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Calabrian (Eopleistocene) micromammal assemblages from the lacustrine and fluvial deposits of the Southern Trans-Urals and chronological position of some regional stratigraphic units

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ABSTRACT

In the Southern Trans-Urals, the Quaternary deposits dated back to the Early Pleistocene (2.58–0.77 Ma) are scarce, incomplete, and often severely eroded. Data scarcity is a major challenge for accurate geological correlation and for integration of regional data into continent-wide stratigraphic frameworks. We provide a review of stratotypes and type localities for regional stratigraphic subdivisions of the Eopleistocene (the units correlated with the Calabrian stage of the Western European stratigraphical timescale, 1.8–0.77 Ma) with particular focus on small mammals and their biochronological significance. Subdivisions of the Eopleistocene which have been officially accepted in Russia include three regional chronostratigraphic units (Horizons) starting from Uvel'ka to Chumlyak, and Sarykul. We show that the Calabrian deposits are characterized in the Southern Trans-Urals by sequential changes in the evolutionary level of micromammal assemblages that could be directly correlated with the mammal-based biochronological zones MQR of Russia (Vangengeim and Tesakov, 2008; Tesakov and Titov, 2013) within the interval from MQR 10 to MQR 8. Analysis of micromammal assemblages reveals incongruent positioning of the officially accepted Uvel'ka, Chumlyak, and Sarykul' Horizons in the regional stratigraphic chart. The revealed incongruences appear to be a result of the difficulty to delineate chronostratigraphic units using the highly eroded and reworked sediments of fluvial origin. The complete cycles of alternating fluvial-lacustrine sedimentation and subaerial exposure provide the most reliable sections to establish the chronostratigraphic units of the Calabrian stage of the Early Pleistocene in the Southern Trans-Urals. The position of Chumlyak and Sarykul' Horizons in the regional stratigraphic chart of the Southern Trans-Urals is proposed to be changed. The validity of the Uvel'ka Formation as a chronostratigraphic unit should be further verified, with a particular focus on faunal proxies (mollusks, ostracods, and small mammals).

1. Introduction

Geographic situation of the Ural Mountains and the peculiarities of its geological history during the Quaternary determine the crossroad position of the region between European and Asian biogeographic sectors of the Palearctic. Stretching submeridionally for more than 2000 km from the Arctic Ocean in the north to the steppes of Kazakhstan in the south and bridging the eastern and western terrestrial biogeographic realms in northern Eurasia during the last 2.6 Ma, the Urals has kept a variety of paleoarchives that enable correlation between European and Siberian biostratigraphic frameworks, and thus provides a basis for continent-wide geological correlations. However, due to complex topography and different genesis of the quaternary archives on the western and eastern slopes of the Urals, the unified regional stratigraphic framework is far from being clearly established. The western foothills of the Ural Mountains gradually pass in the East European Plain while the eastern slopes abruptly go down, adjoining to flat West Siberian. The western slope is much better studied and the stratigraphic schemes are regularly updated (see a comprehensive literature review by Danukalova, 2010 and also Danukalova, 2006, 2014). The quaternary deposits of the eastern slope have been studied in much less detail (Stefanovsky, 1997, 2006; Stefanovsky and Borodin, 2002).

Here, we provide a revision of the localities dated back to the Eopleistocene (1.8–0.78 Ma) and situated in the region of the Southern Trans-Urals, starting from the eastern slope of the Ural Mountains that transform to the East into broad peneplain foothills buried to a certain extent under the loose, easily pulverized deposits of the West Siberian

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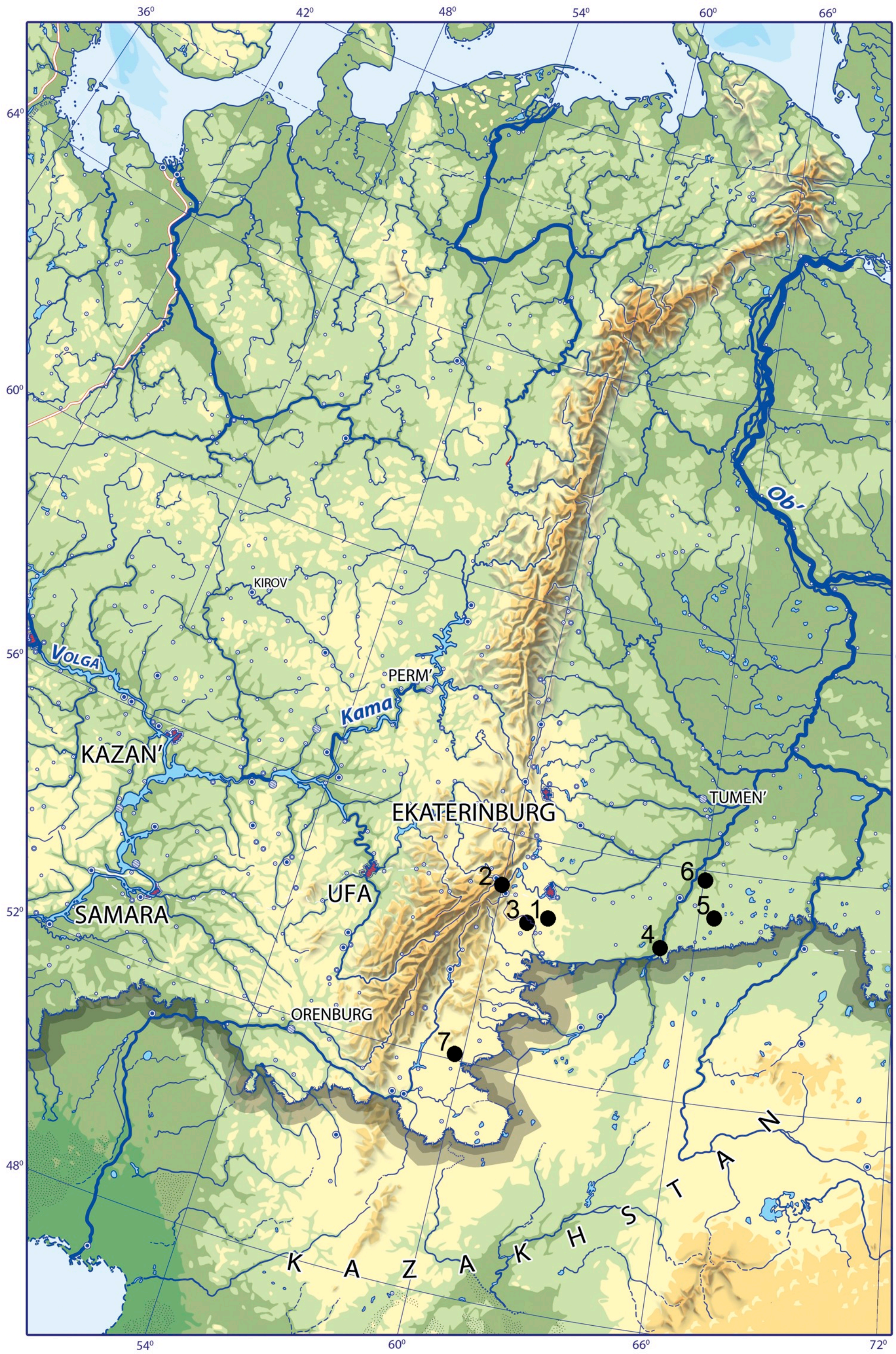

Fig. 1. Stratotype and key sections for the Eopleistocene chronostratigraphic units of the Southern Trans-Urals.
1 – Baturino quarry – a coal quarry located 1.5 km N of Emanzhelinsk, Chelyabinsk Region; 2 – Miass quarry – a brick quarry in Miass City, Chelyabinsk Region; 3 – Outcrop 472-II – a trench for gas pipelines on the left bank of the Kabanka River, a right tributary of the Uvel'ka River, 6 km SW of Krasnogorskiy Settlement, Chelyabinsk Region (Krylova, 1981; Stefanovsky, 2006, p. 64); 4 – Outcrop 443-A (= Outcrop 110), Tobol River near Zverinogolovskoye Settlement, Kurgan Region; 5 – Boreholes SV 980 and SV 981, 2.8 km S of Neverovskoe Settlement, Kurgan Region; 6 – Borehole SV 770, 3.4 km SE of Mokino Settlement, Kurgan Region; 7 – Outcrop ? – Parastratotype section of Uvelka Horizon – Outcrop of the Suunduk River terrace near Kvarkeno Settlement, Orenburg Region [not confirmed].

Plain (Fig. 1).

2. Materials and methods

The data discussed in this paper were collected during long-term field campaigns under supervision of Dr. V.V. Stefanovsky, the Ural Geological Survey Expedition, Ekaterinburg, Russia (Stefanovsky, 1965, 1997, 2006; Stefanovsky and Borodin, 2002). The published papers are based on field descriptions of geological sections carried out by V.V. Stefanovsky, E.S. Sinitskikh, Yu. N. Podkorytov, Yu. N. Zykov, as summarized by V.V. Stefanovsky. In the previous studies, spores and pollen were identified by O.N. Vasilyeva, L.A. Gribenyuk, plant macrofossils – by K.P. Proskurin, mollusk remains – by L.I. Krylova, ostracods – by S.M. Vinitskikh. Large mammal remains were identified by E.A. Vangengeim, E.M. Belyaeva, P.A. Kosintsev, and I.E. Kuzmina. Small mammal remains were identified by A.G. Maleeva, N.V. Pogodina, and A.V. Borodin. Paleomagnetic studies were carried by D.K. Nurgaliev, P.G. Yasonov, Sh.Z. Ibragimov, and P.G. Leonov. The analyses were primarily done at the Laboratory of Paleomagnetism, Kazan' State University. The methods are briefly described in previous publications (Stefanovsky and Borodin, 2002).

2.1. Arvicoline rodents as biochronological proxies

In this study, arvicoline rodents are identified using the previously developed approaches (Borodin, 2009; Borodin and Markova, 2015) and some metric criteria to distinguish the species of *Borsodia*, *Prolagurus*, and *Allophaiomys*, including HH-index of hypsodonty (Rabeder, 1981; Tesakov, 1993), relative length of the anteroconid (A/L) and posterior loop of M3 (P/L), BTQ-index of enamel differentiation, and some other measurements proposed for the Early Pleistocene Arvicolinae (Rekovets, 1994; Tesakov, 2004).

To establish evolutionary level of micromammals, the species composition of each assemblage has been correlated with the micromammal biochronological zones of the Quaternary (biozones MQR) established for European Russia (Vangengeim et al., 2001; Vangengeim and Tesakov, 2008; Tesakov and Titov, 2013). The zones are defined by the first and last occurrence of the key taxa of Arvicolinae (Cricetidae, Rodentia).

2.2. Taxonomic names and discrepancies among taxonomic lists provided in previous publications

Taxonomic names are provided following the original publications with few exceptions. Mollusk taxa are listed according to the scientific names and authors provided in two publications (Krylova, 1981; Stefanovsky, 2006). The lists are not revised. However, some minor changes include 1) spelling corrections, 2) addition of the years of description for all species, 3) exclusion of one dubious taxon, *Transversalis caperata* (Mart.) mentioned among the mollusk taxa from the key section 1 of the Uvel'ka Formation (Stefanovsky, 2006).

Taxonomic names for the micromammals from Chumlyak and Sarykul' Formations are listed according to Stefanovsky and Borodin, 2002 with minor corrections. In particular, we use scientific name *Prolagurus ternopolitanus* (Topachevsky, 1973) instead of *Prolagurus praepannonicus* Topachevsky, 1965. *Allophaiomys pliocaenicus* Kormos, 1932 is considered here as *Allophaiomys pliocaenicus* sensu lato, including several previously described taxa (Borodin, Ivakina (Pogodina), 2000; Stefanovsky and Borodin, 2002; Stefanovsky, 2006).

It should be noted that taxonomic lists of micromammals provided for the holostratotypes of Cuml'yak and Sarykul' Formations (Stefanovsky, 2006, p. 70) contain typographical mistakes that could be ruled out by comparison with the original species lists (Stefanovsky and Borodin, 2002). The discrepancies between the previously published species lists of micromammals from the deposits of Uve'la Formation (Stefanovsky, 1997, 2006) are briefly discussed in Appendix 1.

2.3. Abbreviations used in this study

Official names of organizations: IUGS – the International Union of Geological Sciences, UGSE – the Ural Geological Survey Expedition, UrFU – Ural Federal University, IPAE – Institute of Plant and Animal Ecology Ural Branch of the Russian Academy of Sciences, GIN RAS – Geological Institute of the Russian Academy of Sciences. Zones MNR and MQR – micromammal-based biochronological zones for the Neogene and Quaternary of the European Russia. Designations of rodent teeth: m1, m2, m3 – lower molars, M1, M2, M3 - upper molars numbered according to the position in the tooth row. Tooth measurements: L – occlusal length, W – occlusal width, A – anteroconid length, W—W' – maximal width of the anteroconid triangles of m1, B – the width of the anterior cap of m1 in its base, H – height of the crown, HH – index of hypsodonty, As, Asl, Asd, Hsd, Hsld, Ds, Prs, Misd – abbreviations of the dentine tracts according to Tesakov (2004).

2.4. Geological terminology

Formal subdivision of the Quaternary period sanctioned by IUGS (Head and Gibbard, 2005; Head et al., 2013; Cohen et al., 2016) is different from the subdivision officially accepted in Russia (Zastrozhnov et al., 2018). In this paper, we follow the terminology accepted in Russia to keep reasoning closer to original publications, and the correspondence between stratigraphic frameworks is shown on illustrations. Within the time span discussed, the correspondence between the two stratigraphic schemes is as follows: Lower Pleistocene, Gelasian, base 2.58 Ma (IUGS) is equal to Paleopleistocene (Russia); Lower Pleistocene, Calabrian, base 1.8 Ma (IUGS) is equal to Eopleistocene (Russia); Middle Pleistocene, base 0.77 Ma (IUGS) is equal to Lower Neopleistocene (Russia). The term Pliocene is used in citations only, when the exact time frames are not clearly indicated in the original text.

To avoid confusion with eponymous designations of local and regional litho- and chronostratigraphic units existing in publications, all local lithostratigraphic units are referred to as units in the narrow sense, or as layers (e.g., Sarykul' unit = Sarykul' layers). Regional lithostratigraphic units are referred to as formations (e.g., Sarykul' Formation) and chronostratigraphic units are referred to as Horizons (e.g., Sarykul' Horizon).

3. Stratigraphical subdivision of the Eopleistocene and Lower Neopleistocene of the Southern Trans-Urals

Relative position and volume of some regional stratigraphic units of the Eopleistocene in the Southern Trans-Urals have been differently interpreted during the last decades (Stefanovsky, 1997, 2006; Stefanovsky and Borodin, 2002). Here, we present the data following the most recent chronostratigraphic subdivision of the Eopleistocene (Stefanovsky, 2006, Fig. 1.2) and summarize the data on faunal proxies related to the three chronostratigraphic units characterizing the Eopleistocene of the Southern Trans-Urals – Uvel'ka, Chumlyak, and Sarykul' Horizons. The stratotypes and key sections are listed in Table 1.

3.1. Uvel'ka Horizon

Deposits of the Uvel'ka Formation constitute the erosional-accumulative terrace above the floodplain in meridional sections of modern river valleys in the Southern Trans-Urals. Fluvial sediments of Uvel'ka Formation rest with the erosional surface upon the Neogene Zverinogolovskoe Formation, the Paleogene Kurtamysh Formation, or upon the Mesozoic crust of weathering, and they are primarily overlain by deluvial deposits of the Late Pleistocene age. The formation is composed of polymictic pebbles and sands with lenses of silty clays in the Trans-Uralian peneplain area, and primarily of quarts sands with quartz- and flint-bearing gravel interlayered with silty clays further east, towards the West Siberian Plain.

Holostratotype section is described in a gas pipeline trench (Outcrop 472-II) on the right bank of the Kabanka River, a right tributary of the Uvel'ka River near Krasnogorskoe Settlement, Uvel'sky district, Chelyabinsk Region (Krylova and Stefanovsky, 1973; Stefanovsky, 2006) (Fig. 1). The sands of Uvel'ka Formation yield an assemblage of freshwater mollusks with minor admixture of terrestrial species. The shells are well-preserved suggesting that the remains have not been long transported or redeposited. Based on the stable composition of genera and the presence of thermophilic species, the Uvel'ka faunal complex of mollusks has been established for the Lower Eopleistocene (Lower Calabrian) of the Southern Trans-Urals (Krylova, 1981).

The two parastratotypes are described. The first parastratotype (Outcrop 443-A (=110)) is near Zverinogolovskoe Settlement, Kurgan Region (Stefanovsky, 2006) (Fig. 1). Uvel'ka Formation is represented here by two layers (beds 4–5) of fluvial origin separated by an erosional surface. The lower layer (bed 5) is represented by sands with gravel lenses and the upper bed 4 is formed by clayey sands. The entire stratum contains remains of freshwater mollusks and the sands of bed 5 yield micromammals, rare ostracods, and spores and pollen. The mollusk assemblage is biochronologically informative suggesting the Early

Table 1
Key Eopleistocene sites of the Southern Trans-Urals and holostratotype sections for the regional chronostratigraphic units.

Official timescale						Southern Trans-Urals region		
IUGS			Russia					
System	Series	Subseries	Superdivision	Division	Subdivision	Horizon	Stratotype/Holostratotype sections (Stefanovsky, 1997, 2006; Stefanovsky and Borodin, 2002)	Key sections (listed by locality)
Quaternary	Pleistocene	Middle	Pleistocene	Neopleistocene	Lower	Miass	***Holostratotype***: Miass quarry, Outcrop 114, beds 8–10: 8 [e]*, 9 [e], 10 [e], 15.0–17.3 m (Stefanovsky, 2006, p. 8, 79)	Baturino quarry: Outcrop 104, bed 5 [e], 6.4–6.9 m; Outcrop 53, bed 5 [e], ~; Outcrop 52-A, bed 5 [e], 4.8–5.2 m; Outcrop 69, bed 5 [e], total thickness is up to 1.0 m (Stefanovsky, 2006, p. 79). Section Baturino-014, paleosol beds A, AB, B, BC, total thickness is 1.47 m (Dergacheva et al., 2016). Miass quarry: Section Miass 013, paleosol beds A′, B′, A”, B”, total thickness is 2.35 m (Dergacheva et al., 2016).
		Lower		Eopleistocene	Upper	Sarykul'	***Holostratotype***: Baturino quarry, north-eastern wall, outcrop 52-A, beds 6–7: 6 [a], 7 [la], 5.2–7.2 m**.	Baturino quarry: Outcrop 52, beds 6-6a [l, la], ~; Outcrop 53, bed 6 [la], ~; Outcrop 104, bed 6 [la], ~; Outcrop 624, beds 6–7: 6 [l, la], 7 [a], ~. Miass quarry: bed 11 [?], 17.0–20.5 m; Borehole SV 980: beds 5–6; 5 [l], 6 [a], 6.1–10.0 m (Stefanovsky, 2006).
						Chumlyak	***Holostratotype***: Baturino quarry, northern wall, outcrop 52, beds 7–10: 7 [e], 8 [l], 9 [l], 10 [a], 8.6–11.0 m.	Borehole SV 980: beds 7 [l]–8 [a], 10.0–17.9 m (Stefanovsky, 2006).
					Lower	Uvel'ka	***Holostratotype***: Outcrop 472-II, bed 3 [a]; 1.5–2.1 m. ***Parastratotype***: Outcrop of the Suunduk River terrace near Kvarkeno Settlement, Orenburg Region – not confirmed. ***Parastratotype:*** Outcrop 443-A (=110), beds 4 [a] −5 [a]; 2.0–3.2 m.	Borehole SV 770: bed 4 [a], 3.0–5.5 m; beds 5–6 [?], 5.5–13 m (Stefanovsky, 2006).

IUGS divisions are given according to Head et al. (2013); *[a], [e], [la], [l], [?] – Genetic types of deposits, as indicated in cited works: a – alluvial, e − eluvial, la – lacustrine-alluvial, l – lacustrine, ? – deposit genesis was not indicated; ** – 5.2–7.2 m – depth interval, ~ – depth/thickness was not indicated in the original publication.

Table 2
Mollusk species from the deposits of Uvel'ka and Chumlyak Horizons summarized from available publications (Krylova, 1981; Stefanovsky, 2006).

Taxa	Eco-logy	Key sections				
		Uvel'ka Horizon			Chumlyak Horizon	
		1[a]	2[b]	3[a]	4[a]	5[a]
Lymnaea stagnalis (Linnaeus, 1758)	s	+	–	–	+	–
Lymnaea peregra (Müller, 1774)	s	+	–	–	–	–
Lymnea palustris (Müller, 1774)	s	–	–	–	+	–
Lymnaea cf. *palustris*	s	+	–	–	–	–
Lymnaea cf. *zebrella* (Dybowsky, 1913)	s	+	+	–	–	–
Lymnaea truncatula (Müller, 1774)	n	–	–	+	–	+
Planorbis planorbis (Linnaeus, 1758)	s	+	–	+	+	+
Planorbarius corneus (Linnaeus, 1758)	s	+	–	–	–	–
Anisus vortex (Linnaeus, 1758)	s	+	–	–	+	–
Anisus leucostoma Millet, 1813	s	+	–	–	+	–
Anisus spirobis (Linnaeus, 1758)	s	–	–	–	–	+
Choanomphalus rossmaessleri (Auerswald in Schmidt, 1851)	s	+	–	+	–	+
Armiger crista (Linnaeus, 1758)	s	+	–	–	–	+
Borysthenia pronaticina (Lindholm, 1932)	r	+	+	+	–	–
Valvata piscinalis (Müller, 1774)	r, s	+	–	+	–	–
Valvata ambigua Westerlund, 1873	n	–	+	–	–	–
Valvata confusa Westerlund, 1897	n	–	+	–	–	–
Valvata klinensis Milaschewitsch, 1881	n	–	+	+	–	+
Valvata cf. *borealis* Milaschewitsch, 1881	n	–	–	+	–	–
Valvata sp.	n	–	–	–	+	–
Valvata pulchella Studer, 1789	s	–	–	–	–	+
Bithynia leachii (Sheppard, 1823)	s	–	–	+	–	–
Bithynia cf. *leachii*	s	+	–	–	–	–
Bithynia kirgisorum Lindholm, 1932	n	–	–	+	–	–
Bithynia tentaculata Linnaeus, 1758	r, s	–	–	+	–	–
Bithynia sp.	s	–	+	–	+	–
Succinella oblonga (Draparnaud, 1801)	t	+	–	+	–	–
Succinea putris (Linnaeus, 1758)	t	–	–	+	–	–
Vallonia pulchella (Müller, 1774)	t	+	–	–	+	+
Sphaerium corneum (Linnaeus, 1758)	s	+	–	–	–	–
Pisidium amnicum (Müller, 1774)	r	+	–	–	–	+
Pisidium nitidum Jenyns, 1832	r, s	+	–	–	–	–
Hydrobia sp.	n	–	+	–	–	–
Sphaeriastrum rivicola (Lamarck, 1818)	r	–	+	–	–	–
Euglesa nitida Jenyns, 1832	r	–	–	+	–	–
Euglesa casertana Poli, 1791	r	–	–	+	+	–
Euglesa supina (A. Schmidt, 1851)	n	–	–	–	–	+

Ecology – preferred habitat type, as indicated in original publications (Krylova, 1981; Stefanovsky, 2006): r – rivers and reservoirs with flowing water, s – stagnant and/or weakly–flowing water, t – terrestrial, n – not indicated.
Key sections: 1 – Outcrop 472-II Kabanka River (Stefanovsky, 2006); 2 – Uvel'ka River, 6 km SW of Krasnogoskiy (Krylova, 1981); 3 – Outcrop 443-A (=110), bed 5 (Stefanovsky, 2006); 4 – Chumlyak bed 9 (Stefanovsky, 2006); 5 – borehole SV 981 (Stefanovsky, 2006).
[a] Complete species list.
[b] The most typical taxa.

Eopleistocene age of the deposits (Stefanovsky, 2006) (Table 2). Spore and pollen spectrum suggests the existence of light coniferous pine and birch forests with patches of xerophytic steppes. Based on the presence of thermophilic species, the climatic conditions are interpreted as more favorable than today (interpretation by L.A. Gribenyuk).

Micromammal assemblage from Uvel'ka beds (Outcrop 443-A, bed 5) has never been fully described. Taxonomic lists provided in two available publications are contradictory (Stefanovsky, 1997, p. 100; Stefanovsky, 2006, p. 65), and most of the remains have not been identified to species. Here we undertake a revision of the collection of micromammals from the Outcrop 443-A, bed 5 in order to clarify the taxonomic identity of the remains and to assess the evolutionary level of the key taxa. The collection was obtained by water screening of the Uvel'ka sands in 1992.

The list of identified species shown in Table 3 comprises arvicoline rodents of different evolutionary levels. The most primitive forms recovered in Uvel'ka sands include two genera – *Borsodia* and *Mimomys*. Among six specimens of *Borsodia*, one m1 is identified as *B. praehungarica* (Fig. 2) based on the overall morphology and the value of the HH-index. This species represents an intermediate stage of *Borsodia* dental evolution typical for the biochronological zones MNR 2 – MNR 3 (Tesakov and Titov, 2013). Two M1 (Fig. 3) are not identifiable to species but possess well-developed dentine tracts suggesting the advanced stage of *Borsodia* dental evolution known for the genus, most probably, the MQR11 zone. Four rooted molars with scarce cement depositions in re-entrant angles of the crown are close to *M.* ex. gr. *hintoni*, which should not be younger than biochronological zone MNR 3 sensu Tesakov and Titov, 2013.

Genus *Prolagurus*, a direct descendant of *Borsodia*, is represented by both early (*P. ternopolitanus*) and late Calabrian taxa (*P. pannonicus*). *P. ternopolitanus* (biochronological zones MQR 10 - MQR 9) is the most numerous species in the assemblage (Fig. 4). All m1 possess typical values of the anteroconid index. One of 14 specimens exhibit a *Mimomys*-ridge. The ridge is getting less pronounced towards the crown base and shows no dentine tract, thus suggesting that this feature represents a *Lagurodon*-like morphotype of *P. ternopolitanus*. A single m1 with the more advanced morphology and a higher value of the anteroconid index is identified as *P. pannonicus*, a species typical for biochronological zones MQR 8 – MQR 7. Genus *Allophaiomys* (Fig. 3) is represented by 5 molars with a clearly negative type of enamel differentiation that allows us to identify all specimens as *A. deucalion* (MQR 10 – MQR 11).

Table 3
Taxonomic composition of the micromammal assemblages recovered from the deposits of Uvel'ka, Chumlyak, and Sarykul' Horizons of the Southern Trans-Urals.

Taxa	Assemblage (section/bed)				
	Uvel'ka (443-A/5)[a]	Chumlyak I (52/9)[b]	Chumlyak II (52/8)[b]	Sarykul I (52/6a; 624/7)[b]	Sarykul II (52/6)[b]
Sorex sp.	–	+	–	+	+
Sorex cf. *araneus* Linnaeus, 1758	–	–	–	–	+
Sorex ex gr. *minutus* Linnaeus, 1766	–	–	–	–	+
Sorex aff. *Drepanosorex*	–	–	–	–	+
Desmana sp.	–	–	–	+	–
D. cf. *moschata* Linnaeus, 1766	–	–	–	–	+
Mustelidae ex gr. *nivalis-erminea*	–	–	–	+	–
Ochotonidae gen. et spec. indet.	1	–	–	–	–
Ochotona sp.	–	–	–	–	+
Spermophilus sp.	2	–	–	+	+
Marmota sp.	–	–	–	+	+
Trogontherium sp.	–	–	–	+	
Sicista sp.	–	+	–	+	+
S. cf. *vinogradovi* Topachevsky, 1965	–	–	–	–	+
Allactaga ex gr. *jaculus* Pallas, 1778	–	–	–	–	+
Cricetus ex gr. *cricetus* Linnaeus, 1758	–	–	–	+	+
Prosiphneus sp.	–	–	–	–	+
Clethrionomys (total)	–	–	–	–	2
Cl. ex gr. *socolovi* Topachevsky, 1965 (m1)	–	–	–	2	–
Borsodia (total)	5	38	–	–	–
B. praehungarica Schevtschenko, 1965 (m1)	1	–	–	–	–
Borsodia sp. (M1, advanced form)	2				
B. fejervaryi Kormos, 1934 (m1)	–	9	–	–	–
B. prolaguroides Zazhigin, 1980 (m1)	–	2	–	–	–
Prolagurus (total)	24	–	2	69	16
P. ternopolitanus (Topachevsky, 1973) (m1)	14	–	–	14	–
P. pannonicus Kormos, 1930 (m1)	1	–	–	–	3
Lagurus lagurus Pallas, 1773 (m1)	7	–	–	–	–
Lagurini gen. et sp. indet. (no roots, no cement)	48	–	–	–	–
Mimomys (total)	5	7	2	15	51
M. ex gr. *hintoni* Fejfar, 1961	4	–	–	–	–
M. ex gr. *intermedius* Newton, 1881 (m1)	–	–	–	6	4
M. ex gr. *savini* Hinton, 1910 (m1)	–	–	–	6	6
M. pusillus Méhely, 1914 (m1)	–	–	–	3	3
Allophaiomys (total)	5	20	1	98	164
A. deucalion Kretzoi, 1969 (m1)	3	6	1	9	–
A. pliocaenicus Kormos, 1932 (m1)	–	–	–	12	34

[a] Collection housed in Zoological Museum of the Ural Federal University.
[b] Collection housed in Phylogenetics & Biochronology Lab, Institute of Plant & Animal Ecology UrB RAS.

The most advanced arvicoline taxa are represented by a terminal taxon of the Lagurini lineage - *Lagurus lagurus* (Fig. 3) suggesting that the age of the remains of this species is not older than the Late Pleistocene (MQR 2 – MQR 1).

Thus, the revision of micromammal remains from the parastratotype of the Uvel'ka Formation near Zverinogolovskoe Settlement (Outcrop 443-A (=110)) suggests that the assemblage represents a mixture of the key taxa of Arvicolinae typical for the Late Gelasian (MNR 3, MQR 11), Early-to-Late Calabrian (MQR 10 – MQR 8), and also for the Late Pleistocene (MQR 1 – MQR 2). Although the Early Calabrian taxa prevail among the arvicolines, the presence of pre- and post-Calabrian species in the micromammal assemblage provides no substantiation for the Early Calabrian age of the entire lithostratigraphic unit entitled Uvel'ka sands in the Outcrop 443-A. Analysis of the cross-section (Stefanovsky, 2006, p. 54) allows us to hypothesize that the water-screened materials might comprise both the Uvel'ka complex of micromammals and the admixtures from the above- and underlying deposits. The existence of a distinguishable sedimentary layer yielding a pure Calabrian assemblage of small mamals in the Outcrop 443-A should be further tested. Thus, the parastratotype of Uvel'ka Formation near Zverinogolovskoe Settlement is pending verification.

The second parastratotype is mentioned in publications as an outcrop of the Suunduk River terrace near Kvarkeno Settllement, Orenburg Region (Stefanovsky, 1997, 2006) (Fig. 1). Bones and teeth of *Archidiscodon meridionalis* Nesti, 1825 had been discovered in that locality and determined by E.M. Belyaeva. Neither exact place of the site nor description of the geological sequence has been provided in the publications. Based on that, the parastratotype of Uvel'ka Formation on the Suunduk River is considered here as non-verified.

A key section of Uvel'ka Formation is also described in borehole SV 770 in the Tobol River valley 3.4 km SW of Mokino Settlement, Belozerskiy District, Kurgan Region (Stefanovsky, 2006) (Fig. 1). The sands of Uvel'ka Formation yield numerous ostracods. The underlying silty clays comprise poorly preserved mollusk shells and plant debris. The lower layer of clays yields a spore-and-pollen spectrum of a forest-steppe type with xerophytic herbs, birches and pines, with the significant portion of ferns (identified by O.N. Vasilyeva).

3.2. Chumlyak Horizon

Chumlyak Formation of fluvial and lacustrine origin is embedded in the ancient erosional depressions and lake bowls, which are not distinguishable in modern relief. It fills the erosional cap-shaped incisions in diatomites of the Paleogene Irbit Formation or rests with the erosional surface on silty clays and silts of the Paleogene Kurtamysh Formation, and it is overlain by the deposits of the succeeding Sarykul' Formation.

Holostratotype section for Chumlyak Horizon is studied in Baturino coal quarry (Outcrop 52) near Emanzhelinsk City, Chelyabinsk Region (Stefanovsky and Borodin, 2002; Stefanovsky, 2006) (Fig. 1). Three facies are distinguished from the bottom of the unit: basal fluvial sands and gravel (bed 10), lacustrine clays (beds 8–9), and a paleosol (bed 7).

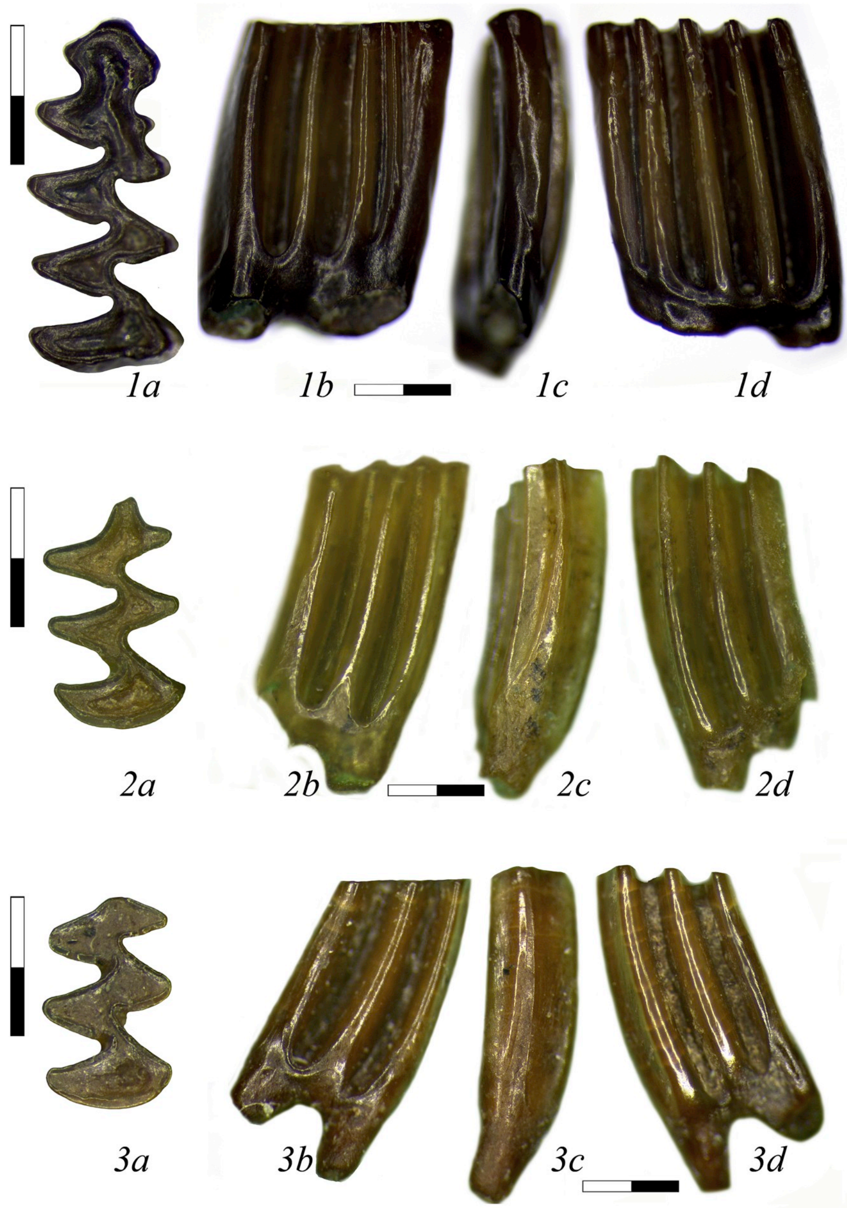

Fig. 2. Pre-Calabrian arvicolines identified in the assemblage of micromammals from the parastratotype of Uvel'ka Formation (Outcrop 443-A). *1* – Right m1 of *Borsodia praehungarica*, *2–3* - right m2 of *Mimomys* ex gr. *hintoni* identified in the revised collection of micromammals housed in UrFU; *a* – occlusal, *b* - buccal, *c* - anterior, and *d* - lingual views. Scale bar indicates 1 mm.

Headstream of the eponymous Chumlyak River is located north of the Baturino quarry, and basal sediments of the formation probably represent ancient alluvium of that river. Detailed descriptions of the section are provided in a previous publication (Stefanovsky and Borodin, 2002).

The holostratotype section of Chumlyak Formation represents a complete accumulative sedimentation cycle. It begins with basal sandy-gravely alluvial facies, which underlie the clayey lacustrine facies with a buried soil at the top. The thickness is 3–5 m.

The boundary between beds 8 and 9 is sharply defined and exhibits ice wedges up to 1.8 m high and 0.7–0.8 m wide at the top. Bed 9 yields an assemblage of micromammals with *Borsodia* and *A. deucalion* that allows us to correlate the fauna with biozone MQR11 of the Late Paleopleistocene. The succeeding bed 8 comprises a younger assemblage correlated with zone MQR 10 based on the presence of *Prolagurus* sp. and *A. deucalion*. Thus, the evolutionary level of micromammal assembalges characterizes the faunas of the Late Paleopleistocene (bed 9) and the Late Paleopleistocene – Early Eopleistocene (bed 8).

Mollusk remains recovered in bed 9 are rather well preserved but heavily fossilized (Table 2). In the opinion of L.I. Krylova, the list of identified taxa characterizes a wide chronological period from the Pliocene to the Holocene (Stefanovsky, 2006).

Ostracod remains are found in beds 8–9. The assemblage comprises the Plio-Pleistocene taxa along with the typical representatives of the Kochkovsky complex of ostracods of the Western Siberia (*Limnocythere scharapovae* Schweyer, 1949*; L. caspiensis* Negadaev-Nikonov, 1957), thus suggesting the Eopleistocene age of the deposits (Stefanovsky, 2006).

The sediments are primarily reversely magnetized (Matuyama Chron) with the exception of two samples taken from the depth interval of 9.1–9.3 m in bed 8, and showing normal polarity. This paleomagnetic anomaly has been related to the Cobb-Mountain event (1.21–1.24 Ma) and the entire Chumlyak Horizon has been assigned to the end of the Early – beginning of the Late Eopleistocene (Stefanovsky, 2006).

Thus, the basal sands of the Chumlyak Formation (bed 10) yield large mammal remains of the Paleopleistocene – Eopleistocene age. The

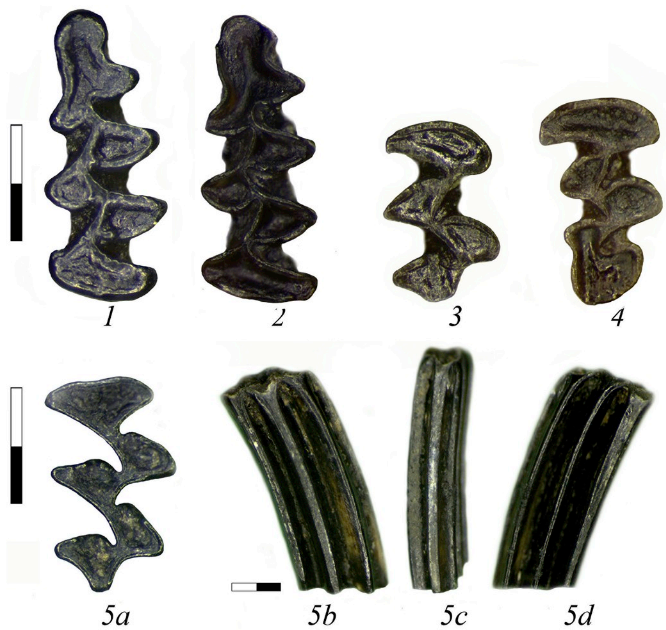

Fig. 3. *Allophaiomys deucalion* (1–4) and *Borsodia* sp., an advanced form (5) from the parastratotype of Uvel'ka Formation (Outcrop 443-A). *1–2* – left m1, *3* – left M2, *4* – right M3, *5* – left M1, *a* – occlusal, *b* – buccal, *c* – anterior, *d* – lingual view. Scale bar indicates 1 mm.

lacustrine clays of bed 9 yield a micromammal fauna of the Late Paleopleistocene. Accumulation of bed 9 terminated under cold climatic conditions (based on the presence of ice wedges and the cold-resistant elements in the palynological spectra), and the succeeding lacustrine clays (bed 8) yield an assemblage of micromammals characterizing the Late Paleopleistocene - Early Eopleistocene.

Key sections of the Chumlyak Formation are described in Boreholes SV 980 and SV 981 (Stefanovsky, 2006) (Fig. 1). The boreholes are close to each other and situated in the Tobol River valley 2.8 km S of Neverovskoe Settlement, Makushinsky District, Kurgan Region. The key section is provided for SV 980 (Stefanovsky, 2006, p. 71). Chumlyak Formation (beds 7–8) rests with the erosional surface upon the deposits of Kurtamysh Formation and is overlain by the sediments of the succeeding Sarykul' Formation. Bed 8 yields plant debris and numerous ostracods. Plant macrofossil analysis suggests that the vegetation was similar to the present-day Uralian vegetation. Ostracod assemblage comprises the species of a wide chronological interval, although the species typical for Kochkovsky complex and characterizing the Eopleistocene are also present: *Zonocypris membranae* Livental, 1929, *L. scharapovae*, *L. producta* Jaskevich et Kazmina, 1975*, L. ornata* Mandelstam et Kazmina, 1960. A sample from the depth of 14.5 m in borehole SV 981 yields a mollusk assemblage comprising the species of a wide chronological interval with no biochronologicaly informative species.

Thus, the analysis of different biotic proxies suggests that there is a contradiction between the relative position of the Uvel'sky and Chumlyaksy Horizons in the generally accepted stratigraphic scale of the Southern Urals. This contradiction is revealed by the analysis of micromammal assemblages, the results of which are summarized in Fig. 5.

A comparison of other faunal proxies (ostracods and mollusks) recovered from the deposits of Uvel'ka and Chumlyak Formations suggests that further analysis of mollusk assemblages might be informative when solving the problem of chronological arrangement of Chumlyak and Uvel'ka units. A review of the species lists and ecological preferences of the mollusk species listed for Chumlyak and Uvel'ka units allows us to hypothesize that the differences between Chumluak and Uvel'ka mollusk assemblages might be related to ecological factors. The species found in fluvial deposits of Uvel'ka and listed as the markers of the eponymous faunal complex are primarily confined to rivers (Krylova, 1981; Stefanovsky, 2006). Those species are absent from the published species lists for lacustrine deposits of Chumlyak Formation (Table 2).

3.3. Sarykul' Horizon

Deposits of Sarykul' Formation overlay the deposits of Chumlyak Formation without any visible unconformity, or rest with the erosional surface upon the Paleogene diatomite of the Irbit Formation filling in the ancient erosional depressions indistinguishable in modern relief. In the river terraces, the Sarykul' Formation rests on the Miass fluvial complex**,** a local lithostratigraphic unit defined for the eastern slope of the Southern Urals and considered to be analogous to the deposits of Chumlyak Formation in its narrow sense (Stefanovsky, 2006). However, unlike Chumlyak, the Miass fluvial complex contains no paleontological data to substantiate its chronological position.

Holostratotype section for Sarukul' Horizon is described in Baturino coal quarry (Outcrop 52-A) near Emanzhelinsk City, Chelyabinsk Region (Stefanovsky and Borodin, 2002; Stefanovsky, 2006) (Fig. 1). The name of the Horizon is derived from the Sary-Kul' Lake situated southeast of the Baturino quarry.

Sarykul' beds are well-distinguishable in the outcrops of Baturino quarry (Table 4). They overlay the deposits of Chumlyak Formation without any visible unconformity (Outcrop 104) or rest with the erosional surface upon the Paleogene diatomite of the Irbit Formation (Outcrops 52-A, 53) (Stefanovsky and Borodin, 2002) (Fig. 1). Total thickness of Sarykul' deposits is about 3–5 m. In Baturino quarry, the Sarykul' lithostratigraphic unit is represented by three subunits characterizing a cycle of lacustrine sedimentation: basal sands of fluvial origin (bed 7), fine lamination of sands, silts, and clays of lacustrine origin (beds 6 and 6 a), sandy loams of the chernozem-like Sarykul' paleosol (bed 5) with clearly distinguishable small and sharp wedges in all walls of the Baturino quarry marking off the deposits of Sarykul' Formation.

In the regional stratigraphic scales, the position and volume of Sarykul' Horizon is rather problematic. Initially, the entire Sarykul' unit has been assigned to the Sarykul' Horizon placed at the boundary of the Upper Eopleistocene and Lower Neopleistocene (Stefanovsky, 1997). Later, based on the analysis of micromammal assemblages recovered from the lacustrine deposits of beds 6 and 6 a (Stefanovsky and Borodin, 2002), the lower boundary of the Horizon had been lowered to the Upper Eopleistocene (Stefanovsky, 2006, p. 76). Based on the paleomagnetic data and the correlation with other local stratigraphic sequences, the upper normally magnetized Sarykul' paleosol had been assigned to the newly defined Miass Horizon of the Lower Neopleistocene (Stefanovsky, 2006, Fig. 1.2), and the lower fluvial and lacustrine layers (Outcrop 52-A, beds 6–7) had been referred to as the stratotype section of the Sarykul' Formation in its narrow sense (Stefanovsky, 2006, p. 73).

Paleomagnetic data indicate zones of reversed (lower part of the Sarykul' unit), normal (lower middle part), reversed (upper middle part), and normal (the upper part of the Sarykul' unit). According to the generally accepted interpretation, the lower normal episode within the Sarykul' deposits corresponds to the Jaramillo, 0.99 Ma (Stefanovsky, 2006). The upper part with normal polarity represents the beginning of Brunhes Epoch.

Based on the evolutionary level of micromammals, the fauna recovered from the fluvial subunit of the Sarykul' unit (Outcrop 52, bed 6a; Outcrop 624, bed 7) is correlated with the biochronological zones MQR 10 – MQR 9. Owing to the appearance of *A. pliocaenicus*, this fauna may be considered as the evolutionary succession of the fauna of Chumlyak, bed 8 (MQR 10). The lacustrine subunit of the Sarykul' unit (Oucrop 52, bed 6) is correlated with biozone MQR 8.

Key sections of the Sarykul' Formation are described in Borehole SV

Fig. 4. The Calabrian micromammal taxa, *Prolagurus ternopolitanus (1–12)*, *P. pannonicus (13)*, and the Late Pleistocene *Lagurus lagurus (14–18)* recovered in the assemblage of small mammals from the parastratotype of Uvel'ka Formation (Outcrop 443-A). *1, 2, 6–8 13, 14, 17* - left m1, *3–5, 13, 15* - right m1, 9 - left mandible with m1 and m2, *10–12* - M3, *18* – right mandible with m1 and m2; *a* - lingual view, *b* - occlusal view. Scale bar indicates 1 mm.

980 in the Tobol River valley 2.8 km S of Neverovskoe Settlement, Makushinsky District, Kurgan Region (Stefanovsky, 2006) (Fig. 1). The layers 5–6 confined to Sarykul' Formation comprise numerous ostracods and broken mollusk shells.

Several key sections are described in Baturino and Miass quarries (Fig. 1). Outcrop 104, bed 6 and Outcrop 53, bed 6 in Baturino comprise more or less the same biotic proxies as the holostratotype section (Stefanovsky and Borodin, 2002; Stefanovsky, 2006) (Fig. 1). In Miass quarry, bed 11 confined to Sarykul' Formation comprises no biotic proxies (Fig. 1). Its' chronological interpretation has been supported by paleomagnetic data obtained for the entire geological section in the Miass quarry (Stefanovsky, 2006).

Incongruence between initial and updated interpretations of the Sarykul' Formation is summarized in Table 4 using the holostratotype section in Baturino quarry as an example.

3.4. Miass Horizon of the Lower Neopleistocene

Holostratotype section for the Miass Horizon has been described in the Miass quarry belonging to a brick factory in the northern outskirts

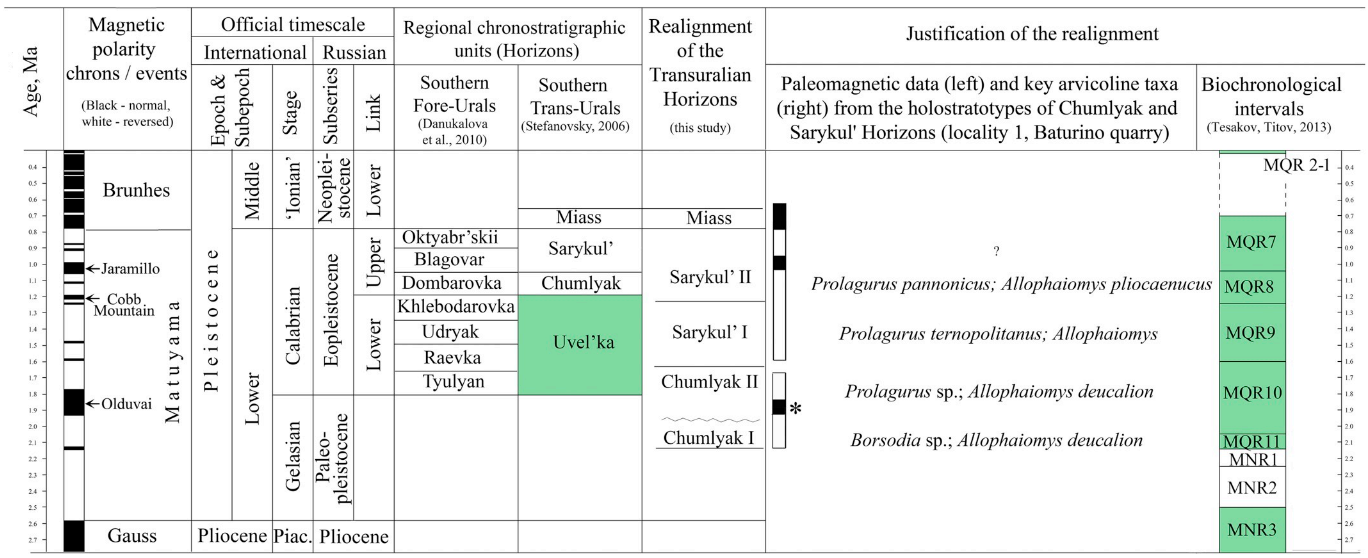

Fig. 5. A scheme showing regional stratigraphic subdivisions (Horizons) of the Calabrian (Eopleistocene) in the Southern Urals, and the proposed realignment of the regional chronostratigraphic units of the Southern Trans-Urals based on the arvicoline rodents as biochronological proxies.
Chronological position of the faunas is determined by the evolutionary level of key taxa correlated to the biochronological zones MNR and MQR of the Eastern Europe (Vangengeim and Tesakov, 2008; Tesakov and Titov, 2013). Magnetic properties of the sediments are illustrated for Chumlyak and Sarykul' layers (Outcrops 52 and 104 in Baturino quarry (Stefanovsky and Borodin, 2002)). Asterisk indicate the paleomagnetic anomaly, chronological interpretation of which is proposed to be changed from Cobb Mountain (Stefanovsky and Borodin, 2002; Stefanovsky, 2006) to Olduvai based on the evolutionary level of the key taxa of micromammals (this study). Green colour indicate the evolutionary level of micromammal assemblages from the parastratotype of the Uvel'ka Formation (Outcropp 443-A near Zverinogolovskoe Settlement). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

of the town of Miass, Chelyabinsk Region (Stefanovsky, 2006) (Fig. 1).

Deposits characterizing Miass Horizon are represented by a complex of double paleosols (the Lower Miass double paleosol). The lower boundary of the Miass Horizon has been established in the base of the lower member of the Lower Miass double paleosol and corresponds to the Matuyama-Brunhes polarity transition. The deposits of Miass Horizon are normally magnetized correspond to the beginning of the Brunhes Chron.

The lithological facies described in the Miass brick quarry correspond to several regional stratigraphic units: Karpiysk, Chernorechka, Loz'va, Baturino, Tyn'ya, Miass, Sarykul' Horizons, and a local lithostratigraphic unit called Miass fluvial complex that should not be confused with the Miass Horizon (Stefanovsky, 2006).

Sediments related to Miass Horizon rest upon the deposits of Sarykul' Formation with the wedge-shaped boundary and are overlain by Tyn'ya deluvium with the uneven boundary, with wedge-shaped upward intrusions of the upper member of the doubled paleosol. The holostratotype section of Miass Horizon includes three beds:

Bed 8. Depth interval 15.0–15.6 m – Upper member of the Lower Miass double paleosol: brown buried soil of forest type (leached chernozem). Dark-gray loam, gleyey, calcareous, with big carbonate contractions and traces of bioturbation. Humus content – 3.49%.

Bed 9. Depth interval 15.6–16.4 m – Greyish-brown loam, calcareous, with macropores. The upper and lower boundaries are uneven.

Bed 10. Depth interval 16.4–17.3 m – Lower member of the Lower Miass double paleosol: sod-podzol buried soil of forest type (leached chernozem). Dark gray to black loam, gleyey, thick, with big carbonate contractions. The lower boundary is wedge-shaped. Humus content – 3.09%.

Large mammal remains were found in situ in Tyn'ya deluvium: 3 femur fragments of *Bison* sp., 1 fragment of an elephant bone (determined by I.E.Kuzmina, ZIN RAS) and in the layer 3 – the finding of a big archaic form of *Equus* ex gr. *caballus* Linnaeus, 1758 (determined by E.A. Vangengeim, GIN RAS). Large mammal remains correspond to the Lower Neopleistocene.

The above-laying Loz'va limno-deluvium comprises an ostracod assemblage (determined by S.M. Vinitskikh, UGSE) suggesting the Early Neopleistocene age of the layer.

Paleosols yield similar spore-pollen spectra of birch-pine forests with fir, alder and motley grass and ferns in the undergrowth. Based on that, the buried soils (layers 8 and 10) have been correlated with the Early Neopleistocene Miass interglacial (Stefanovsky, 2006).

Table 4
Geological description of the Holostratotype section of the Sarykul' Formation in Baturino quarry, outcrop 52-A, and differences between initial (Stefanovsky, 1997; Stefanovsky and Borodin, 2002) and updated (Stefanovsky, 2006) interpretations of the Sarykul' lithostratigraphic unit.

Depth, m	Description of the Sarykul lithostratigraphic unit	Chronological interpretation (regional stratigraphic unit)	
		Initial	Updated
4.8–5.2	Sarykul' buried soil that consists of black gleyed sandy loam with desiccation wedges [Bed 5]	Sarykul' Horizon (Sarykul Formation)	Miass Horizon (?)[a]
5.2–6.5	Thin horizontal-sinuous alternation of light gray fine-grained to dusty quartz sand, gray siltstone, and dark gray kaolinhydromica clay. Laminae range in thickness from 2 to 3–5 cm. All varieties enclose quartz gravel, Fe—Mn "beans," ferruginate nests, and mollusk shells [Bed 6]		Sarykul' Horizon (Sarykul Formation)
6.5–7.2	Gravelly sand mainly composed of quartz grains with roundness index of 3–4 and enclosing molluscan shells. The lower boundary is erosional [Bed 7]		

[a] Regional stratigraphic unit is not clearly defined; here, we use a tentative designation 'Sarykul'-Miass paleosol' for the regional unit and 'Sarykul' paleosol' for the upper subunit (bed 5) of the Sarykul' unit in Baturino.

A detailed paleopedological analysis of the Lower Miass double paleosol and a comparison with the Sarykul' paleosol suggests that the paleosols exhibit similar morphological characteristics and similar parameters of humus substances (Dergacheva et al., 2016). Based on the humus and humic acid characteristics, it has been concluded that climate conditions during the Sarykul'-Miass paleosol formation changed from relatively warm and humid to less warm and more humid (Dergacheva et al., 2016).

4. Discussion

Deposits of the Lower Pleistocene within the Calabrian Stage are characterized in the Southern Trans-Urals by the sequential change in the evolutionary level of micromammal assemblages starting from the biochronological zone MQR 10 to MQR 8. Replacement of the archaic pre-Calabrian forms (*Borsodia*) by more advanced representatives of the same lineage (*Prolagurus*) is observed in the materials recovered from the two sequential layers of the Holostratotype section of the Chumlyak Formation in Baturino quarry. The boundary between the lower layer yielding MQR 11 assemblage (Chumlyak I fauna) and the upper layer with the more advanced forms (MQR 10, Chumlyak II fauna) is sharp and exhibits ice wedges. Thus, the clear difference in the structure of the micromammal assemblages from the archaic to the more advanced is in agreement with the sequential position of the two lithostratigraphic units.

Transition from MQR 10 to MQR 8 is rather gradual with no abrupt changes in the species composition. The micromammals are primarily recovered from laminated sediments of lacustrine and fluvial origin and the sedimentary bedding pattern provides no grounds for distinguishing the exact boundaries between the micromammal assemblages of different evolutionary levels characterizing the period from the beginning of the Early Eopleistocene to the first half of the Late Eopleistocene.

It is noticeable that in the Southern Trans-Urals there are no micromammal assemblages correlated with the biochronological zone MQR 7 typical for the end of the Late Eopleistocene of the Eastern Europe. It might be related to the erosion processes during the Oktyabr'skii time, when tectonic activity and incision of the hydrographic network were maximal for the entire Quaternary period in the Southern Urals and adjacent platform areas (Danukalova, 2010).

According to the most recent points of view, there are three regional lithostratigraphic formations and the eponymous chronostratigraphic units defined for the Eopleistocene of the Southern Trans-Urals (Stefanovsky, 2006). The sediments of Uvel'ka Formation comprise ostracods of the Kochkovsky faunal complex typical for the Eopleistocene of the West Siberian Plain, and a specific mollusk assemblage – Uvel'ka faunal complex of mollusks that is characterized by the combination of the pre-Calabrian species along with more advanced forms. Based on the evolutionary level of micromammals recovered in one of the parastratotype sections (Outcrop 443-A), the sediments of Uvel'ka Formation (at least in this section) comprise the Early-to-Late Calabrian taxa typical for biochronologic zones MQR 10 – MQR 8 along with the micromammal remains dated back to the Late Gelasian (MNR 3, MQR 11), and to the Late Pleistocene (MQR 1 – MQR 2). Two hypotheses might be proposed to explain origin of the mixed assemblage of micromammal recovered in the Uvel'ka sands in the Outcrop 443-A. First, it might be solely the result of fluvial reworking. If so, the sands should have the Late Pleistocene age according to the evolutionary level of the most advanced arvicolines found in the stratum (*L. lagurus*). Second, the Uvel'ka sands might be of the Calabrian age, and the chronologically mixed assemblage of micromammal might be a result of the admixture of allochthonous materials from under- and overlying sediments due to a combination of factors. Among these factors we consider i) redeposition from the underlying Zverinogolovskoe Formation that is known to comprise numerous remains of micromammals, in particular, *B. praehungarica* and *M. hintoni* (Pogodina and Strukova, 2013); ii) bioturbating activity of burrowing rodents that is typical for the study area; iii) rough sampling that might have obscured fine lithostratigraphic details of the Uvel'ka sands. Judging from the predomination of typical Calabrian arvicolines in the assemblage (*Prolagurus*, *Allophaiomys*), we suppose that the second hypothesis is more likely to be accepted. Distinguishability of the lithostratigraphic units yielding the micromammal assemblages of different geological ages should be further assessed in the field. Until it is done, the parastratotype of the Uvel'ka Formation near Zverinogolovskoe Settlement (Outcrop 443-A) should be regarded as a parastratotype pending verification.

The sediments of Chumlyak Formation comprise biotic proxies characterizing the period spanning from the end of the Paleopleistocene to the Early Eopleistocene (mammals, this study) or from the end of the Paleopleistocene to the entire Eopleistocene (mollusks and ostracods, Stefanovsky, 2006). Reversed magnetic polarity of the deposits suggests that the deposits have been accumulated during the Matuyama Chron. The magnetic anomaly within the bed 8 of the holostratotype section has been correlated to the Cobb-Mountain event (Stefanovsky and Borodin, 2002; Stefanovsky, 2006). However, if we accept the reliability of micromammals as chronostratigraphical proxies, then we have to conclude that the deposits of Chumlyak Formation should have to be correlated with one of the earlier paleomagnetic excursions (Fig. 5). This suggestion is not in agreement with the Late Eopleistocene chronological position of the Chumlyak Horizon accepted in regional and national chronostratigraphic charts (Stefanovsky, 2006; Zastrozhnov, 2014).

Biochronological interpretation of the biotic proxies recovered from the deposits of Sarykul' Formation is in agreement with its relative position in the regional stratigraphic scale of the Eopleistocene. However, the upper boundary and volume of the Sarykul' Formation have been differently interpreted during the past decades. According to the last interpretation, the Sarykul' Formation should be interpreted in its narrow sense – as a regional stratigraphic unit characterized by the reversed-polarity magnetization of deposits and by the micromammal assemblages of the two sequential evolutionary stages correlated with biozones MQR 9 and MQR 8. Chronologically, that corresponds to the second half of the Early – first half of the Late Eopleistocene.

A comparison of the evolutionary levels of micromammal assemblages from Uvel'ka, Chumlyak, and Sarykul' Horizons suggest that the faunas of Chumlyak II, Sarykul' I, Sarykul' II represent a gradual evolutionary succession from biochronological stages MQR 10 to MQR 8 with no clear boundaries, and with no interruptions. The mixed assemblage from Uvel'ka comprises principally the same Calabrian micromammal taxa as the Chumlyak and Sarykul' faunas along with a significant portion of admixed remains from the above and below-laying deposits. Thus, there is no chronological specificity of the micromammal assemblage from the Uvel'ka Formation to substantiate the Low Calabrian (Low Eopleistocene) position of the epomymous chronostratigraphic unit in the regional stratigraphic chart. We suggest that Uvel'ka Formation of fluvial origin might be a chronological analogue of the Chumlyak and Sarykul' Formations of lacustrine-and-fluvial origin.

Based on the ovreview of the stratotypes and key localities within the time span considered in this paper, we should mention that the Early-Middle Pleistocene subseries boundary is clearly defined, and the Gelasian – Calabrian (Paleopleistocene – Eopleistocene) boundary is not yet defined in the Southern Trans-Urals due to the incompleteness and scarcity of the eroded sediments of that time related to the increased tectonic activity and the incision of the hydrographic network. The base of the Uvel'ka Formation is primarily eroded and might not serve as a key reference for the Paleopleistocene – Eopleistocene boundary in the region. However, the evolutionary levels of micromammals recovered in the holostratotype section of the Chumlyak Formation in Baturino quarry suggest that the deposits characterizing the Paleopleistocene – Eopleistocene transition might be recovered in the basal layers of the Chumlyak Formation. Further studies and new data are necessary to substantiate this claim and to verify the chronological position of the lower boundary of the Chumlyak Formation and its applicability as a key reference for the Paleopleistocene – Eopleistocene boundary in the Southern Trans-Urals.

5. Conclusions

Summarized data on micromammal assemblages ever recovered in the Southern Trans-Urals from the deposits characterizing three regional chronostratigraphic units of the Eopleistocene (Calabrian) reveal incongruences in relative chronological order of the officially accepted stratigraphic units – Uvel'ka, Chumlyak, and Sarykul' Horizons. The revealed incongruences appear to be a result of the difficulty to delineate chronostratigraphic units using the highly eroded and reworked sediments of fluvial origin. The sections with full sedimentation cycle from the fluvial to the lacustrine appear to be more informative. To date, the complete accumulative sedimentation cycles exposed in the walls of the Baturino coal quarry appear to be the most reliable sections to establish the chronostratigraphic units of the Calabrian stage of the Early Pleistocene in the Southern Trans-Urals.

The most problematic chronostratigraphic unit in the regional stratigraphic chart is the Uvel'ka Horizon (Early Calabrian) delineated by the occurrence of the specific mollusk assemblage comprised in the deposits of Uvel'ka Formation of fluvial origin. The revision of micromammals recovered in one of the parastratotypes of the Uvel'ka Formation (Outcrop 443-A, bed 5) does not confirm the chronological position of the Uvel'ka chronostratigraphic unit. The assemblage is chronologically mixed and comprises some pre- and post-Calabrian taxa along with the specific Calabrian arvicolines biochronologically synchronous to those found in the Chumlyak II and Sarykul' I faunas. Since the Uvel'ka Formation was originally delineated by the mollusk proxies, further analysis of mollusk assemblages would be necessary to solve the problem of chronological arrangement of the Uvel'ka unit. Tentative review of the ecological preferences of the mollusk species listed for Chumlyak and Uvel'ka units allows us to hypothesize that the differences between Chumlyak and Uvel'ka mollusk assemblages might be related to rather ecological than chronological factors.

Micromammal assemblages from the two clearly distinguishable sequential layers in the Holostratotype section of the Chumlyak Horizon (beds 9 and 8) represent two successive evolutionary stages of the micromammal fauna development. Using the evolutionary level of the key taxa found in the upper layer (bed 8, fauna Chumlyak II) as the upper chronological limit for accumulation of the lower layer (bed 9, fauna Chumlyak I), we conclude that the deposits of Chumlyak Formation should have been accumulated during the Late Paleopleistocene (Gelasian) – Early Eopleistocene (Calabrian), but not in the Late Eopleistocene as it is officially accepted.

Micromammal faunas recovered from the deposits of Sarykul' Formation characterize the period between the late Early Eopleistocene and the second half of the Late Eopleistocene. The deposits of Sarykul' Formation are crowned by a well-developed paleosol, which is normally magnetized and is presently referred to as the deposits of Miass Horizon of the Lower Neopleistocene. Paleosols of the Miass Horizon are represented by well correlated local lithostratigraphic units – Sarykul' and Miass paleosols that might be used as key references for the Eopleistocene – Early Neopleistocene boundary in the Southern Trans-Urals.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2019.01.033.

Appendix 1. Description of the arvicoline rodents from the Uvel'ka sands in the Outcrop 443-A (bed 5)

Order RODENTIA BOWDICH, 1821
Family CRICETIDAE FISCHER, 1817
Subfamily ARVICOLINAE GRAY, 1821

Genus Mimomys F. Major, 1902

In the assemblage of micromammals from the Uvel'ka sands, the genus *Mimomys* has been mentioned as *Mimomys* sp. (late form) and *M. intermedius* (Stefanovsky, 1997, 2006). The revised collection from the Outcrop 443-A, bed 5 housed at the Ural Federal University comprises 5 specimens of *Mimomys*, and a label suggesting that 8 specimens (presumably, *Mimomys*) were transferred elsewhere for taxonomic identification. Four of five specimens housed at the Ural Federal University are described below.

Mimomys ex gr. hintoni Fejfar, 1961

Material: 2 m2, 2 M1.
Biochronological interval: MNR 3 (Tesakov and Titov, 2013).

Description: Small teeth with roots and scarce cement in re-entrant angles of the crown. Measurements of m2 (hereinafter allмeasurements are given in mm): L = 1.69 and 1.53; W = 1.02 and 0.92; ASD = 2.30; HSD = 1.63 and 1.79; HSLD = 1.43 and 0.36. HH-index – 2.17 and 1.83 respectively. Posterior root is an acrorhyzal position on both m2. Both M1 have three roots. Measurements of M1: L = 2.15; W = 1.23; DS = 3.66; AS = 1.79; ASL = 0.61; L = 2.10; W = 1.22; dentine tracts reach the occlusal surface.

Genus Borsodia Janossy et van der Meulen, 1975

In the assemblage of micromammals from the Uvel'ka sands, the genus *Borsodia* is mentioned in Stefanovsky (1997) as *Villanyia* sp. in Stefanovsky (2006), this taxon is not mentioned in the same assemblage. The revised collection from the Outcrop 443-A, bed 5 housed at the Ural Federal University comprise 5 speciemens (2 M1, 1 M3, 1 m1, 1 m2), of which 4 belong to the identifiable stages of *Borsodia* dental evolution.

Borsodia praehungarica Schevtschenko, 1965

Material: 1 m1.
Biochronological interval: MNR 2 – MNR 3 (Tesakov and Titov, 2013).

Description. Medium-sized teeth with roots and with no cement in the re-entrant angles of the crown. A single m1 possess a *Mimomys*-ridge; its enamel band is poorly preserved, close to the negative type of enamel differentiation. Measurements of m1: L = 2.45; W = 0.92; ASD = 2.07; HSD = 2.40; HSLD = 2.10. HH-index – 3.19. M3 exhibits no enamel islet. Measurements of M3: L = 1.74; W = 1.00.

Borsodia sp. (an advanced form)

Material: 2 M1 (nearly identical teeth, probably of the same individual).

Biochronological interval: The remains are not possible to identify to species but the advanced morphology (high dentine tracts) allows us to hypothesize an advanced stage of *Borsodia* dental evolution sensu Tesakov (1993) that suggests the middle-to-late Gelasian age of the remains (MNR1 – MQR11 sensu Tesakov and Titov, 2013).

Description: Small specimens: L = 1.87 and 1.84; W = 1.07. Dentine tracts DS and ASL reach the occlusal surface, AS practically reaches the occlusal surface (in less than 1 mm of it). Enamel band thickness is rather uniform.

Genus Prolagurus Kormos, 1938

In the assemblage of micromammals from the Uvel'ka sands, the genus *Prolagurus* is mentioned as *Prolagurus praepannonicus* (Stefanovsky, 1997), and as *Lagurodon pannonicus* (*P. pannonicus-arankae*) (Stefanovsky, 2006). The revised collection from the Outcrop 443-A, bed 5 housed at the Ural Federal University comprise 25 speciemens of the genus *Prolagurus* (14 m1, 1m2, 6 M1, 4 M3). The teeth are small, with neither roots nor cement.

Prolagurus ternopolitanus Topachevsky, 1973

Material: 13 m1, a mandible with c m1 and m2, 4 M3.

Biochronological interval: MQR 10 – MQR 9 (Tesakov and Titov, 2013).

Description: Small teeth with simple anteroconid. Measurements of m1 (min–mean–max): L = 2.04–2.26–2.45; W = 0.72–0.88–0.97; B = 0.15–0.20-0.26. Index A/L varies from 38 to 47.9; on average – 43.8. Measurements of M3: L = 1.48 and 1.64; W = 0.77.

Prolagurus pannonicus Kormos, 1930

Material: 1 m1.

Biochronological interval: MQR 8 – MQR 7 (Tesakov and Titov, 2013).

Description: Small tooth with the anterior cap divided from the triangles in the base of the anteroconid, an advanced morphotype. Measurements: L = 2.24; W = 0.82; Index A/L −47.7.

Genus Lagurus Gloger, 1841

In the assemblage of micromammals from the Uvel'ka sands, the genus *Lagurus* has not been previously identified (Stefanovsky, 1997, 2006). The revised collection from the Outcrop 443-A, bed 5 housed at the Ural Federal University comprise at least 8 speciemens of *Lagurus* (6 m1, 2m2). The teeth are rather small but bigger than those of *Prolagurus*. No roots, no cement.

Lagurus lagurus Pallas, 1773

Material: 4 m1, 2 mandibles with m1 and m2.

Biochronological interval: MQR 1 – MQR2 (Vangengeim and Tesakov, 2008).

Description: The teeth are bigger than those of *Prolagurus*. Measurements of m1: L = 2.66–2.71–2.81; W = 1.02–1.07–1.07.

Lagurini gen. et sp. indet

The revised collection from the Outcrop 443-A, bed 5 housed at the Ural Federal University comprise 48 M (m2, m3, M1, M2) of Lagurini morphology, with no roots, without cement in reentrants. Most of the M1 and M2 specimens are small and possess no *Lagurus* fold in the lingual reentrants, or the fold is weakly expressed. Three specimens are slightly bigger and exhibit well-developed *Lagurus* fold in lingual reentrants. The group of small specimens might be tentatively identified as *Prolagurus* sp., and the bigger specimens might represent *Lagurus*. However, there are not enough criteria for exact taxonomic identification.

Genus Allophaiomys Kormos, 1932

In the assemblage of micromammals from the Uvel'ka sands, the genus *Allophaiomys* was identified as *Allophaiomys* sp. (Stefanovsky, 1997, 2006) and *A. pliocaenicus* (Stefanovsky, 2006). Revision of the collection from the Outcrop 443-A, bed 5 reveals no specimens that might be clearly identified as *A. pliocaenicus*. All specimens exhibit negative type of enamel differentiation and simple morphology, thus suggesting the presence of the less advanced form of *Allophaiomys*, which is closer to *A. deucalion* than to *A. pliocaenicus*. The teeth are of medium size, with no roots, with abundant cement in re-entrant angles of the crown.

Allophaiomys deucalion Kretzoi, 1969

Material: 2 m1, 1 M2, 1 M3.

Biochronological interval: MQR 11 – MQR 10 (Tesakov and Titov, 2013).

Description: Measurements of m1: L = 2.50 and 2.61; W = 1.02 and 1.12. Anteroconid is relatively short (A/L): 38.2 and 38.8. Indices: B/W−W' – 33.3; C/W−W' – 16.7; BTQ – 70.0 and 90.3 relatively. Measurements of M2: L = 1.50; W = 0.95; BTQ = 51.8. Measurements of M3: L = 1.76; W = 1.02; A/L = 40.6; BTQ = 57.9.

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