565.

spina pinna pectoralis, 1 1st vertebra), Esocidae: *Esox* sp. (1 basioccipitale, 3 teeth, 3 vertebrae praecaudales), Percidae: Percinae gen. indet. (1 basioccipitale, 1 vertebra praecaudales, 2 vertebrae caudales). Previously, *Esox* sp. and *Rutilus* sp. were reported from the similar-age localities of Cherlak and Krutaya Gorka (Sychevskaya et al. 2016). The presence of Siluridae catfish was previously reported for the Middle-Late Miocene (Zykin 2012) and Middle Pleistocene (Sychevskaya et al. 2016) of Western Siberia, but it is unknown from Pliocene sites.

For the sake of comparison, we mention the fauna of Obukhovka 1 in the north of the Azov Sea region. It is dated to the late Early Pliocene, and includes *Acipenser* sp., *Leuciscus* sp., *Rutilus* sp., *Scardinius ponticus* KOVALCHUK, 2014, *Scardinius erythrophthalmus* (LINNAEUS, 1758), *Chondrostoma* sp., *Abramis* sp., *Aspius* sp., *Barbus* sp., *Tinca* sp., *Esox moldavicus* SYTCHEVSKAYA, 1974, Percidae gen. et sp. indet. (Kovalchuk 2017). Certain taxonomic similarity of these ichthyofaunas may be a result of wide ranges of fishes covering East Europe to Western Siberia under the warm temperate climate of the Early Pliocene.

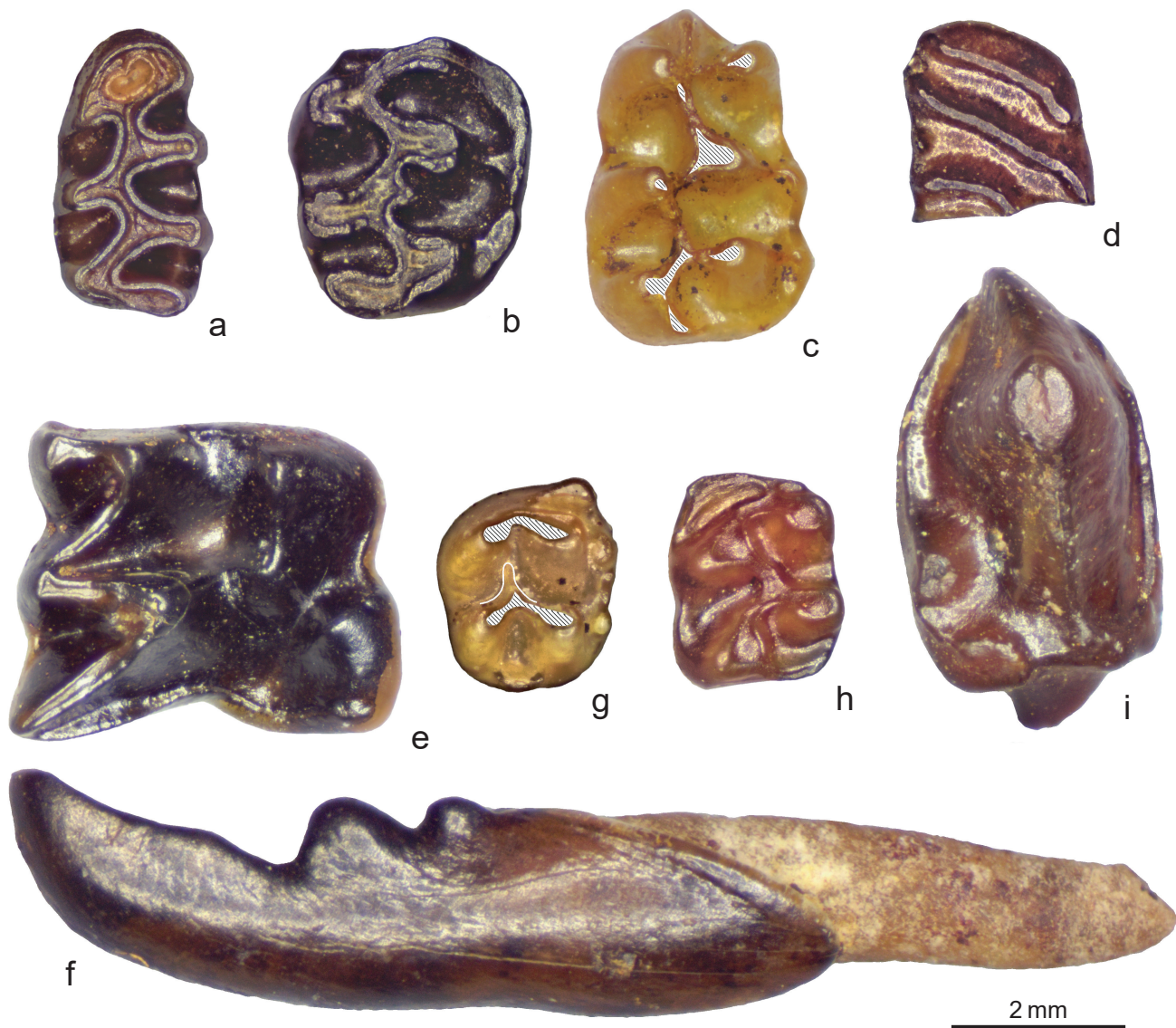
## Small mammals

An association of bone remains of small vertebrates (Text-fig. 10) was obtained from the bone horizon in member 1 by washing. The total number of remains amounts to several hundred fossils. Small vertebrates are represented by the remains of fish, amphibians, birds, and mammals. The herpetofauna is represented by a few remains of Siberian salamander (*Salamandrella* sp.) and anurans. The following mammal taxa were identified: Desmaninae 1 and 2, *Sorex* sp., *Paranourosorex* cf. *gigas* RZEBIK-KOWALSKA, 1975, *Parasoriculus* sp., *Ochotona* sp., *Pliolagomys* sp., *Muscardinus* cf. *pliocenicus* KOWALSKI, 1963, Sciuridae gen., cf. *Trogontherium* (*Euroxenomys*) sp., *Prosiphneus* sp., *Lophocricetus ultimus* ZAZHIGIN, LOPATIN et POKATILOV, 2002, *Orientalomys* sp., Cricetini gen., *Baranomys* cf. *loczyi* KORMOS, 1933, *Promimomys* cf. *davakosi* VAN DE WEERD, 1979. The remains of pikas and voles predominate in the micromammal association, and the remains of shrews are quite numerous.

The dominant element of the micromammalian fauna of Novaya Livenka is the primitive protomimomyan vole *Promimomys* cf. *davakosi* (VAN DE WEERD, 1979). Below we provide its brief description.

## Systematic palaeontology

We use the taxonomic system where all arviculines without cement and well-defined pachyknem schmelzmuster (Rabeder 1981), but with expressed mimomyoid dental morphology (variably expressed *Mimomys* ridge and enamel islets in m1 and M3) are placed in the genus *Promimomys* KRETZOI, 1955. This Ruscinian group is clearly ancestral to numerous genus-level lineages of Arvicolinae of Villanyian and Biharian age, such as *Mimomys* s. l., *Borsodia*, *Dolomys*, *Propliomys*, *Pitymimomys*, etc., and cannot be phylogenetically attributed to an advanced lineage of *Mimomys* of Villanyian-Biharian age, based on *Mimomys pliocenicus* FORSYTH MAJOR, 1902. Taxonomic problems



**Text-fig. 10.** Small mammals from Novaya Livenka section. a: *Baranomys* cf. *loczyi*, m1 sin, GIN-1189/201. b, c: *Lophocricetus ultimus*. b: m2 dex, GIN-1189/211. c: m1 dex, GIN-1189/212. d: *Muscardinus* cf. *plioaenicus*, M1 dex, fragment, GIN-1189/222. e–f: *Parasoriculus* sp. e: M1/2 dex, GIN-1189/225. f: i1 sin, GIN-1189/226. g: *Orientalomys* sp., m2 dex, GIN-1189/251. h: Cricetini gen., m2 sin, GIN-1189/253. i: *Paranourosorex* cf. *gigas*, A1 sin, GIN-1189/261. a–e, g–i: occlusal surface. f: labial side, isolated teeth.

within the vast Early Pliocene *Promimomys* radiation are in many aspects similar to that of the early *Microtus* radiation, labelled the *Allophaiomys* “metaregion” by Martin and Tesakov (1998).

**Order Rodentia BOWDICH, 1821**  
**Family Cricetidae G. FISCHER, 1817**  
**Subfamily Arvicolinae GRAY, 1821**  
**Genus *Promimomys* KRETZOI, 1955**

***Promimomys* cf. *davakosi* (VAN DE WEERD, 1979)**  
 Text-figs 11–13

**Material.** 25 m1, 10 m2, 17 m3, 23 M1, 25 M2, 36 M3, fragments of mandibles, and palates.

**Description.** Primitive brachyodont vole species with very low dentine tracts, molar teeth lacking cement, early root formation, and nearly uniform enamel thickness

on leading and trailing edges of occlusal triangles. Advanced over the more underived *Promimomys* by expressing a *Mimomys*-ridge (kante) and distinct crenulations on the anteroconid of juvenile m1s. Lower molars have two roots, and the upper molars, three roots.

**Lower molars.** m1 (Text-fig. 11a–c). The anteroconid shows well developed reentrant folds. The anteroconid cap bears shallow juvenile folds (crenulations) in the youngest specimens. Both *Mimomys* and islet reentrants and a *Mimomys*-ridge are well expressed, and extend down the crown nearly to the enamel-dentine juncture. LRA4 is relatively deep. Its mean elevation above a lingual enamel baseline drawn below LRA1 is 0.95 mm (n = 21). The enamel islet is closed at a very early ontogenetic stage. The islet is oval or slightly curved in molars with higher crowns and becomes more circular with wear. The islet disappears with wear at crown heights less than 0.9 mm. T1 and T2 are widely confluent at all wear stages. In medium-worn

**Table 1. Measurements in mm of *Promimomys cf. davakosi*, Novaya Livenka, m1.**

m1	N	Mean	SE	Min	Max	SD	CV
L	25	2.68	0.025	2.35	2.90	0.126	4.71
W	25	1.25	0.013	1.14	1.40	0.066	5.29
A	25	1.08	0.021	0.90	1.37	0.103	9.47
A/L	25	41.53	1.378	33.33	69.64	6.892	16.59
H	25	1.30	0.111	0.30	2.15	0.555	42.62
H/L	25	49.00	4.285	11.11	78.43	21.422	43.72
ASD	23	0.70	0.023	0.55	0.95	0.111	15.72
HSD	24	0.21	0.011	0.10	0.30	0.056	26.96
HSLD	25	0.11	0.011	0.05	0.20	0.053	47.47
HH-index	24	0.79	0.021	0.57	1.00	0.102	12.85
$\Sigma$ _tract	23	1.03	0.023	0.85	1.22	0.110	10.67
$\Sigma$ _tract/L	23	38.43	0.910	31.58	46.04	4.362	11.35

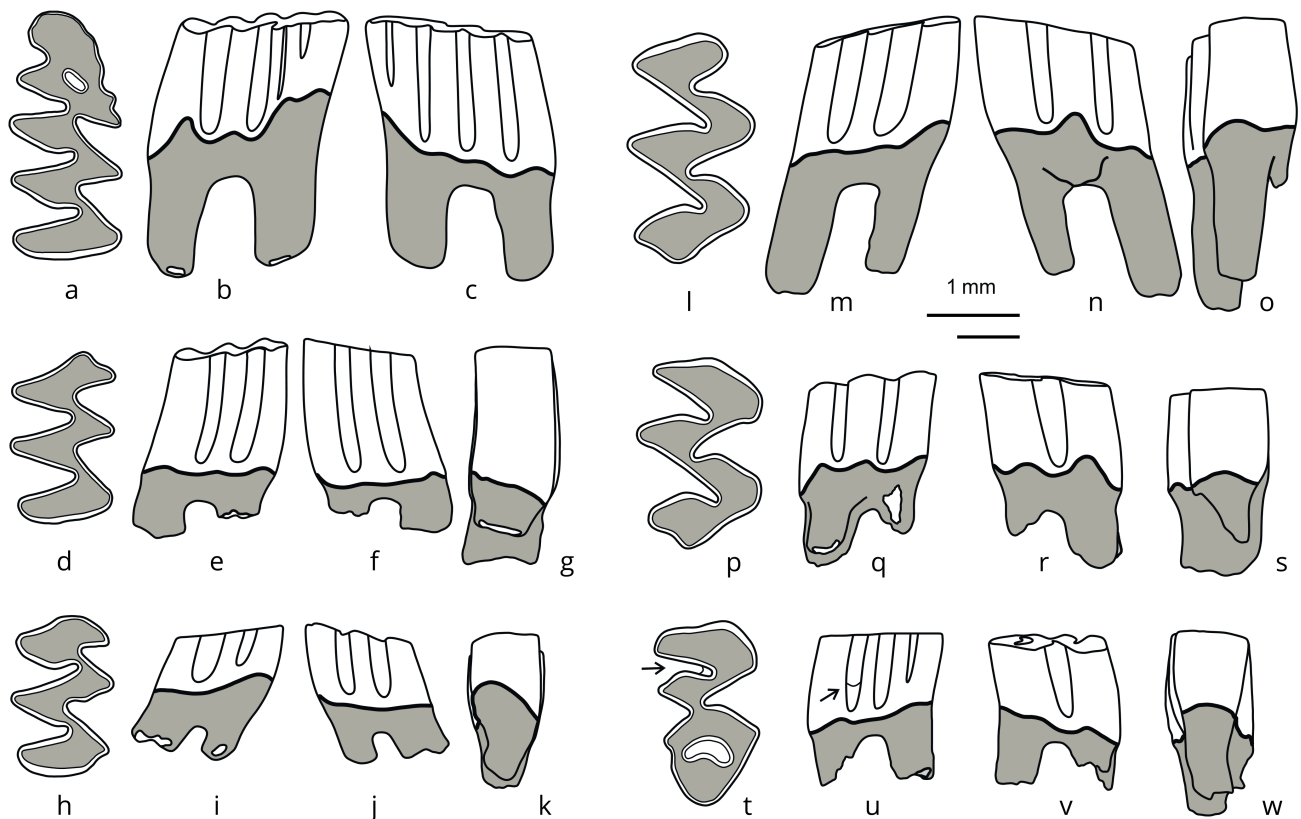
molars, tips of lingual reentrants curve anteriorly. Especially strong provergence (anterior curving) is shown by LRA2. Much weaker curving is shown by LRA3, and even less so in LRA1. Dentine tracts are low (see Tab. 1), form a sequence from highest to lowest as ASD-HSD-HSLD. ASD commonly shows curving of an incipient mimosinuid at the base of the *Mimomys* ridge.

m2 (Text-fig. 11d–g). The pairs of occlusal triangles T1-T2 and T3-T4 are widely confluent at all wear stages.

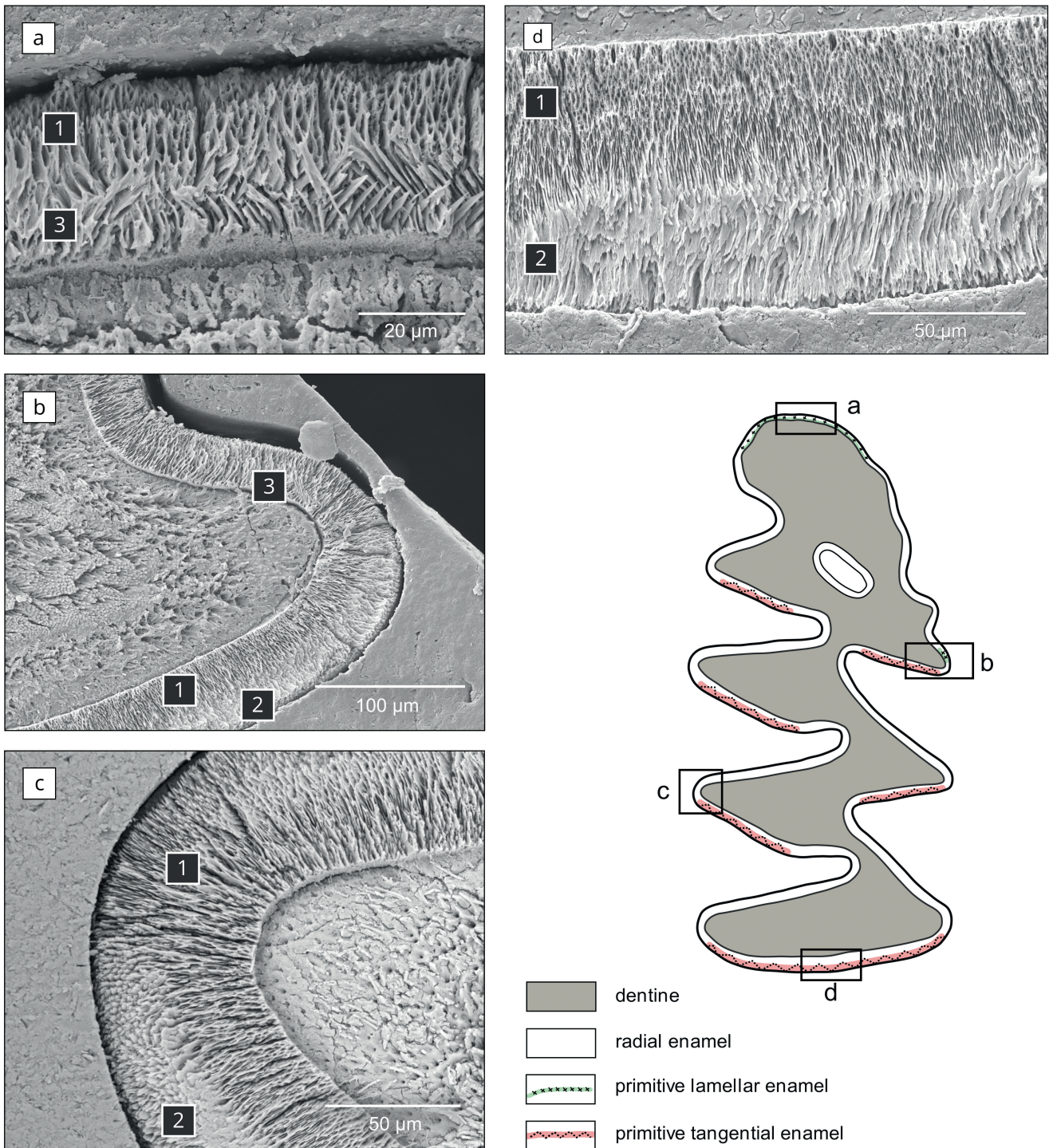
The posterior root of m2 has a fork-like shape and is placed upon the dorsal surface of the lower incisor (pleurorhiz condition).

m3 (Text-fig. 11h–k). The confluence of occlusal elements is similar to m2.

**Upper molars.** M1 (Text-fig. 11l–o). Occlusal dentine triangles are confluent with the strongest confluence between dentine fields of T3 and T4. Reentrant folds are wide and “V-shaped.”



**Text-fig. 11. Morphology of molars of *Promimomys cf. davakosi*, Novaya Livenka. a–c: m1, GIN-1189/001. d–g: m2 (reversed), GIN-1189/002. h–k: m3 (reversed), GIN-1189/003. l–o: M1, GIN-1189/004. p–s: M2, GIN-1189/005. t–w: M3, GIN-1189/006. a, d, h, l, p, t: occlusal surface; b, e, i, m, q, u: labial side; c, f, j, n, r, v: lingual side; g, k: anterior side; o, s, w: posterior side. Scale bars for occlusal and lateral views, 1 mm.**



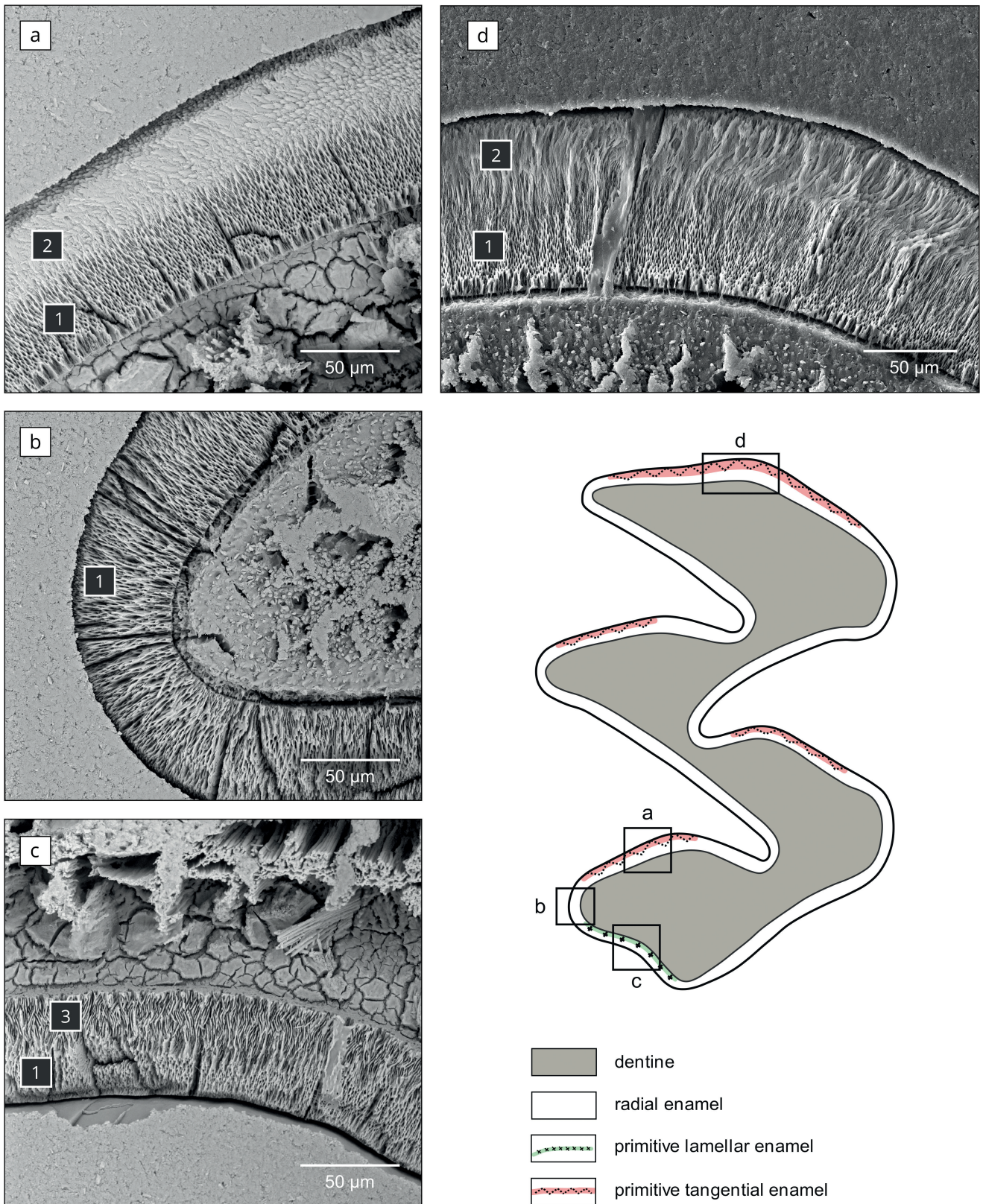
**Text-fig. 12.** Schmelzmuster of m1 of *Promimomys cf. davakosi*, Novaya Livenka, GIN-1189/001. a: lamellar enamel on apex of anteroconid; b: BSA3 (small portion of lamellar enamel on leading edge and tangential enamel on trailing edge); c: radial and tangential enamel at LSA2; d: radial and primitive tangential enamel in middle of closing enamel. 1 – radial enamel; 2 – primitive tangential enamel; 3 – primitive lamellar enamel.

M2 (Text-fig. 11p–s). The tip of BSA2 protrudes labially only slightly further than that of BSA1. The reentrants mirror those of M1.

M3 (Text-fig. 11t–w). An anterior enamel islet forms in the antero-labial reentrant (BRA1) at a relatively deep level, occurring above the base of BRA1 in the range of 0.15–0.77–1.4 mm (min–mean–max; n = 36). The height of the labial dentine tract (hyposinus) ranges from 0.02 to 0.1, with a mean of 0.05 mm (n = 28). A few specimens

(n = 3) show a complete reduction of this islet formation. The posterior enamel islet closes at early wear stages by isolation of LRA3. The islet has a curved shape at earlier stages and becomes more circular in more worn molars. The islet extends nearly to the base of the crown.

**Schmelzmuster.** The basically undifferentiated enamel thickness shows a slightly negative differentiation, with thinning in the deep parts of reentrant folds. In molars used for microstructure studies, the differentiation quotient, BTQ,



**Text-fig. 13.** Schmelzmuster of M2 of *Promimomys cf. davakosi*, Novaya Livenka, GIN-1189/005. a: tangential enamel on trailing edge of T4; b: radial enamel at tip of BSA3; c: lamellar enamel in leading edge of T4; d: tangential enamel in middle of closing enamel. 1 – radial enamel; 2 – primitive tangential enamel; 3 – primitive lamellar enamel.

equals (m1) = 113.33; (M1) = 113.33; (M2) = 123.33. The Schmelzmuster was studied in the first lower molar (Text-fig. 12), and the first and second (Text-fig. 13) upper molars. There is no difference in the structure of enamel between the lower and upper molars. The type of microstructure is

eopachyknem in transition to protopachyknem (Rabeder 1981): leading edges consist of radial enamel, trailing and closing edges consist of radial and primitive tangential enamel (Text-fig. 12c, d). In addition, primitive lamellar enamel was found on m1 and M2. The most conspicuous

zone of lamellar enamel is located on the apical part of the anteroconid of m1 (Text-fig. 12a). We propose to define apical enamel as a separate opening enamel type as opposed to the closing enamel on the posterior wall of the posterior loop. The smaller zones of lamellar enamel are also observed on the leading edge of BSA3 (Text-fig. 12b) in m1, and in the leading edge of incipient BRA3 in M2 (Text-fig. 13c).

**C o m p a r i s o n .** *Mimomys moldavicus* KORMOS, 1932. The Siberian form is notably more advanced as compared to the range of Early Pliocene forms attributed to *Promimomys* (= *Mimomys*) *moldavicus* in Romania, Moldova, and south-western Ukraine. The type material of this species shows very low indentations of the enamel-dentine boundary, poorly dissected anteroconid in m1, and poorly differentiated T3 and T4 coupled with shallow or absent LRA3 in M1 (Radulescu and Samson 1989, Crespo et al. 2023).

*Promimomys antiquus* ZAZHIGIN, 1980. *Promimomys* from Novaya Livenka is notably more advanced in hypsodonty than the monotypical *P. antiquus* from a borehole in the Ob' River Plateau, which shows a very low or absent anterosinuid, less developed reentrants and a more triangular anteroconid (Zazhigin 1980: 96, fig. 19: 4).

*Mimomys davakosi* VAN DE WEERD, 1979. The Siberian vole is very similar in size and tooth morphology to the form from Greece. The observable difference is in somewhat higher hypsodonty expressed in the height of the anterior dentine tract (Ea or anterosinuid), with a range of 0.55–0.7–0.95 (min-mean-max; n = 23) compared to 0.0–0.26–0.47 (min-mean-max?; n = 21) or mean value of 0.41 (n = 14) in the type locality of Ptolemais 3 (van de Weerd 1979, Fejfar et al. 1990). Another hypsodonty-related distinction is somewhat deeper enamel islets in m1 in the Siberian form: islets are obliterated by wear below crown heights of 0.9–0.8 mm. In the type sample of *P. davakosi*, enamel islet disappears between crown heights of 1.15 and 0.89 mm (van de Weerd 1979). The maximum crown height in the form from Greece, ca. 2.02 mm (van de Weerd 1979: fig. 9) or lower (Hordijk and de Bruijn 2009), is slightly lower than in Novaya Livenka (Hmax = 2.15).

*Mimomys vandermeuleni* FEJFAR, MEIN et MOISSENET, 1990. The Siberian form is more hypsodont than the Spanish form (anterosinuid ranging from ca. 0.5–0.6 mm). Another important distinction is deeper juvenile folds (crenulations) on the anteroconid of the vole from Almenara (Fejfar et al. 1990). The main difference indicating separate lineages is the predominance of two-rooted M3 in *P. vandermeuleni* in contrast to the three-rooted condition in *P. cf. davakosi* from Siberia.

**C o m m e n t s .** Attribution of a vole species in West Siberia to the species described from northern Greece is forced by a surprising similarity of morphology of both forms, but our identification of the Novaya Livenka species is tentative. We suspect an independent taxon in Siberia after at least one million years of protomimomyid vole evolution in Eurasia, with several regional radiation centers. At the current state of knowledge, we refrain from a description of a new species, awaiting more data and recognition of more distinctive characters, most importantly on enamel microstructure, on Ruscinian *Promimomys* forms from the western Palearctic. The geological age of the type locality

of *P. davakosi*, Ptolemais 3 in Greece is precisely bracketed by radiometric data between 4.9–4.81 Ma (Hordijk and de Bruijn 2009). This seems to be older than the estimates of the Krutaya Gorka formation by Zykin (2012), 4.5–4.3 Ma. This age difference may account for a higher hypsodonty stage in the Siberian vole.

Nevertheless, the similarity in dental evolutionary stage of the Novaya Livenka *Promimomys* to *P. davakosi* provides important biochronological information that obviously needs an accurate age calibration in future.

## Discussion

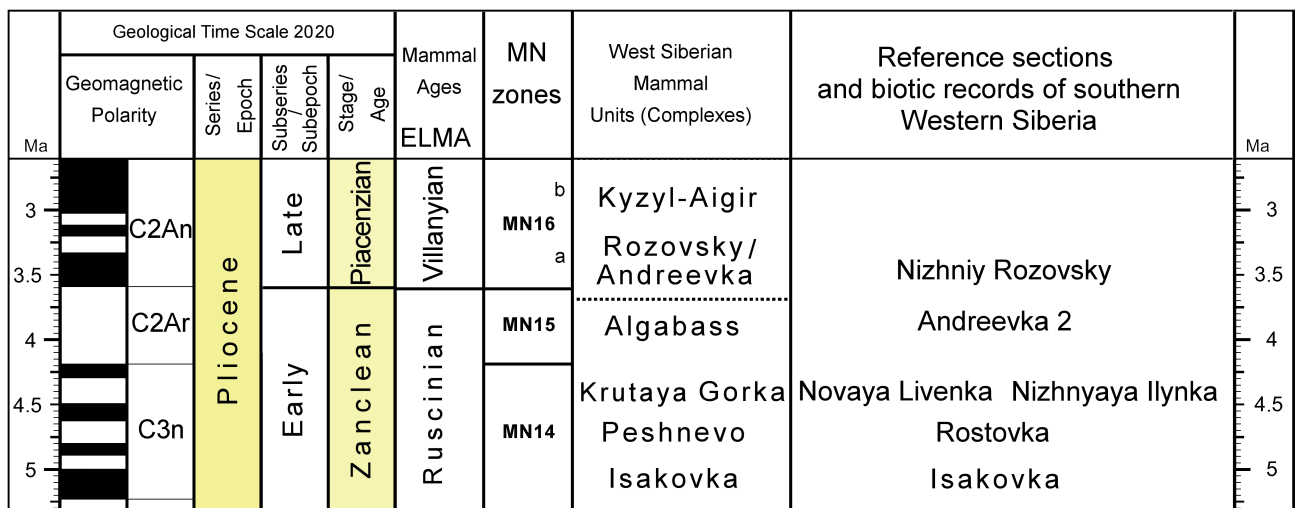
### Palynology

Palynological data on pollen zone III is important for regional stratigraphy, because it correlates with one of the stratigraphic intervals of the Lower Pliocene – the Krutaya Gorka Formation, according to V. S. Zykin's scheme (Zykin 2012). It is assumed that the sediments of this formation were palynologically studied by V. S. Volkova and L. A. Panova in two sections near the villages of Beshcheul and Nizhnyaya Ilyinka in different areas of the Irtys River valley. The absence of pollen diagrams for both sections makes it difficult to compare their palynological spectra; nevertheless, some differences can be noted. Based on the results of the study of the Beshcheul section, the authors reconstructed the predominance of steppe conditions for this time (Volkova and Panova 1975). The palynoflora from Nizhnyaya Ilyinka is characterized by a small amount of tree species pollen (9–15 %) and spores, and a complete absence of broad-leaved species pollen (Volkova and Kulkova 1984). In later works, V. S. Volkova (Arkhipov et al. 1993) noted a significant lack of palynological materials obtained mainly in the 1970s, and their weak connection to stratigraphic subdivisions. Nevertheless, in the same article, without reference to specific data, she had described the flora of the Krutaya Gorka time as entirely steppe (dominated by various cereals and xerophytes), and brings it closer to the flora of modern steppes in the south of Western Siberia.

In comparison with these data, our results show the existence of dynamic steppe and forest-steppe ecosystems, with local presence of both coniferous and broad-leaved species with background abundance of aquatic and riparian vegetation in the Krutaya Gorka time. The fact that the vegetation of the Krutaya Gorka time is not similar to the modern one is evident when comparing with palynological spectra from surface samples, including those from Novaya Livenka section (Text-fig. 4).

### Biochronology and biostratigraphy

The stratigraphic structure of the West Siberian Pliocene was elaborated by Zykin and Zazhigin, based on biochronological stages of evolution of small mammals and molluscs (Zazhigin and Zykin 1984). These stages/mammalian complexes correspond to the series of usually eponymous superposed lithological formation/suites (Text-fig. 14). Much later, the succession of primitive voles found in Western Siberia was supplemented by the first record of the primitive *Promimomys insuliferus* KOWALSKI, 1958



Text-fig. 14. Biochronological chart of West Siberian Pliocene.

from the Isakovka locality (Zykin and Zazhigin 2004). Recently, the sequence of localities was updated by V. S. Zazhigin (Vasilyan et al. 2017, Zazhigin and Voyta 2019). Judging from the level of hypsodonty, the *Promimomys* vole of Novaya Livenka is somewhat more advanced than *Promimomys antiquus* ZAZHIGIN, 1980 from the deposits of the Peshnevo Formation / mammalian unit, and is less hypsodont than the *Promimomys* and *Mimomys* of the Biteke Formation (Algabass mammalian unit) of the terminal Early Pliocene. Our comparative material on *Promimomys antiquus* comes from the Rostovka locality of the Peshnevo unit (Bondarev et al. 2016). Several localities of the Krutaya Gorka Formation/mammalian unit are available in the region of study. The most important are localities in the type section of the formation near the village Nizhnyaya Ilyinka, and near Olkhovka (Text-fig. 1b). All these sites produced vole remains of *Promimomys* cf. *davakosi*. The comparative materials from latest Ruscinian level with vole association of *Mimomys*, *Propliomys*, and *Promimomys* come from Andreevka 2, near Omsk. Thus, the new fauna of small mammals can be dated to the middle of the Early Pliocene, the upper levels of the Early Ruscinian, the Krutaya Gorka mammalian complex.

Another rodent group important for biochronology of the Siberian Early Pliocene is Lophocricetidae, as revised by Zazhigin et al. (2002). The assemblage of Novaya Livenka includes *Lophocricetus ultimus* ZAZHIGIN, LOPATIN et POKATILOV, 2002, a terminal form of its lineage typical for later Early Pliocene faunas of the Krutaya Gorka and Biteke formations (Vasilyan et al. 2017).

Based on the paleomagnetic data from the stratotype section near the village of Nizhnyaya Ilyinka, with basal normal polarity and overlying reversed polarity intervals (Gnibidenko and Donchenko 1994), Zykin (2012) correlates the accumulation time of the Krutaya Gorka Formation with the interval of the magnetostratigraphic scale, including the upper part of the Nunivak Subchron (C3n.2n) and the lower part of the reversed subchron (C3n.1r), below the Kochiti Subchron (C3n.1n) of the mid Zanclean, i.e., ca. 4.5–4.3 Ma.

The European Land Mammal chronology of the Early Pliocene, and especially its MN zonal/unit aspect

as defined by Fejfar et al. (1998), Hordijk and de Bruijn (2009), and revised by van Dam (Hilgen et al. 2012), shows different approaches and criteria. According to the recent chronological knowledge of early vole evolution (Hordijk and de Bruijn 2009), the reference faunas of units MN 14 (Podlesice) and MN 15 (Perpignian) as defined by Mein (1990) clearly date to the very beginning and very end of the extensive Early Pliocene. There are two general versions of the placement of a boundary between MN 14 and MN 15: subequal duration with the boundary below the Kochiti Subchron at 4.3 Ma (Fejfar et al. 1998), and a longer MN 15 and very short MN 14 delimited below Sidufjall Subchron at ca. 4.9 Ma (Hordijk and de Bruijn 2009). We favor the first option of Fejfar et al. (1998) based on the interpretation of the fossil record given below. A potentially reliable boundary criterion that can be traced through Eurasia could be the first extensive genus-level radiation of Arvicolinae, including the appearance of first true *Mimomys*, with cement in the reentrant folds and pachykneum schmelzmuster (see above), which took place in the Late Ruscinian (Csarnotanum). The replacement of primitive *Promimomys* voles with a simple, rounded anteroconid on m1 by *Promimomys* voles with trifoliate anteroconids in the Early Ruscinian does not represent the appearance of *Mimomys*. Indeed, these forms (*P. moldavicus*, *P. antiquus*, *P. vandermeuleni*, *P. davakosi*, etc.) represent a stem group of MN 14 vole radiation, potentially ancestral to many later genera of Arvicolinae. It was proposed to include this array of forms in a separate subfamily, the Promimomyinae (Martin 2008). Alternatively, this group was considered as a tribe Promimomyini (Agadjanian, 2009).

#### Paleoenvironment

The palynological study of the lower part of the section allows recognition of the conditions of steppe and forest-steppe formations, with the local presence of both coniferous and broad-leaved trees and an abundance of aquatic and riparian vegetation associated with a water body.

The association of plant macrofossils is represented by seeds of water plants, indicating a water body of the stagnant type, or a river with a slow current.



**Text-fig. 15.** Artistic view of Novaya Livenka Early Pliocene environment. Figure by K. E. Zvorygina. In elevated areas, mixed forest with spruce, diverse pines, hemlock, broad-leaved trees and ferns in understory alternate with patches of herbaceous vegetation dominated by grasses and composites. The banks of a slow river or an oxbow lake are covered with diverse riparian vegetation (cattail, bur-reed, water soldiers), its surface is covered with aquatic plants (water lilies *Nuphar* and *Nymphaea*, watershield *Brasenia*, water fern *Azolla*). Among herbivorous mammals, pikas and voles, associated with meadow habitats, dominate. There are obligate forest species (hazel dormouse) and near-water species (beaver). Insectivoran mammals are diverse, represented by terrestrial mesophilic and near-water forms, such as shrews and desmans. The body of water is inhabited by a variety of fish, mainly limnophilic, such as tench, catfish, and small stagnophilic molluscs.

The preserved molluscan assemblage, based on the presence of numerous internal casts of the small bivalves with two closed valves, and a few fossils of *Planorbarius* sp., indicates weak hydrodynamics, such as an oxbow lake, or a small river with a weak current.

The fish association is characterized by a predominance of limnophilic species, which is typical for abandoned channels, deltas, and river estuaries. The presence of catfish (*Silurus*), missing in the extant fish fauna of the region, indicates a warm summer temperature of 18–20 °C, critical for the spawning period of these fish.

The mammalian association of the Novaya Livenka includes taxa indicating conditions of open steppe-like landscapes (pikas, hamsters), meadows (voles), and numerous forms associated with mesophytic habitats of forests (hazel dormouse, shrews) and forest-steppe type (lophocricetes, orientalomyid mice). There is also a presence of species associated with water basins (desmans, beavers).

Taken together, the biotic data consistently indicate a water basin (abandoned channel or a small stream) with aquatic vegetation, rimmed by forested and open

landscapes under the quite warm and humid climatic conditions. The artist's view on this environment is shown in Text-fig. 15.

## Conclusions

This study presents a recent attempt to create a synthetic picture of the Early Pliocene biota of Western Siberia based on diverse paleontological data from a new and rich locality of fossil remains of continental plants and animals. We hope that this study creates a benchmark for further research in the terrestrial Pliocene of Siberia. The joint study of several biotic groups provides means of cross-correlation of different environmental and biostratigraphic signals. Particularly promising, for example, is recognition of the same groups of water plants in palynological spectra and plant macrofossils. Important independent environmental signals of molluscs and fishes call for further and more detailed studies in these groups.

For the first time in the region, a detailed palynological study of Pliocene deposits is directly chronologically controlled by the fauna of small vertebrates, especially small mammals.



To reach the overall goal of the study, we provided detailed description of vole remains from Novaya Livenka, including data on hypsodonty and schmelzmuster, important for further comparisons. Based on the considerable amount of fossil material available, *Promimomys* cf. *davakosi* from Western Siberia provides the potential to define the fine stages of the early *Promimomys* radiation, not only in Siberia but throughout Northern Eurasia, from Western Europe to China. Due to the very fast dental evolution of hypsodont cricetines, especially voles, they serve as the most important tool for continental stratigraphy (Fejfar et al. 1998, 2011). The new data from Western Siberia contribute to the Neogene continental biochronology.

New palynological data provide the opportunity to revise vague, previously published palynological results on the region, which sometimes lacked proper documentation, and were poorly correlated with regional geological history. Indeed, the palynological study of the lower part of the Novaya Livenka section indicated an environment of forest-steppe ecosystems with the local presence of both coniferous and broad-leaved trees, and abundant aquatic and riparian vegetation. Paleobotanical and paleozoological data indicate quite warm and humid climatic conditions. This contradicts earlier published limited accounts on sediments correlated with the Krutaya Gorka Formation in the south of Western Siberia (Zykin 2012), the latter implying a vegetation of dry steppe with a significant reduction of forest coenoses. New data obtained in the current study show that filling the gaps in the Pliocene stratigraphic sequence of southern Western Siberia will make it possible to identify more climatic cycles that correspond to the complex bioclimatic history of this region.

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## References

- Agadjanian, A. K. (2009): Melkie mlekopitayushchie plitsen-pleystotsena Russkoy ravniny [Pliocene-Pleistocene small mammals of the Russian Plain]. – Nauka, Moskva [= Moscow], 676 pp. (in Russian)
- Arkipov, S. A., Volkova, V. S., Zykin, V. S. (1993): Kalendar' bioticheskikh i abioticheskikh sobytii pozdnego kaynozoya Zapadnoy Sibiri [Calendar of Biotic and Abiotic Events of the Late Cenozoic of Western Siberia]. – Stratigraphy and Geological Correlation, 1(6): 53–58. (in Russian)
- Bogachev, V. V. (1908): Presnovodnaya plitsenovaya fauna Zapadnoy Sibiri [Freshwater Pliocene fauna of Western Siberia]. – Izvestiya Geologicheskogo Komiteta, 27(4): 259–299. (in Russian)
- Bogachev, V. V. (1924): Presnovodnaya fauna Evrazii. Chast' I [The freshwater fauna of Eurasia. Part I]. – Trudy Geologicheskogo Komiteta, novaya seriya, 135: 1–248. (in Russian)
- Bogachev, V. V. (1961): Materialy k istorii presnovodnoy fauny Evrazii [Materials on the history of freshwater fauna of Eurasia]. – Akademiya nauk Ukrainskoy SSR, Kiev [= Kyiv], 404 pp. (in Russian)
- Bondarev, A. A., Dorogov, A. L., Tesakov, A. S. (2016): Rostovka – novoe mestonakhozhdenie pozvonochnykh rannego plitsena Zapadnoy Sibiri [Rostovka, a new vertebrate locality of Early Pliocene in Western Siberia]. – In: Zelenkov, N. V., Parhaev, P. Yu. (eds), Abstracts of 13th all-Russia conference of young scientists paleontologists, 10th–12th October 2016, A. A. Borissiak Paleontological institute RAS, Moskva [= Moscow], pp. 7–8. (in Russian)
- Crespo, V. D., Vasile, Ş., Petculescu, A., Răţoi, B. G., Haiduc, B. S. (2023): The Early Pliocene small mammals (Eulipotyphla, Rodentia, Lagomorpha) from Bereşti and Măluşteni (eastern Romania): A fresh look at old collections. – Earth and Environmental Science Transactions of the Royal Society of Edinburgh, 114(1-2): 49–63. <https://doi.org/10.1017/S175569102200024X>
- Dorofeev, P. I. (1963): Tretichnye flory Zapadnoy Sibiri [The Tertiary floras of Western Siberia]. – Izdatel'stvo Akademii Nauk SSSR, Moskva, Leningrad, 346 pp. (in Russian)
- Fejfar, O., Heinrich, W.-D., Kordos, L., Maul, L. (2011): Microtoid cricetids and the early history of arvicolids (Mammalia, Rodentia). – Palaeontologia electronica, 14(3): 1–38.
- Fejfar, O., Heinrich, W.-D., Lindsay, E. H. (1998): Updating the Neogene rodent biochronology in Europe. – Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO, 60: 533–554.
- Fejfar, O., Mein, P., Moissenet, E. (1990): Early Arvicolids from the Ruscinian (Early Pliocene) of the Teruel Basin. – In: Fejfar, O., Heinrich, W. D. (eds), International Symposium: Evolution, phylogeny and biostratigraphy of arvicolids (Rodentia, Mammalia). Geological Survey, Prague, pp. 133–164.
- Gnibidenko, Z. N., Donchenko, V. V. (1994): Magnetostratigraphy of upper Neogene deposits of a section near the village of Nizhnaya Ilyinka. – Geology and Geophysics, 35(4): 50–58.
- Gorbunov, M. G. (1962): Ocherk razvitiya tretichnoy flory Zapadnoy Sibiri (po dannym izucheniya ostatkov listiev) [Essay on the development of Tertiary flora of Western Siberia (based on fossil leaf remains)]. – In: Lebedev, I. V. (ed.), Biostratigrafiya mesosoyskikh i tretichnykh otlozheniy Zapadnoy Sibiri [Biostratigraphy of Mesozoic and Tertiary deposits of Western Siberia]. Gosop-tekhnizdat, Leningrad, pp. 312–327. (in Russian)
- Gurari, F. G., Volkova, V. S., Babushkin, A. E., Golovina, A. G., Nikitin, V. P., Nekrasov, A. I., Kriventsov, A. V., Dolia, Zh. A., Kolykhalov, Yu. M. (eds) (2001): Unifitsirovannye regional'nye stratigraficheskie skhemy paleogenovykh i neogenovykh otlozheniy Zapadno-Sibirskoy ravniny. Ob'yasnitel'naya zapiska i skhema [Standard Regional Stratigraphic Schemes for Neogene and Paleogene Deposits of the West Siberian Plain. Explanatory Notes]. – Siberian Scientific Research Institute

- of Geology, Geophysics and Mineral Resources, Novosibirsk, 84 pp. (in Russian)
- Hilgen, F. J., Lourens, L. J., van Dam, J. A. (2012): The Neogene Period. – In: Gradstein, F. M., Ogg, J. G., Schmitz, M., Ogg, G. (eds), *The Geologic Time Scale 2012*. Elsevier, Oxford, pp. 924–956.  
<https://doi.org/10.1016/B978-0-444-59425-9.00029-9>
- Hordijk, K., de Bruijn, H. (2009): The succession of rodent faunas from the Mio/Pliocene lacustrine deposits of the Florina-Ptolemais-Servia Basin (Greece). – *Hellenic Journal of Geosciences*, 44: 21–103.
- Ivanova, A. V., Sizov, A. V. (2024): Pervye palinologicheskie dannye po razrezu Novaya Livenka (nizhniy plio-tsén–pleystotsén), Omskoe Priirtysh'e [The first palynological data on the Novaya Livenka section (Lower Pliocene–Pleistocene), Omsk region]. – In: Tkachenko, M. A. (ed.), *Proceedings of the LXX session of the Paleontological Society of the Russian Academy of Sciences, April 1st – 5th 2024, Saint Petersburg, Russia*, pp. 62–64. (in Russian)
- Koenigswald, W. von (1980): Schmelzstruktur und morphologie in den molaren der Arvicolidae (Rodentia). – *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, 539: 1–129.
- Kovalchuk, O. M. (2017): Regional fish-based biostratigraphy of the Late Neogene and Pleistocene of Southeastern Europe. – *Vestnik zoologii*, 51(5): 375–392.  
<https://doi.org/10.1515/vzoo-2017-0045>
- Kuzmina, O. B., Gnibidenko, Z. N., Khazin, L. B., Khazina, I. V. (2017): New data on stratigraphy (palynomorphs, ostracods, paleomagnetism) of Cenozoic continental deposits of the Ishim plain, Western Siberia. – *Stratigraphy and Geological Correlation*, 25(3): 342–361.  
<https://doi.org/10.1134/S0869593817020046>
- Lindholm, W. A. (1932): Presnovodnye molluski iz plio-tsénovykh otlozheniy po r. Irtyshu (Yugo-Zapadnaya Sibir') [Freshwater molluscs from the Pliocene deposits of the Irtysh River (SW Siberia)]. – *Trudy Vsesoyuznogo geologo-razvedochnogo ob'edineniya NKTP SSSR*, 239: 3–27. (in Russian)
- Maderni, U. N. (1968): Kaynozoyskie presnovodnye molluski kontinental'nykh otlozheniy Severo-Zapadnogo Kazakhstana i yuga Zapadnoy Sibiri [Cenozoic freshwater molluscs of continental deposits of Northwestern Kazakhstan and southern Western Siberia] (Abridged abstract of the dissertation for the degree of candidate of geological and mineralogical sciences). – *All-Union Geological Research Institute, Leningrad*, 19 pp. (in Russian)
- Martens, E. von (1864): Fossile Süßwasser-Conchylien aus Sibirien. – *Zeitschrift der Deutschen geologischen Gesellschaft*, 16(2): 345–351.
- Martin, R. A. (2007): Arvicolidae. – In: Janis, C., Gunnell, G. F., Uhen, M. D. (eds), *Evolution of Tertiary Mammals of North America. Volume 2. Small Mammals, Xenarthrans, and Marine Mammals*. – Cambridge University Press, New York, 480–497.  
<https://doi.org/10.1017/CBO9780511541438.029>
- Martin, R. A., Tesakov A. S. (1998): Introductory remarks: does *Allophaiomys* exist?. – *Paludicola*, 2(1): 1–7.
- Mein, P. (1990): Updating of MN zones. – In: Lindsay, E. H., Fahlbusch, V., Mein, P. (eds), *European Neogene Mammal Chronology*. – Plenum Press, New York, London, pp. 73–90.  
[https://doi.org/10.1007/978-1-4899-2513-8\\_6](https://doi.org/10.1007/978-1-4899-2513-8_6)
- van der Meulen, A. (1973): Middle Pleistocene smaller mammals from the Monte Peglia (Orivieto, Italy) with special reference to the phylogeny of *Microtus* (Arvicolidae, Rodentia). – *Quaternaria*, 17: 1–144.
- Nikitin, V. P. (1969): Paleokarpologicheskiy metod (rukovodstvo po metodike izucheniya iskopaemykh semyan i plodov) [Paleocarpological method (a guide to the methodology of studying fossil seeds and fruits)]. – Tomsk University, Tomsk, 82 pp. (in Russian)
- Nikitin, V. P. (1961): Pervaya nakhodka verkhnepliotse-novoy semennoy flory v Zapadnoy Sibiri [The first discovery of the Upper Pliocene seed flora in Western Siberia]. – In: Rostovcev, N. N. (ed.), *Resheniya i trudy mezhdedomstvennogo soveshchaniya po dorabotke i utochneniyu stratigraficheskikh skhem Zapadno-Sibirskoy nizmennosti* [Decisions and proceedings of the interdepartmental meeting on finalizing and clarifying stratigraphic schemes of the West Siberian Lowland]. Gosoptekhizdat, Leningrad. pp. 315–320. (in Russian)
- Nikitin, V. P. (2006): Paleokarpologiya i stratigrafiya paleogena i neogena Aziatskoy Rossii [Paleocarpology and the Paleogene-Neogene Stratigraphy in Asiatic Part of Russia]. – *Geo, Novosibirsk*, 229 pp. (in Russian)
- Nikolaev, V. A. (1968): Stratigrafiya i fauna kontinental'nogo oligotsena i neogena Zapadno-Sibirskoy nizmennosti [Stratigraphy and Fauna of the Continental Oligocene and Neogene of the West Siberian Lowland]. – In: Nikolaev, V. A. (ed.), *Cenozoic of Western Siberia*. Nauka, Novosibirsk, pp. 3–16. (in Russian)
- Rabeder, G. (1981): Die Arvicoliden (Rodentia, Mammalia) aus dem Pliozän und dem älterem Pleistozän von Niederösterreich. – *Beiträge zur Paläontologie von Österreich*, 8: 1–343.
- Radulescu, C., Samson, P. (1989): Contribution to the knowledge of the mammalian faunas from Malusteni and Beresti (Romania). Order Rodentia, family Arvicolidae. – *Travaux de l'Institut Spéologie "Emile Racovitza"*, 28: 43–56.
- van der Schootbrugge, B., Koutsodendris, A., Taylor, W., Weston, F., Wellman, C., Strother, P. (2024): Recognition of an extended record of euglenoid cysts: Implications for the end-Triassic mass extinction. – *Review of Palaeobotany and Palynology*, 322: 105043 (12 pp.).  
<https://doi.org/10.1016/j.revpalbo.2023.105043>
- Shirokova, Yu. F. (1964): O shirotnoy zonal'nosti rastitel'nosti v srednem oligocene Zapadno-Sibirskoy nizmennosti (po dannym sporovo-pyl'tsevogo analiza) [On the latitudinal zonation of vegetation in the Middle Oligocene of the West Siberian lowland (according to pollen analysis data)]. – *Izvestiya Sibirskogo Otdeleniya Akademii Nauk SSSR, Serya biologo-meditsinskikh nauk*, 12(3): 21–28. (in Russian)
- Storch, G., Zazhigin, V. S. (1996): Taxonomy and phylogeny of the *Paranourosorex* lineage, Neogene of Eurasia (Mammalia: Soricidae: Anourooricini). – *Paläontologische Zeitschrift*, 70: 257–268.  
<https://doi.org/10.1007/BF02988282>
- Sytchevskaya, E. K. (1966): Shchukoobraznye Zapadnoy Sibiri [Esocidae of Western Siberia]. – *Byulleten'*

- moskovskogo obshchestva ispytateley prirody, otdel geologicheskoy, 6:142–143. (in Russian)
- Sytchevskaya, E. K., Kurshakov, S. V., Tesakov, A. S., Bondarev, A. A. (2016): Materialy po ikhtiofaune pozdnego kaynozoya yuga Zapadnoy Sibiri [Materials on the ichthyofauna of the late Cenozoic in the south of Western Siberia]. – in Arkad'ev, V. V. et al. (eds), Proceedings of the LXII session of the Paleontological Society of the Russian Academy of Sciences, April 4th – 8th 2016, Sankt Petersburg, Russia, pp. 273–274. (in Russian)
- Tesakov, A. S. (1998): Early stage of *Allophaiomys* in eastern Europe. – *Paludicola*, 2: 98–105.
- Tesakov, A. S., Bondarev, A. A. (2022): Down to the roots of lemmings: A new species of basal lemming from the upper Pliocene of West Siberia. – *Journal of Vertebrate Paleontology*, 41(5): e2036173 (16 pp).  
<https://doi.org/10.1080/02724634.2021.2036173>
- Tesakov, A. S., Bondarev, A. A., Kurshakov, S. V., Yakimova, A. A., Sorokin, A. D., Dorogov, A. L. (2024): Novaya Livenka – mestonakhozhdenie melkikh pozvonochnykh rannego plitsena yuga Zapadnoy Sibiri [Novaya Livenka – locality of small vertebrates of the Early Pliocene of the South of Western Siberia]. – In: Tkachenko, M. A. (ed.), Proceedings of the LXX session of the Paleontological Society of the Russian Academy of Sciences, April 1st – 5th 2024, Sankt Petersburg, Russia, pp. 266–267. (in Russian)
- Vasilyan, D., Zazhigin, V. S., Böhme, M. (2017): Neogene amphibians and reptiles (Caudata, Anura, Gekkota, Lacertilia, and Testudines) from the south of Western Siberia, Russia, and Northeastern Kazakhstan. – *PeerJ*, 5: 1–65.  
<https://doi.org/10.7717/peerj.3025>
- Velichkevich, F. Y. (1982): Pleystotsenovye flory lednikovykh oblastey Vostochno-Evropeyskoy ravniny [Pleistocene Floras of the Glacial Regions of the East European Plain]. – *Nauka i Tekhnika*, Minsk, 208 pp. (in Russian)
- Volkova, V. S., Arkhipov, S. A., Babushkin, A. E., Kulkova, I. A., Guskov, S. A., Kuzmina, O. B., Levchuk, L. K., Mikhailova, I. V., Sukhorukova, S. S. (2002): Stratigrafiya neftegazonosnykh basseynov Sibiri. Kainozoy Zapadnoy Sibiri [Stratigraphy of Oil-and-Gas Basins of Siberia. Cenozoic of Western Siberia]. – *Geo*, Novosibirsk, 249 pp. (in Russian)
- Volkova, V. S., Kulkova, I. A. (1984): Izmenenie sostava palinoflory Sibiri v pozdnem kaynozoe [Changes in the composition of palynoflora of Siberia in the late Cenozoic]. – In: Shatsky S. B. (ed.), *Sreda i zhizn' na rubezhakh epokh kaynozoya v Sibiri i na Dal'nem Vostoke*. Nauka, Novosibirsk, pp. 54–63. (in Russian)
- Volkova, V. S., Panova, L. A. (1975): Palinologicheskaya kharakteristika neogenovykh otlozheniy Zapadno-Sibirskoy ravniny [Palynological characterization of Neogene sediments of the West Siberian Plain]. – In: Volkova, V. S. (ed.), *Palinologiya kainozoya v Sibiri*. Nauka, Novosibirsk, pp. 34–54. (in Russian)
- van de Weerd, A. (1979): Early Ruscinian rodents and lagomorphs (Mammalia) from the lignites near Ptolemais (Macedonia, Greece). – *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, ser. B., 82(2): 127–170.
- Zazhigin, V. S. (1980): Gryzuny pozdnego plitsena i antropogena yuga Zapadnoy Sibiri [Late Pliocene and Anthropogene Rodents of the South of Western Siberia]. – *Nauka*, Moskva [= Moscow], 156 pp. (in Russian)
- Zazhigin, V. S., Lopatin, A. V. (2005): Istoriya tushkanchikoobraznykh gryzunov (Rodentia, Mammalia) i aridizatsiya Azii v neogene [The history of Dipodoidea (Rodentia, Mammalia) and the aridization of Asia during the Neogene]. – *Byulleten' moskovskogo obshchestva ispytateley prirody, otdel biologicheskoy*, 110(4): 69–72. (in Russian)
- Zazhigin, V. S., Lopatin, A. V., Pokatilov, A. G. (2002): The History of the Dipodoidea (Rodentia, Mammalia) in the Miocene of Asia: 5. *Lophocricetus* (Lophocricetinae). – *Paleontological Journal*, 36(2): 180–194.
- Zazhigin, V. S., Voyta, L. L. (2019): Northern Asian Pliocene–Pleistocene beremendiin shrews (Mammalia, Lipotyphla, Soricidae): A description of material from Russia (Siberia), Kazakhstan, and Mongolia and the paleobiology of *Beremendia*. – *Journal of Paleontology*, 93(6): 1234–1257.  
<https://doi.org/10.1017/jpa.2019.51>
- Zazhigin, V. S., Zykin, V. S. (1984): Novye dannye po stratigrafii plitsena yuga Zapadno-Sibirskoy ravniny [New Data on the stratigraphy of Pliocene of the south of the West Siberian Plain]. – In: Arkhipov, S. A. (ed.), *Stratigraphy of the Boundary Deposits of the Neogene and Anthropogene of Siberia*. Institute of geology and geophysics, Novosibirsk, pp. 29–53 (in Russian)
- Zykin, V. S. (1979): Stratigrafiya i unionidy plitsena yuga Zapadno-Sibirskoy ravniny [Stratigraphy and unionids of the Pliocene of the South of the West Siberian Plain]. – *Novosibirsk*, 135 pp. (in Russian)
- Zykin, V. S. (2012): Stratigrafiya i evolyutsiya prirodnoy sredy i klimata v pozdnem kaynozoe yuga Zapadnoy Sibiri [Stratigraphy and Evolution of Environments and Climate During Late Cenozoic in the Southern West Siberia]. – *Geo*, Novosibirsk, 487 pp. (in Russian)
- Zykin, V. S., Zazhigin V. S. (2004): New biostratigraphic level of Pliocene in Western Siberia and the age of the stratotype of Lower-Middle Miocene Bescheul Horizon. – *Doklady Earth Sciences*, 398(7): 904–907.