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Late Middle Pleistocene sequences in the lower Ob' and Irtysh (West Siberia) and new multi-proxy records of terrestrial environmental change

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ABSTRACT

The Middle Pleistocene environmental history of the north of West Siberia is very incomplete. Only a few poorly preserved paleoarchives are known so far in this huge part of Eurasia encompassing up to one million square kilometers. Here we present new data (micromammals, insects, plant macrofossils and luminescence dating) from the lower reaches of the Ob' and Irtysh Rivers. We reconstruct the circumstances of the formation of the fossil-bearing sites Bolshava Ob 440 km - Khashgort (BOB440) and Gornopravdinsk 2 (GP2) and compare the results with the current state of knowledge of the environmental change in this area. The combined evidence suggests that the fossil-bearing unit known as the Khashgort diagonal sands at BOB440 yields 1) a late Middle Pleistocene complex of fauna and flora of a cold terrestrial environment with tundra-like vegetation, 2) a Middle Pleistocene flora of interglacial environment with temperate vegetation, and 3) reworked fossils form the Late Cretaceous - Oligocene. Geochronometric data suggest that the Khashgort sand unit at BOB440 might have been formed during the Middle/Late Pleistocene transition. However, because of a high variation in results obtained on repeated samples from the same strata, some uncertainty of the luminescence dating remains, which requires further verification. The fossil-bearing fluvial sequence at GP2 represents the lower part of the Chembakchino Formation and encompasses the lower part of the Tobolian Horizon (correlated with Holsteinian). The micromammal complex comprises Dicrostonyx simplicior (intermediate morphological stage S2 sensu Smirnov et al., 1997), Lasiopodomys gregalis, Microtus nivaloides lidiae and other taxa, which are characteristic of the early evolutionary stage of late Middle Pleistocene faunas in the north of West Siberia. The paleoecological analysis of plant and animal remains at GP2 suggests an environmental change from cold, tundra-like landscapes at the Shaitanian/Tobolian transition (MIS 12 - MIS 11) to non-analogous open patchy landscapes with highly productive moss and herbaceous vegetation during the early Tobolian time.

1. Introduction

The large-scale environmental fluctuations during the late Middle Pleistocene (MIS 11–6, the Middle Neopleistocene of the Russian chronostratigraphic chart (e.g., Volkova, 2009)) have attracted much attention from researchers over the last decades due to the considerable number of unsolved questions that hinder interregional correlations of paleoclimatic records. The disputable questions include the number of climatic events (Schreve, 1998, 2001), the extents of glaciations (Astakhov, 2011, 2013; Ehlers et al., 2013), sea level changes (Barlow et al.,

2017), differentiation of particular interglacials in the continental record (Roe et al., 2009), and correlation of climatic events with the stages of the marine oxygen isotope record (Geyh and Müller, 2005; Nitychhoruk et al., 2006). In a wider perspective, this period is important to understand the role of environmental changes in hominin dispersal and modern human evolutionary divergence (Hublin et al., 2017; Schlebusch et al., 2017; Lauer and Weiss, 2018). Moreover, particular intervals of the late Middle Pleistocene (e.g., MIS 11) may potentially serve as models to understand the future of the current Holocene interglacial and the impact of abrupt climate changes on ecological and

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Received 20 April 2023; Received in revised form 16 July 2023; Accepted 27 July 2023 Available online 4 August 2023 1040-6182/© 2023 Elsevier Ltd and INQUA. All rights reserved. geomorphological systems without human intervention (Candy et al., 2014).

The late Middle Pleistocene was characterized by the sea level increases up to 13m higher than that of today during warm climatic phases, e.g. MIS 11 (Dutton et al., 2015; Robinson et al., 2017) and by extensive but uneven spread of continental ice sheets during cool phases (Ehlers et al., 2013). Some of the climatic events during this period have been detectable on a global scale (e.g., sea level rise in MIS 11) while the effects of others appear to vary and are yet to be characterized at the level of particular regions.

The consequences of the large-scale environmental fluctuations that affected the north of West Siberia during the Quaternary have attracted researchers' interests for more than two centuries starting from the works of Pallas (1776). Multidisciplinary investigations and first reconstructions of the past environments based on geological, paleogeographical, paleobotanical and paleozoological records began in the first half of the XXth century. Those studies were primarily focused on the valleys of the major rivers Ob' and Irtysh and resulted in V.I. Gromov's elaboration of the first stratigraphic scheme of the West Siberian Quaternary in 1940 (Volkova, 1966). Later, the state geological mapping in the north of West Siberia included this region in the unified stratigraphic scheme of the USSR. By that time, the extents and timing of glaciations and marine transgressions in the north of West Siberia had become the important subjects of controversy (Volkova, 1966; Arkhipov, 1971; Kaplyanskaya and Tarnogradsky, 1974). However, many issues are still unresolved and discussions on the number, extent and timing of glaciations are ongoing (e.g., Volkova, 2009).

The modern chronostratigraphic scheme of the late Middle Pleistocene of the north of West Siberia includes four units (Horizons): Tobolian and Shirtinian interglacials, and Samarovian and Tazovian glacial stages (State geological ..., 2009). The equivalence of the Samarovian glacial stage with MIS 8 and the lack of knowledge of the climatic events corresponding to MIS 10 and MIS 9 in the north of West Siberia have been emphasized (State geological ..., 2009; Volkova, 2009). The correlation of the Tobolian Horizon with MIS 11 is supported by thermoluminescence (390 \pm 80 ka) and electron paramagnetic resonance dating (326.9 ka). The Shaitanian cold stage and the Last Interglacial mark the boundaries of the late Middle Pleistocene in the North of West Siberia but the sequences are primarily incomplete and interrupted owing to the complicated history of this lowland territory with multiple phases of river channels cutting and infilling.

Lacustrine and fluvial deposits of the late Middle Pleistocene in the north of West Siberia vield vertebrate and invertebrate remains, plant macro- and microfossils. Climatic fluctuations have been established based on paleobotanical data (Arkhipov and Volkova, 1994; Volkova, 2009). Several publications describe micromammal assemblages (Volkova, 1966; Borodin and Smirnov, 1984; Smirnov et al., 1986; Krukover, 1992; Borodin, 1996; Kosintsev et al., 2004). Key rodent taxa indicative of the late Middle Pleistocene age are known in some micromammal-bearing localities (Smirnov et al., 1986; Krukover, 1992). However, it is generally accepted that the assemblages are often mixed and characterize wider intervals within the Pleistocene (State geological ..., 2009). To date, correlation of micromammal faunas with particular chronostratigraphic units remain uncertain, not only because of a high degree of reworking. In some cases, there is also a problem of taxonomic misinterpretation (e.g., mentioned by Markova and Borodin (2022)).

This study aims to present new data on the history of the late Middle Pleistocene biota obtained in the north of West Siberia with particular focus on small mammals, plant macrofossils and coleopterans. We also revise the micromammal faunas previously described for the late Middle Pleistocene of the north of West Siberia and consider them in the context of environmental change.

2. Regional setting

The West Siberian Plain is located in the central part of Eurasia between the Ural Mountains in the west and the Yenisei River in the east and covers an area of about 2.6 million square kilometers. The northern geomorphological province includes the Siberian Uvaly, a low hilly region stretching across the plain from west to east, and the part of the plain to the north. The modern relief of the northern province was formed by repeated glaciations and marine transgressions, although the preservation of glacial features is rather poor (Astakhov, 2013). The glacial deposits extend as far south as 60° N and the area of the northern Ob-Irtysh interfluve is usually considered as the periglacial zone and a part of the north of West Siberia (Smirnov et al., 1986).

Repeated glaciations and marine transgressions associated with periodic changes in the West Siberian river systems have resulted in poor preservation of Quaternary sequences. Regional variations in relative sea-level change driven by glacial isostatic adjustment suggested for the Eurasian Arctic might result in the considerably higher sea-level rises at the mouth of the Ob' River in West Siberia compared to the East Siberian coastline (Whitehouse et al., 2007). The surfaces of marine, glacial, and lacustrine-and-fluvial accumulation are widely complicated by cryogenic processes (Krivtsov and Vodorezov, 2016).

The Tobolian Horizon (= Holsteinian) represents the base of the late Middle Pleistocene in the north of West Siberia. It includes several regionally recognized units. The Tobol interglacial alluvium (Tobol Fm) is widely distributed in the southern province of the West Siberian Plain and is replaced to the north by the alluvial layers of the Chembakchino Formation in the lower reaches of the Irtysh River. Cross-bedded ('diagonal') sands of fluvial origin represent the deposits of this age. Similar diagonal sands are also outcropped further north, on the right bank of the Ob River. However, their equivalence with the Tobolian Horizon is not yet clearly established. Paleontological data from the locality Khashgort suggest the presence of the late Middle Pleistocene complex of small mammals (Smirnov et al., 1986). However, there is also an opinion that the diagonal sands with micromammals outcropped near Khashgort are analogous to the sand and clay sediments of the Khashgort Formation recognized using the data from the borehole 4 near Khashgort (Kontorovich and Surkov, 2000). Coastal marine depositional environments have been suggested for the Khashgort sand and clay sediments based on the presence of boreal foraminifera (Kontorovich and Surkov, 2000) and the Late Pleistocene age (Kazantsevian Horizon, MIS 5) has been suggested despite the TL date of 153 ka (Arkhipov et al., 1977). The Kazantsevian age of this 'marine' unit has been called into question by Astakhov and Nazarov who suggested the Middle Pleistocene age (Astakhov and Nazarov, 2010).

The Samarovo ice advance (MIS 8) is thought to be the most southerly-reaching glaciation of the late Middle Pleistocene in West Siberia (Ehlers et al., 2013). It was responsible for the formation of an ice-dammed lake, in which the glacigenic sediments were deposited (Samarovo glaciolacustrine strata). Further north (closer to the Ob-Irtysh confluence), the glaciolacustrine strata are facially replaced by the Samarovo till that overlies the deposits of Chembakchino Formation.

The Samarovian (MIS 8), Shirtinian (MIS 7) and Tazovian (MIS 6) Horizons are often considered as one chronostratigraphic unit – the Bakhtinian Suprahorizon. In the Ob-Irtysh Interfluve, this suprahorizon is represented by the Suzgun sequence. When complete, it contains up to three paleosols and the reworked sediments of the Samarovian age in the base. However, the sequence is often incomplete and appears variable in different sections.

3. Materials and methods

3.1. Field investigations

During 2016–2022 field campaigns carried out by the Phylogenetics

& Biocronology Lab, the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences, two localities containing fossil faunas and floras have been investigated in the north of West Siberia (Fig. 1, 1–2).

BOB440, or Bolshaya Ob 440 km – Khashgort (N $65^{\circ}24'25.4''$ E $65^{\circ}38'28.2''$) is the section studied in 2016–2022 at the mouth of a ravine on the right bank of the Ob River 8 km upstream of the settlement Khashgort, Yamalo-Nenets Autonomous Okrug. In 1981, this exposure named Khashgort (= Khashgort 1981) yielded arvicolines of Middle Pleistocene age (Borodin and Smirnov, 1984; Smirnov et al., 1986).

GP2, or Gornopravdinsk 2 (N $60^{\circ}02'17.1''$ E $69^{\circ}56'54.7''$) is a new locality on the right bank of the Irtysh River, 1.7 km upstream of the Kaygarka River mouth and 2.3 km upstream of the settlement Gornopravdinsk, Khanty-Mansi Autonomous Okrug. The section GP2 is on the high steep bank of the Irtysh (Gornofilinsky Yar), 46.4 m above the river and 72.6 m above sea level.

Geological descriptions were carried out on vertical sections of the outcrops using the Global Navigation Satellite System receivers EFT M1 Plus and EFT M3 Plus for geospatial data collection.

Samples for OSL and IRSL were taken from the layers of sand into opaque plastic or metallic tubes 5 cm in diameter and minimum 50 cm long (three tubes for each sample), covered and sealed immediately after sampling.

The excavated sediments were water-screened in the river for microvertebrates with 1 mm mesh size using river water, air-dried and transported to the laboratory for extraction of fossils. Bulk sediment samples (not water-screened) were also taken for carpological and paleoentomological analyses.

3.2. Geological sections

Section BOB440 (2016–2022) is divided into two parts, of which the lower one includes the cross-bedded unit known as the Khashgort diagonal sands, the stratigraphic position of which has been regarded controversial (see Section 2 for details). In this study, we focus on the lower part of the section, which is divided into 11 layers. Lithological



Fig. 1. Geographic situation of new fossil-bearing sections described in the study (I), localities of the late Middle Pleistocene micromammal faunas in the north of West Siberia considered in this study (II) and an example of the outcropped diagonal sands at BOB440 (III). 1 – BOB440, 2 – GP2 (new sections); 3 – Chembakchino, 4 – Bobrovka, 5 – Gornaya Subbota, 6 – Demyanskoe, 7 – Khashgort 1981 (Smirnov et al., 1986; Krukover, 1992).

properties of the strata and places of sampling are described in Appendix A. The position of paleontological and geochronometric samples in the section BOB440 is shown on Fig. 2.

Section GP2 (2019–2020) is divided into 16 layers, some of which are further divided into sublayers to characterize the exact places of sampling (Appendix A, Fig. 3). The fossil-bearing strata (Layers 11–16) correspond to the lower part of Tobolian (Layers 11–13), Shaitanian (Layers 14–15), and, tentatively, Talagaikian Horizon (Layer 16) of the West Siberian stratigraphic chart.

3.3. Sample codes and abbreviations

Paleontological sample codes indicate layers and particular lithofacial units from which the sediments were taken. In GP2, sample codes are the same for vertebrates, insects and plant macrofossils. In BOB440, mv indicates the samples water-screened for microvertebrates in the field; paleocarpological and paleoentomological samples taken without water-screening in the field are marked as C or carp (the bulk of the sediments), and p (peat fragments).

Abbreviations: Abs. - adsolute height, BOB440 - Bolshava Ob 440 km - Khashgort, C (c, carp) - carpological and/or coleopterological samples at BOB440, EN – Early Neopleistocene, Fm – formation, GP2 – Gornopravdinsk 2, H - Holocene, IRSL - samples collected for infrared stimulated luminescence dating on feldspar, ka - one thousand years, LN - Late Neopleistocene, LP - Late Pleistocene, mv - samples waterscreened for microvertebrates, m1, m2, m3 - lower molars, M1, M2, M3 – upper molars, M3-P3 – Late Cretaceous - Oligocene, N – Neogene, NL - laboratoty code for dates obtained at the Nordic Laboratory for Luminescence Dating, Department of Geoscience, Aarhus University, Denmark, N1 - Miocene, N2 - Pliocene, OSL - samples collected for optically stimulated luminescence dating on quartz, p - allochthonous peat samples, P - Paleogene, P3 - Oligocene, Q - Quaternary, Q1 - Early Pleistocene, Q2 - Middle Pleistocene, Q3 - Late Pleistocene. RGI - laboratory code for dates obtained at the Laboratory of optically stimulated luminescence in the Russian Geological Research Institute (VSEGEI).

3.4. Analysis of vertebrates

Among vertebrates, a particular emphasis is made on small mammals and arvicoline rodents as the most abundant and biochronologically informative group in the Quaternary fossil record of northern Eurasia. Vertebrates other than mammals are identified at the class level.

Taxonomic identification of small mammals relies on the comparisons with reference collections; arvicoline rodents are identified following the previously described criteria (Smirnov et al., 1997; Borodin, 2009; Borodin and Markova, 2015). When establishing evolutionary levels of consecutive chronospecies in Dicrostonyx, both traditional descriptive approaches (Fejfar, 1966; Zazhigin, 2003; Agadjanian, 2009) and measurements of M1 and M2 (Smirnov et al., 1997) are used. The latter approach allows distinguishing evolutionary levels within D. simplicior Feifar (1966) based on the index b/a (Smirnov et al., 1997 and figure 10 therein), where b is the width of the additional element in place of T5 and a is the width of T3 (here and thereafter terminology of dental elements of arvicoline dentition follows Van der Meulen, 1973). Morphological stages within D. simplicior (sensu Smirnov et al., 1997) are ranged from the most archaic S1 to the most advanced S4 (S1: b/a≤0.59; S2: b/a = 0.6–0.69; S3: b/a = 0.7–0.79; S4: b/a≥0.8). Species identification of Microtus sensu lato with 'arvaloid molars' relies on the recently described morphometric approach (Markova and Borodin, 2022).

Evolutionary levels of micromammal assemblages are correlated with the biochronological MQR zones of Eastern Europe and the Pontocaspian region (Vangengeim and Tesakov, 2008; Krijgsman et al., 2019). In order to summarize faunal biostratigraphy based on small mammals, published data on late Middle Pleistocene micromammals are included for comparison (Smirnov et al., 1986; Krukover, 1992;



Fig. 2. Bolshaya Ob 440 km – Khashgort: general view in 1981 and 2018, western exposure (I), geological section and position of samples (II), selected places of sampling in the section, northerm exposure (III, V), and IV – a view on the subunits of the Layer 21 indicating sampling levels, western exposure. A – clay, B – dense clay, C – clay with sand, D – gravel of clay ('clayey pellets'), E – 'clayey pellets' with plant debris, F – loess-like loam, G – scattered plant debris, H – fragments of allochthonous peat, I – coarse woody debris, J – gravel, K – position of interlayers water-screened for microvertebrates, L – samples for carpology and paleoentomology, M – samples for luminescence dating.

Borodin, 1996; Kosintsev et al., 2004). Published species lists are updated according to the criteria used in this study (synonymy of scientific names is mentioned wherever discussed).

Ecological groups of arvicolines are based on previously developed classifications. To infer arvicoline habitat humidity we calculate frequencies of the species that prefer 1) xeric, 2) mesic to xeric, 3) mesic, 4) mesic to wet, and 5) wet habitats (Markova et al., 2022). To reconstruct predominating vegetation in biotopes we calculate frequencies of the species confined to the habitat types: herb - herbaceous vegetation preferred by *Microtus* sensu lato, moss – moss ground cover preferred by Lemmini, shrub – shrublands preferred by *Dicrostonyx*, tree - woodlands or forests preferred by *Clethrionomys* (Markova et al., 2018). Number of m1 is used for calculating frequencies of ecological groups. If m1 is lacking and a taxon is identified based on other molars, the number of m1 in that sample is taken equal to 1. Comparisons of frequencies of m1 morphotypes, ecological groups, and arvicoline habitat types rely on the criteria r and I (Zhivotovskii, 1979), where r is the index of similarity and I is the criterion to determine statistical significance.

3.5. Analysis of insects and other invertebrates

Six samples from the section BOB440 and six samples from GP2 were taken in the field and processed according to the standard methods adopted for paleoentomological analysis (Kiselev, 1987). Sediments were air-dried in laboratory and then separated with a series of sieves with mesh sizes from 0.25 to 2 mm. Each portion was inspected using binocular microscope MBS-10. Insect remains were selected, washed and set into storage boxes. Taxonomic identification relied on comparisons with reference collections of modern and fossil coleopterans. Ecological preferences and modern distribution of species are taken from literature (Kryzhanovskij et al., 1995; Silfverberg, 2004; Sher and Kuzmina, 2007).

In two water-screened vertebrate samples (21/mv1 and 21/mv2+21mv3), insect remains were also found and included in the analysis. In sample 21/mv2+21mv3, minor admixture of modern invertebrates was revealed including few beetles with appendages, well-preserved elytra with no signs of deformation and one shell of a





Fig. 3. Gornopravdinsk 2 (GP2): general view (I), geological section and position of samples (II), selected places of sampling (III). 1-16 – layers; a-m – interlayers within particular layers;/- sample codes (layer number/sample number). Lihology: A – clay, B – dense clay, C – clay with sand, D – gravel of clay ('clayey pellets'), E – 'clayey pellets' with plant debris, F – loess-like loam, G – interbedding of small-grained sands, banded clays and loams, H – sand, I – diagonal (cross-bedded) sand, J – sand with 'clayey pellets', K – sand with plant debris, L – sand with cryogenic deformations, M – layered sand, N – soil, O – loam, P – dusty loam, Q – loam with sand, R – sandy loam, S – alternation of sand, clay and 'clayey pellets'.

freshwater mollusk with soft tissues. Coleopteran species are typical for aquatic and riparian habitats in the study area: *Rhanthus* sp., *Amara similata, Bembidion litorale, Simplocaria metallica, Cardiophorus* sp., *Plagiodera versicolora, Otiorhynchus ovatus.* The admixture apparently came from the river water used for water-screening and was easily distinguished from fossil remains by its good preservation. The admixed taxa were excluded from further analysis.

3.6. Analysis of plant macrofossils

Five samples from BOB440 and five samples from GP2 were taken in the field and then processed in laboratory according to the standard methods adopted for paleocarpological analysis (Nikitin, 1969). The samples were washed on sieves with a mesh size of 0.25 mm and sifted into fractions through a column of soil sieves (2.0, 1.0, 0.5 and 0.25 mm). Each portion was analyzed using Zeiss Stemi 2000-C stereomicroscope. Moreover, allochthonous peat samples p1-p3 taken in the field at the section BOB440 were analyzed for the presence of identifiable plant macrofossils. Taxonomic identification of plants was based on the reference collection of the IPAE UB RAS museum (Ekaterinburg) and identification atlases (Katz et al., 1965; Dorofeev, 1986; Nikitin, 2006; Velichkevich and Zastawniak, 2006, 2008). Modern ranges and ecological characteristics of plants are taken from publications (e.g., Flora of Siberia, 1990; Lisitsyna and Papchenkov, 2000) and electronic resources (Plantarium..., 2007-2023 (https://www.plantarium.ru)).

3.7. Geochronometric data

Luminescence dating using both OSL and IRSL protocols was performed at the Nordic Laboratory for Luminescence Dating, Department of Geoscience, Aarhus University, Denmark (laboratory code NL) and at the Laboratory of optically stimulated luminescence in the Russian Geological Research Institute VSEGEI (laboratory code RGI). In both laboratories, all measurements were made on multi-grain aliquots using Risø TL/OSL readers. Radionuclide concentrations were measured using high-resolution gamma spectrometry (Murray et al., 1987). Details of the sample preparation, quartz and feldspar extraction, protocols and luminescence characteristics of quartz and feldspar relavant to the ages obtained for NL samples are shown in Appendix B. Geochronological study is carried out with elements of blind dating, without mentioning the sampling depths and samples positions in the chart.

4. Results

4.1. Vertebrate assemblages

In BOB440, numerous bones, teeth and fossilized feces (coprolites) of micromammals are found in water-screened samples 21/mv1 (23–30%) and 21/mv2 (70–77% of all identified micromammal teeth); single unidentifiable bones are found in 20/mv and few bones and single molars of *Lemmus* – in 21/mv3. Because no differences in taxonomic composition were found between 21/mv1 and 21/mv2 (r = 0.995–0.999, I = 0.1–1.4, p > 0.05), the data from different sampling levels within Layer 21 were pooled (Table 1). Micromammal remains consist mostly of isolated elements, and few fragments of skulls and mandibles with complete tooth rows. Bones and teeth often have reddish-brown or rarely bluish-green stains on the surface and appear sensitive to drying (become fragile while stored under laboratory conditions).

Few damaged teeth and fragments of arvicoline bones (identical in color and surface condition to those found in the water-screened samples) are also extracted from the fragments of the allochthonous peat (Section 4.3.1).

Micromammals are represented exclusively by arvicolines, among which *Lemmus* and *Dicrostonyx* predominate. Among non-mammalian vertebrates, there are freshwater fish remains (Osteichthyes) and a single damaged tooth of a small shark *Carcharias* sp. redeposited from the Late Cretaceous-Oligocene sediments (identified by T.P. Malyshkina).

In GP2, vertebrate remains are found in Layers 11–16 of the lower part of the section (Table 1). Most of the vertebrate material comes from Layers 12f – 13m, and the highest concentrations of bones and teeth are found at the levels marked by the interlayers of rounded 'clayey pellets'. The composition of micromammal taxa is principally the same throughout the vertebrate-bearing sequence: Siberian lemmings and grey voles of the *Microtus* s.l. group are the most frequent and predominate in all samples (Table 1). Ochotonidae and Soricidae are also found in several samples. Among other vertebrates, all micromammal bearing samples comprise bony fishes (Osteichthyes), among which freshwater taxa are recognized (preliminary identification by A.E. Nekrasov).

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Table 1

Vertebrates recorded in localities Gornopravdinsk 2 (GP2) and Bolshaya Ob 440 km – Khashgort (BOB440); total number of teeth or number of m1s (where indicated).

Taxon	on GP2 (layer/sample; years)						BOB4040 (layer/sample; years)						
	16/7 14/6 13m/1 13m/9 13l/1 13i/2 13d/3		13d/3,8	12f/4 11/5		21/mv1+21/mv2							
	2019	2019	2020	2020	2019	2019-2020	2019-2020	2019	2019	2016	2017	2018	2020
Class Osteichthyes	+	+	+	+	+	+	+	+	+	+	+	+	+
Class Chondrichthyes													
Carcharias sp.	-	-	-	-	-	-	-	-	-	-	1	-	-
Class Mammalia													
Order Carnivora													
Canidae gen. sp. indet.	-	-	-	-	_	-	-	-	-	-	-	-	1
Order Eulipotyphla													
Soricidae gen. sp. indet.	-	-	2	1	-	-	11	-	-	-	-	-	-
Order Lagomorpha													
Ochotonidae gen. sp. indet.	-	-	3	2	4	1	47	-	-	-	-	-	-
Order Rodentia													
Dicrostonyx simplicior, S2 stage	-	-	-	-	-	-	44	-	-	-	-	-	-
Dicrostonyx simplicior, S3 stage	-	-	-	-	-	-	-	-	-	71	56	8	11
Dicrostonyx sp.	-	-	-	1	-	1	-	3	-	-	-	_	-
Lemmus cf. sibiricus	1	1	39	22	28	20	355	28	1	97	125	17	44
Lagurus sp.	-	-	-	-	-	-	1	-	-	-	-	_	-
Clethrionomys cf. glareolus	-	-	3	-	_	1	2	-	-	-	-	-	-
Generic group Microtus s.l., except m1	1	-	46	20	17	12	315	25	-	9	7	-	2
Lasiopodomys gregalis, m1	-	-	12	6	3	3	30	4	-	-	1	-	1
Alexandromys oeconomus, m1	-	1	7	3	3	4	30	2	-	1	-	-	1
Alexandromys sp. (malei morphs), m1	-	-	1	1	1	-	2	1	-	-	-	-	-
Alexandromys aut Microtus cf. malei	-	-	-	_	_	-	2	-	_	-	-	_	_
Microtus nivaloides lidiae, m1	_	_	1	-	1	1	33	2	_	_	2	_	_
Total, mammals	2	2	114	56	57	43	872	65	1	178	191	25	60

Table 2

Plant taxa recorded in the fragments of allochthonous	s peat at BOB440, Layer 21.
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Chrono-	Ecological groups	Taxon	Samples				
group based on last occurrence	(for vascular plants)		21/p1	21/ p2	21/p3		
Н	-	Bryales	++		++		
Н	-	Sphagnum sp.	-	+	-		
Н	hygromesophyte	Salix spp.	leaves	-	leaves		
		(dwarf forms)	(35) &		(30) &		
			bolls		bolls		
			(9)		(7)		
Н	cryo-xerophyte	Dryas sp.	leaves	-	leaves		
			(31)		(1)		
Н	hydrophyte	Andromeda	leaves	-	leaves		
		polifolia	(1)		(2)		
Н	hygrophyte	Carex spp.	20	-	-		
Н	hydrophyte	Batrachium	1	-	-		
		sp.					
Н	mesophyte	Bistorta	_	-	1		
		vivipara					
Н	not identified	Rumex sp.	1	-	-		
Q2-Q3,	hydrophyte	Azolla	1	-	-		
reworked		interglacialica					
Sample volume, ml			200	15	35		

4.1.1. Environmental interpretation of micromammal assemblages

The assemblage of micromammals from BOB440 reveals low taxonomic diversity and comprises only arvicoline rodents (Table 1). The combination of taxa suggests the conditions of open landscapes resembling modern tundra with well-developed moss cover (judging from the predomination of *Lemmus*), with the presence of shrubs (co-domination of *Dicrostonyx*) and minor role of herbaceous vegetation (rare grey voles of three species – *A. oeconomus, L. gregalis* and the extinct *M. n. lidiae*). The proportion of species associated with relatively wet habitats (65%) is higher than the proportion of those associated with more xeric environments (35%).

In all samples taken in GP2, Lemmus sibiricus predominates or co-

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dominates with other taxa and second and third most abundant species are *A. oeconomus* and *L. gregalis* suggesting the existence of open landscapes. Judging from the presence of rare *Clethrionomys* cf. *glareolus* (up to 3% per sample), arboreal or shrub vegetation might have existed with minor frequency. Predominance of *Lemmus* starting from Layer 131 suggests that the vegetation cover contained a considerable moss component. The variety of *Microtus* sensu lato suggests the existence of highly productive landscapes with herbaceous vegetation.

The ecological structure of samples varies from Layer 13m to Layer 13d. The landscapes reconstructed for the assemblage 13m might be somewhat similar to modern southern tundra or forest-tundra, although Dicrostonyx was quite rare and Clethrionomys voles were present suggesting similarity with forest tundra rather than with tundra. The assemblage 13d indicates the increased role of moss cover in the ecosystem (judging from the increased frequency of *Lemmus sibiricus*), well-developed herbaceous vegetation (based on the abundance of grey voles), and the presence of shrubs (based on the presence of Dicrostonyx). A single find of Lagurus sp. together with Dicrostonyx and Lemmus suggests that landscapes reconstructed for the assemblage 13d were non-analogous, patchy and might represent a gradient of conditions from wetlands in the depressions to highly productive wet meadows on the slopes and more xeric conditions on the uplands (plakors). The difference between the assemblages 13m and 13d is statistically significant (r = 0.95, I = 12.5, p = 0.014). However, it is not possible to judge from micromammals alone if this reflects a climate change or an ecological succession. The hypothesis of successive ecological changes is indirectly confirmed by the signs of burning (charcoal, burned twigs or plant debris) in the sequence of layers between 13m and 13d. Succession stages of tundra plant communities following wildfire disturbance in modern ecosystems suggest the increased above-ground biomass and shrub cover in repeat burn sites over a 30-year period (e.g., Breen et al., 2015) and the peak of moss abundance 30-70 years post-fire (Turetsky et al., 2010). Considering that the rates of fluvial sediment accumulation might be very high - with up to 8 cm/year as established in modern ecosystems (Sedláček et al., 2016) or >1 cm/year for radiocarbon-dated fluvial sediments with the highest rates of accumulation (Ferring, 1986), we can assume that the 7-m high sequence between layers 13m and 13d might have been formed within a minimum of 88-700 years and the

hypothesis of fire-induced ecological successions appears to be plausible. However, the sequence might be incomplete and the assemblages 13m and 13d might be separated by considerably longer time intervals.

4.1.2. Evolutionary level of micromammals

The lower age limit for both localities is implied from the presence of *Lasiopodomys gregalis*, the earliest appearance of which corresponds with biozones MQR 4–5 (Vangengeim and Tesakov, 2008) correlated with MIS 13 – MIS 14. In all m1 molars, triangles T4-T5 are completely separated. Morphotypes of m1 comprise gregaloid, microtid and intermediate variants (morphotypes 1–4 sensu Borodin, 2009; the most advanced morphotype 5 is not present).

In GP2, the microtid m1 morphotype 4 of *L. gregalis* is present with minor frequency in both lower and upper parts of the cross-bedded unit 13, including sublayers 13m (Fig. 4, I, 11) and 13d (Fig. 4, II, 17–18). The differences in m1 morphotypes of *L. gregalis* between sublayers 13m and 13d are not statistically significant (r = 0.984, I = 1.28, p = 0.865).

The upper age limit can be inferred from the evolutionary level of collared lemmings, genus Dicrostonyx. In GP2, Dicrostonyx is a relatively infrequent taxon (0–5% per layer). The sample from layer 13d is large enough for species identification. Based on molar morphology, Dicrostonyx from GP2 13d is similar to D. simplicior Fejfar (1966) described from the deposits of the Upper Biharian in Central Europe and correlated with the Mindel glaciation (Fejfar, 1966). Only simplicior morphotypes of M1 and M2 are found in GP2 and average values of the index b/a (Smirnov et al., 1997) suggest the intermediate S2 stage for D. simplicior in GP2 (b/a_{M1} = 0.68 \pm 0.023; b/a_{M2} = 0.67 \pm 0.027). On m2, there is always an additional element on the lingual side; additional element on the buccal side might be either absent or present. Morphotypes of m3 are mostly simple (Fig. 5I). Six of nine m3 have no additional elements, two m3 have small enamel elements on the lingual side that do not form a true additional prism (m3 rank 0.25 sensu Markova and Smirnov, 2018), and one m3 is broken.

In BOB440, *Dicrostonyx* is the second most frequent taxon after *Lemmus sibiricus* that constitutes about 39–40% in all samples taken in 2016–2020 (Table 1). Only *simplicior* morphotypes of M1 and M2 are

found, and average values of the index b/a is higher than in GP2 (b/a_{M1} = 0.70 \pm 0.018; a/b_{M2} = 0.75 \pm 0.027) suggesting the more advanced S3 stage of D. simplicior (sensu Smirnov et al., 1997). All m2 have additional elements on both lingual and buccal sides. Morphotypes of m3 are extremely variable and mostly show the signs of additional anterior elements on lingual or lingual and buccal sides of the tooth (Fig. 5.II). In one m3 found in 2020, there is also an additional folding of enamel at the posterior lobe (Fig. 5.II, 32) representing a previously described character, called "lpsd" (sensu Markova and Smirnov, 2018). Thus, D. simplicior in BOB440 is slightly more advanced than D. simplicior in GP2.

In Central and Eastern Europe, D. simplicior is a typical chronospecies found in sites of MIS 16 to MIS 6 (Maul and Markova, 2007). Comparisons with samples from the East European Plain (Agadjanian, 2009) show that D. simplicior from GP2 is more advanced than D. s. okaensis Alexandrova, 1982 from the clays correlated with the Oka glaciation underlying the Likhvinian paleosols in Mikhailovka 2 (Agadjanian, 2009). Both GP2 and BOB440 samples of collared lemmings are similar to D. simplicior from cross-bedded fluvial sands underlying the tills in Strigovo and Volzhino, first half of the late Middle Pleistocene (Agadjanian, 2009). Compared to D. cf. henseli (=D. cf. simplicior sensu Agadjanian, 2009 or D. heseli sensu Zazhigin, 2003) from Pavlovka (lacustrine and fluvial sediments correlated with the Moscowian glaciation (Agadjanian, 2009), or MIS 6), collared lemmings from GP2 and BOB440 are significantly less advanced. Thus, the evolutionary level of collared lemmings allows suggesting the late Middle Pleistocene age for both GP2 and BOB440 assemblages within the period from MIS 11 to MIS 7 (or probably to MIS 8, depending on the accepted age of the tills in Strigovo and Volzhino). However, in West Siberia, collared lemmings of the evolutionary level comparable to those in Pavlovka are found in the deposits of the upper part of Chembakchino Formation under the Samarovo moraine-like loams (Smirnov et al., 1986; Krukover, 1992). Thus, the transition from D. simplicior to D. henseli is not yet clear and the uppermost possible limit for both GP2 and BOB440 assemblages should be regarded as MIS6 (based on the last known occurrence of this chronospecies).



Fig. 4. Lasiopodomys gregalis and Lagurus sp. from Gornopravdinsk 2. I – Layers 13m and 13i: L. gregalis, samples 13m/1 (1–11), 13m/9 (15–20), 13i/2 (12–14). II – Layer 13d: L. gregalis, sample 13d (1–18); Lagurus sp., sample 13d (19). Asterisk indicates left molars, mirrored. Scale bars 3 mm.



Fig. 5. Biochronologically informative taxon *D. simplicior* in the samples from GP2 13d, sampling years 2019–2020 (I) and BOB440, sampling years 2016–2020 (II). Asterisk indicates left molars, mirrored. Scale bar 3 mm.

Among other biochronologically informative taxa, there are genera *Alexandromys* and *Microtus*. The former is represented by typical Middle-Pleistocene *A. oeconomus* with a high frequency of morphotypes *gud* and by *Alexandromys* sp. showing morphotypes *malei* and *arvaloid in the malei group* (sensu Chaline, 1972). It is highly probable that the latter represents the most advanced morphotypes of *A. oeconomus* in this assemblage. However, those advanced morphotypes (Figs. 6, 12–14) fall well outside the range of variability of modern *A. oeconomus* and their

identification as a possible different taxon using open nomenclature might be reasonable.

In both localities, *Microtus* is represented by *M. nivaloides lidiae*. The variability of this taxon in GP2 has been recently described (Markova et al., 2022). In BOB440, this species is represented by one complete (Fig. 7) and one damaged m1 (not shown) found in 2017 in 21/mv2 and 21mv/1 samples, respectively. Morphometric characteristics of the complete molar fall within the range of the variability of *M. n. lidiae* from



Fig. 6. Selected m1 of Alexandromys oeconomus (1–11) and Alexandromys sp. with morphotypes malei (12–13) and arvaloid in malei group (14). 1–12, 14 – GP2 13d, 12–13 – GP2 13m; asterisks indicate mirrored molars.



Fig. 7. *Microtus nivaloides lidiae* in the localities GP2 and BOB440.1 - BOB440, 2017; 2 - m1 from Khashgort 1981 previously identified as *Microtus (=A.) middendorffii* (after Smirnov et al., 1986); 3 - holotype of *M. n. lidiae* from GP2 (after Markova and Borodin, 2022).

GP2. Posterior walls of PL, T1 and T2 bear no tangential enamel (analysis of the enamel structure by S.V. Zykov). Thus, both morphometric analysis and scanning electron microscopy reveal no similarity of this specimen with *Alexandromys* and suggest its assignment to *M. n. lidiae*. The comparison with previously published materials from Khashgort 1981; Smirnov et al. (1986) suggests that *Alexandromys* (previously *Microtus*) *middendorfii* was erroneously identified in this locality. An updated interpretation of the fossil record of the most biochronologically significant arvicoline lineages in the study area is shown on Fig. 8.

4.1.3. Micromammal biochronology and biostratigraphy

Comparison of the faunas of GP2 and BOB440 with previously published data from the northern West Siberia (Smirnov et al., 1986; Krukover, 1992; Kosintsev et al., 2004) suggests that the late Middle Pleistocene (Middle Neopleistocene) fauna of this region might be divided into two sequential stages.

The first, older stage is characterized by the material from GP2 13d (this study), as well as by the faunas from Gornaya Subbota and Demyanskoe (Krukover, 1992). In these localities, micromammal assemblages are confined to the lower or middle parts of the Tobol and Chembalchino Formations. The faunas of this age include the taxa listed for GP2 (Table 1) and also *Arvicola* aff. *mosbachensis* in Gornaya Subbota (Krukover, 1992). Steppe lemmings (*Lagurus*) are also present in the faunas of this age but their evolutionary level requires revision. The fauna from BOB440 might be considered as the northern and most advanced variant of this fauna (based on the presence of advanced *D. simplicior*).

The second and younger stage is characterized by the assemblages of Chembakchino 1981; Smirnov et al. (1986), Chembakchino, Bobrovka (Krukover, 1992). Micromammals are found either in deposits of the upper part of the Tobol and Chembakchino Formations overlain by the tills or limnoglacial sediments of the Samarovian Horizon or in cross-bedded sands filling the incisions in the pre-Quaternary deposits. Micromammal-bearing sediments in Chembakchino and Bobrovka comprise mollusk shells (e.g., *Corbicula fluminalis*) that neither found in GP2 and BOB440 nor mentioned from Gornaya Subbota and Demyanskoe. The micromammal assemblages are diverse and comprise the same species as the fauna of the first stage but *D. simplicior* is replaced by the more advanced chronospecies identified as either *D.* cf. *henseli* (Smirnov et al., 1986) or *D.* ex gr. *gulielmi-henseli* (Krukover, 1992). Among grey voles, *Microtus agrestis* might be present with minor frequency.

Thus, we can distinguish two evolutionary stages of faunal development within the late Middle Pleistocene – early and late faunas of the

International Chronostratigraphic Chart	Russian Chronostratigraphic Chart	MIS	Regional Horizons (Volkova, 2009)	Arvicoline biochronology - MQR zones of Eastern Europe (Vangengeim, Tesakov, 2008)	Lasiopodomys gregalis	Alexandromys oeconomus	+Alexandromys sp. (malei)	A. (=M.) middendorffii	† Microtus nivaloides lidiae	Microtus agrestis	Microtus arvalis s.l.	Chronospecies of Dicrostonyx (and morphological stages S1-S3 within <i>D. simplicion</i> after Smirnov et al., 1997)	Local geological formations (Fm) yielding micromammal assemblages
ГЪ	LN	5	Kazantsevian	MQR 1			^	?	^	±	0	Dicrostonyx cf. henseli	Yalbynya Fm, basal layers (with mollusc shells)
ne Neopleistocene		6	Tazovian	MQR 2			ſ	?	~~~~	±	0	D. cf. henseli \	
	cene	7	Shirtinian										
	eistoc	8	Samarovian										
	9		MQR 3									Chembakchino and Tobol Fm, upper parts; lenses of cross-bedded sands	
stoce	10 gdle				Tobolian								over P3 deposits (with C. fluminalis)
Pleis	M										0	D. simplicior (S2)	Chembakchino Fm, lower part
dle		11						0		0			Tobol Fm, lower part
Mid		12						0	~~~~	~~~	0	D. simplicior (S2) \ D. simplicior (S1)	
	EN	13	Shaitanian	MQR 4			v			0			Semeyka Fm
		14		MQR 5									

Fig. 8. Micromammal biochronology for the late Middle Pleistocene of the north of West Siberia showing the most biochronologically informative lineages of *Microtus* sensu lato and *Dicrostonyx* (results of this study and revised data from Smirnov et al., 1986; Krukover, 1992; Kosintsev et al., 2004). Divisions of the International (Cohen et al., 2023) and Russian (State geological ..., 2009) chronostratigraphic charts: LP – Late Pleistocene, EN – Early Neopleistocene, LN – Late Neopleistocene, P3 - Oligocene. Presence or absence of arvicoline taxa: grey color – present; 0 – not found in the assemblages known to date; ? – further revision is required because of the problems of taxonomic identification; \pm - present but the time of appearance is not clear; ^ - extinction; \vee - first finds of morphotypes gud and nivalis typical for *A.* (=*M.*) cf. *malei*; wide arrow indicates a problematic stratigraphic context of the later faunas of the Tobolian Horizon.

Tobolian Horizon. However, their stratigraphic relation remains poorly resolved because the faunas of these two stages have never been found in superposition within one sequence. In GP2 12f, we found a small assemblage, the position of which within the sequence suggests its possible relationship with the younger faunas of the Tobolian Horizon but there are not enough remains of *Dicrostonyx* to identify their chronospecific characters.

4.2. Insect assemblages and environmental interpretations

In BOB440, a total of 120 fragments belonging to minimum 54 individuals (based on the rule of the minimum number of individuals in a sample) is recovered (Appendix C, Table C1).

Samples 21/mv1 and 21/mv2+21/mv3 yield a complex of taxa suggesting relatively cold environmental conditions. The complex includes species showing arctoboreal (Poecilus cf. nordenskjoeldi (Figs. 9 and 2), Pterostichus ventricosus (Figs. 9 and 6), P. pinguedineus, Stereocerus haematopus, Otiorhynchus arcticus (Figs. 9 and 11), arctic (Pterostichus sublaevis, P. vermiculosus) and polyzonal (Tournotaris bimacualtus (Fig. 9. 16), Notaris aethiops) pattern of the present-day distribution. Arctoboreal species Poecilus nordenskjoeldi and Otiorhynchus arcticus should be considered rare for the Quaternary deposits of the region. The weevil Otiorhynchus arcticus occurs in the north of modern boreal zone and in forest tundra but the species' range is now confined to Europe. According to the vertical stratification of modern beetles in terrestrial habitats, these species are attributed to several groups. Herpetobiont beetles (inhabitants of the ground surface) are represented by all carabids and a pill beetle Morychus viridis. Hortoboint group (herbaceous and shrubby vegetation) includes only weevils Otiorhynchus arcticus and Tournotaris bimaculatus. The predominance of herpetobiont beetles may be considered as an indirect evidence of cold climate (Nazarov, 1984). Development of riparian vegetation is suppressed under cold conditions and the number of insect species inhabiting uplands (plakors) increases, thus increasing the number of mesophilic tundra species (following the classification by Sher and Kuzmina, 2007) in fossil assemblages.

Sample 21/C. Despite small sample size, there is *Pterostichus costatus* (Figs. 9 and 4), the present day distribution of which encompasses the high latitudes north of modern southern tundras, thus suggesting very cold environmental conditions. Collectively, these results suggest that the complex of insects from the sample 21/C might have existed in landscapes resembling modern tundra.

Sample 20/C18. Single remains are found, including arctoboreal beetle *Lepyrus* ? *nordenskjoeldi*.

Samples 17/C14 + 17/C14b. Carabid *Agonum exaratum* and weevil *Isochnus arcticus* are found suggesting relatively cold conditions.

Six samples from GP2, Layers 16–13m yield insect remains (Appendix C, Table C2).

Sample13m/9. The most frequent remains are puparia of Diptera (Figs. 9 and 20). Coleoterans are not abundant, mostly those with arctoboreal pattern of modern distribution (*Pterotichus* cf. *pinguedineus, Bembidion* cf. *grapii, Helphorus* cf. *obscurellus*); a single find of a boreal species *Pterostichus diligens,* modern range of which encompasses mostly boreal zone but also the southern part of tundra zone (Andreeva and Eryomin, 1991; Zinovyev and Olshvang, 2003). The assemblage suggests cold climate, probably close to modern forest tundra.

Sample 13m/1. Eleven fragments including arctoboreal species (*Diacheila polita, Bembidion* cf. *grapii, Curtonotus torridus*) and *Stephanocleonus eruditus* (identified by A.A. Legalov (Figs. 9 and 17)) distributed in modern steppes of the south of Eastern Siberia (Legalov, 2010). The latter species was also found in other localities in the middle Ob River and lower Irtysh River reaches (Legalov et al., 2016). The presence of *Stephanocleonus eruditus* might suggest dry conditions and arctoboreal species might suggest colder environments than today in that area.

Sample 13m/lens. Five specimens including two fragments of *O. janovskii* (identified by A.A. Legalov) (Figs. 9, 12 and 13). Modern range of this species is mostly confined to Altai and Sayany, from Tyva and



Fig. 9. Insect remains found in GP2 and BOB440: 1 - Chlaenius costulatus, left elytron, GP2, s. 16/27; 2 - Poecilus cf. nordenskjoeldi, right elytron, BOB440, s. 21/mv2+21/mv3; 3 - Pterostichus cf. pinguedineus - left elytron, GP2, s. 13m/ lens; 4 - Pterostichus costatus - right elytron, BOB440, s. 21/C; 5- Bembidion macropterum, left elytron, GP2, s. 14/25; 6 - Pterostichus cf. ventricosus, left and right elytra, BOB440, s. 21/mv; 7 - Harpalus nigritarsis, right part of pronotum, BOB440, s. 21/mv2+21/mv3; 8 - Pterostichus vermiculosus, pronotum, BOB440, s. 21/mv1; 9 - Pterostichus cf. middendorffii, pronotum, GP2, s. 16/27; 10 -Curtonotus torridus, right part of pronotum, GP2, s. 13m/1; 11 - Otiorhynchus arcticus, right elytron, BOB440, s.21/C19; 12, 13; - Otiorhynchus janovskii, associated elytra (12) and left elytron (13), GP2, s. 13m/lens; 14-Elaphrus riparius, pronotum, GP2, s. 16/27; 15 - Clivina fossor, left elytron, BOB440, s. 21/mv; 16 - Tournotaris bimaculatus, left elytron, BOB440, s. 21/mv; 17. -Stephanocleonuseruditus, head capsule, GP2, s. 13m/1; 18. - Olophrum sp. - left elytra, GP2, s. 14/25; 19 - Morychus viridis, right elytron GP2, s. 13m/lens; 20 -Diptera indet., frarment of puparia, GP2, s. 13m/9.

Mongolia in the south and the upper reaches of the Angara River in the north (Korotyaev, 1990; Gurina et al., 2019). Previously, fragments of *O. janovskii* were found in the Late Pleistocene localities Dubrovino (55°27′07.0″ N, 83°15′17.7″ E), 935 km south-east of Gornopravdnsk (Gurina et al., 2019) and Gornova (54°54′27.30″N, 55°52′48.26″ E) (Dudko, et al., 2022). However, the assemblage also comprises arctoboreal species *Blethisa catenaria*, *Pterostichus* (*Cryobius*) cf. *pinguedineus*, *Morychus viridis* (Figs. 9 and 19). are associated with cold periods of the Quaternary. Species composition of this sample might suggest conditions cooler than present.

Sample 14/25. Fourteen fragments of riparian (*Bembidion* sp., *Olophrum* sp. (Figs. 9 and 18) and aquatic species (*Hydrobius fuscipes*, *Hydroporus* sp.) suggesting a near-water habitat. Occurrence of arctoboreal (subarctic) ground beetle *B.* cf. *macropterum* (=*B. umiatense*)



Fig. 10. Plant macrofossils found in GP2 and BOB440 localities: 1, 2 – *Betula* sect. Albae, GP2, 16/27; 3, 4 – *Picea* sp., BOB440, 21/carp; 5 – *Larix sibirica*, GP2, 16/27; 6 – *Rubus idaeus*, GP2, 16/27; 7 – *Caulinia tenuissima*, GP2, 13m/9; 8–11 – *Potamogeton sibiricus*, GP2, 16/27 (8, 9), BOB440, 21/carp; 13, 14 – *Ranunculus sceleratus*, BOB440, 21/carp; 15, 16 – *Carex bohemica*, GP2, 16/27; 7, 18 – *Typha* sp., BOB440, 20/18; 19–21 – *Bunias cochlearioides*, GP2, 16/27; 22–23 – *Euphorbia* sp., GP2, 16/27; 24–26 – *Potentilla* sp., BOB440, 21/carp; 27–29 – *Potentilla anserina*, GP2, 16/27; 30, 31 – *Linum* sp., GP2, 16/27. Biostratigraphically informative taxa: A – *Potamogeton cf. sarjanensis*, BOB440, 21/carp; GP2, 16/27; D – *Myriophyllum spinulosum*, GP2, 16/27; F – *Carex cf. paucifloroides*, BOB440, 21/carp. Plant taxa recorded in the fragments of allochthonous peat at BOB440, Layer 21: a – *Dryas* sp., BOB, 21/p3; c, d, g – *Salix* sp. (dwarf form) BOB, 21/p3; f – *Bistorta vivipara*, BOB, 21/p3.

(Figs. 9 and 5) cannot indicate a colder climate than today, since its modern distribution also includes more southern areas (Zinovyev, 2007). Dominance of riparian species may be regarded as indirect evidence of climate conditions similar to modern, since in the cooler climate conditions the number of riparian beetles in intrazonal biotopes is much lower (Nazarov, 1984).

Sample 15/26. Despite small number of remains referred to 6 individuals, there is one left elytra of *Pterostichus diligens*, a boreal species suggesting environmental conditions close to the present day in this area. The occurrence of the elytra of *Bembidion macropterum*, having modern arctoboreal (subarctic) distribution, does not contradict the occurrence of *P. diligens*, because *B. macropterum* may inhabit modern middle and northern taiga forests in West Siberia. However, small number of remains allows no detailed reconstructions. Sample 16/27. Boreal species *Pterostichus diligens, Chlaenius costulatus* (Figs. 9 and 1), together with polyzonal beetles *Elaphrus riparius* (Fig. 9. 14), *Notaris aethiops, Hypnoidus rivularuis* and an arctoboreal beetle *P.cf. middendorffi* (Fig. 9 and). *Chlaenius costualtus* occurs in damp habitats in taiga and might be considered as a reliable indicator of moderately warm climate.

Preservation states of insect remains vary among samples in GP2. Relatively poor preservation, comparable to the assemblages dated back to the Early and Middle Pleistocene, should be noted for the samples 13m/1 and 14/25.

4.3. Plant macrofossils

4.3.1. Assemblages and reconstructed biotopes

This Section describes plant macrofossil assemblages dated back to the Quaternary. Taxonomic composition of reworked macrofossils from the pre-Quaternary deposits is shown in Appendix C, Tables C.3-C.5 and discussed in Section 5.1.

In BOB440, a total of 56 plant taxa were identified based on the analysis of more than 600 macrofossils. The most informative assemblage was obtained from the upper subunit of Layer 21 (sample 21/ carp).

Sample 20/C18 contains 9 taxa. Single fragments of spruce needles (*Picea*). Remains of sedges and *Typha*, a shallow water species, prevail among riparian taxa. Among aquatic, there is only *Potamogeton* sp. Megaspores of *Selaginella selaginoides* and *Azolla interglacialica* are present. The assemblage characterizes a woodland (a forest with an open canopy) of spruce in the vicinities of a shallow waterbody with *Typha* and sedges.

Sample 21/C19 contains 18 taxa. Arboreal vegetation includes spruce, birch, willow and *Sambucus*. Near-water vegetation is represented by *Typha*, Alismataceae, sedges. Aquatic vegetation includes *Batrachium*. Single seed of *Papaver*, arcto-alpine section *Scapiflora*. Seeds of *Potentilla* sp. have no veins on the surface that is typical for cry-ophilous species of *Potentilla* (*P. nivea*, *P. kuznetzowii*, *P. hyparctica*). The assemblage characterizes a floodplain forest with birch and spruce near a shallow waterbody, with the areas of disturbed soils populated by cryophilous *Papaver* and by *Rumex acetosella*.

Sample 21/C12 contains 14 taxa. Single remains of arboreal species (willow, elder *Sambucus*). No aquatic species. Sedges might have prevailed in the herbaceous layer. The assemblage is poorly informative.

Sample 21/C contains 11 taxa. A single winged seed of Birch is mineralized that might suggest reworking. Leafs of *Dryas* and seeds of *Salix* have the same state of preservation and color as the remains from the allochthonous peat fragments (samples p1-p3). It is highly probable that the same peat fragment might be a source of the plant remains in this sample. There are no aquatic species. The taxa confined to disturbed soils are infrequent (*Euphorbia, Chenopodium,* Polygonacea). Near-water vegetation includes mostly sedges. The assemblage characterizes a local near-water habitat.

Sample 21/carp comprises 42 plant taxa: boreal species (spruce, larch, birch and Rubus idaeus). Neither cryo- or thermophilous species are found. Swamp species Menyanthes trifoliata, Comarum palustre, Empetrum nigrum. Among aquatic species, there are various pondweeds, including Potamogeton sibiricus. Among near-water plants, there are Scirpus tabernaemontani and Typha sp. S. tabernaemontani has been mentioned in the flora of West Siberia as a mostly steppe and halophilous species (Flora of Siberia, 1990). The most northern species of the genus - T. latifolia currently occurs in the southern part of West Siberia up to 60°N. In general, this complex characterizes the environment of a floodplain coniferous-birch forest of the taiga zone with the elements of southern taiga riparian vegetation. Biostratigraphically significant taxa are represented by single specimens making identification difficult in certain cases. Single endocarp of a pondweed of the group Potamogeton maackianus is most similar with P. cf. sarjanensis Wieliczk. (Fig. 10). The extinct species Carex cf. paucifloroides and

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Fig. 11. Locality BOB440 as a mixed archive of environmental change in the north of West Siberia: percentage of chronological groups based on last occurrence among vertebrates and plants (only last occurrence of taxa is taken into account) (I) and (II) percentage of ecological groups based on preferred habitat humidity calculated for plants (samples p1p3, pooled), insects (all samples, pooled), and arvicolines (all samples, pooled); insects are shown differently because their relationship with habitat humidity is particularly temperature-dependent (preferential use of mesic habitats in cold environments)



Fig. 12. Fluvial sequence at GP2 as an archive of environmental fluctuations in the beginning of the late Middle Pleistocene. I. Environmental reconstructions based on micromammals and changes revealed by the proportions of arvicoline rodent taxa associated with different levels of habitat humidity (pie diagrams) and with different types of vegetation (percentages). II. Reconstructions based on plant macrofossils. See Fig. 3 for lithology and position of the samples in the section.

Aracites interglacialis are also represented by single remains.

Peat samples (p1, p2, p3) taken from the lower part of Layer 21 (Table 2) yield the complex typical for cold intervals of the Pleistocene, and one seed of a relatively thermophilous species of the Lower-Middle Pleistocene age, most probably reworked.

Sample p1. Plant debris of moss twigs, with quartz sand. Leafs of dwarf willows, dryads and *Andromeda* have a dark color. Species composition characterizes dwarf shrubs-moss tundra with dwarf willows and dryad. Fragments of arvicoline bones and teeth of *Lemmus* are also found.

Sample p2. Flat plant debris, leaf fragments of *Sphagnum* sp., fragments of stems of herbaceous plants, quartz grains, and mica.

Sample p3. Plant debris (moss twigs), dwarf willow, dryad and *Andromeda* suggesting a dwarf shrub-moss tundra habitat.

Sample p1 contains macrofossils of sedges (*Carex*) that might suggest more humid local conditions (compared to the sample p3).

The assemblage from water-screened mv samples contain 33 taxa. Arboreal species include *Larix sibiricus, Pinus sibiricus* and *Salix* sp. The taxa of disturbed soil substrates: *Euphorbia, Linum, Coryspermum, Chenopodium, Bunias cochlearioides, Polygonum aviculare.* Near-water vegetation is predominated by sedges and *Menyanthes trifoliata,* a species of forest swamps. Pondweds prevail among aquatic taxa.

In GP2, analysis of plant macrofossils ws carried out for the sequence from the layers 13m to 16. A total of 80 plant taxa (Appendix C, Table C5) was identified based on more than 1300 macrofossils (seeds, fruits, megaspores, needles, cones, etc.). Sample 16/27 from the lowermost layer yielded the most informative complex of plants (Fig. 10). The above-lying part of the section GP2 yielded less informative assemblages.

Sample 13m/9. Twenty taxa including aquatic species, inhabitants of shallow waters and banks (Table C5). The assemblage characterizes floodplain forest of spruce (*Picea*) and birch (*Betula* sect. *Albae*), probably with *Betula* cf. *nana*.

Sample 13m/1. Remains of 18 taxa. Riparian taxa and plants of disturbed soil substrates (*Chenopodium*, few species of *Potentilla*, including *P. anserina*) prevail. No arboreal taxa. Among aquatic plants, there is a relic species *Caulinia tenuissima*. The assemblage characterizes a local floodplain biotope.

Sample 14/25. Remains of 5 taxa. Arboreal species are represented by willow (*Salix*) and spruce (*Picea*). Single remains of aquatic and riparian species. The assemblage is poorly informative and is consistent with a floodplain biotope.

Sample 15/26. Twelve taxa. Riparian plants, inhabitants of disturbed (eroded) soils and aquatic species; only birch among arboreal taxa. There are megaspores of *Azolla interglacialica* and *Selaginella selaginoides*. A local riparian biotope.

Sample 16/27 comprises 58 taxa. Arboreal species are represented by spruce, larch Larix sibirica, birch Betula sect. Albae and a forest shrub Rubus idaeus. Numerous and diverse freshwater plants including Batrachium, Potamogeton, Lemna, Myriophyllum suggest a non-flowing or slowly flowing water body during the period of sediment accumulation. Riparian vegetation of shallow waters was well-developed, with Sparganium, Alismataceae, Menyanthes trifoliata, Hippuris, Eleocharis. Pioneer plans of disturbed areas on the banks included Rumex maritimus, Polygonum lapathifolium, P. aviculare, Chenopodium, etc. (Appendix C, Table C5). Some of those – Rumex maritimus, Ranunculus sceleratus, Potentilla anserina - are halotolerant. Carex bohemica is confined in present to southern regions of West Siberia and often occurs in salt meadows (Flora of Siberia, 1990). Xeroerosiophytes Linum, Euphorbia, Amarantus, Atriplex, Bunias cochlearioides suggest the presence of steppe-like areas. Biostratigraphically significant taxa include Aracites interglacialis, Myriophyllum spinulosum, Azolla interglacialica. The complex of plant macrofossils characterizes a flood-plain coniferous and birch forest with spruce and larch, with well-developed riparian vegetation and steppe-like patches on the riverbanks.

4.3.2. Environmental interpretation of plant assemblages

The most informative complexes of plant macrofossils are obtained from GP2 12/C27 and BOB440 21/carp. Due to the fluvial origin of sediments in both GP2 and BOB440, the majority of the Quaternary complexes of plants are confined to aquatic, riparian habitats and banksides with eroded soil cover. Taxonomic composition is mostly local, a few species have not been previously recorded in the flora of West Siberia. The relic species *Caulinia tenuissima* has a disjunctive modern range and has not been mentioned in the flora of West Siberia (Lisitsyna and Papchenkov, 2000). Obviously, the species might have a wider range in the Pleistocene. The endemic species *Potamogeton sibiricus* has been recorded in the floras of Buryatia, Yakutia, and the Taymyr Peninsula where it occurs from the southern tundras to the northern taiga forests (Flora of Siberia et al., 1988; Pospelova and Pospelov, 2007). Both complexes characterize floodplains in a forest zone and the areas of eroded soils with steppe-like vegetation. Cryophilous species are represented by single remains and include *Papaver* section *Scapiflora, Selaginella selaginoides,* and probably some species of *Potentilla.* Aquatic vegetation is characterized by relatively thermophilous species *Azolla interglacialica, Caulinia tenuissima.* Paleoflores also include taxa that currently tend to occur in the southern part of West Siberia and do not reach the latitudes of the locality BOB440 in present: *Carex bohemica, Scirpus tabernaemontani, Bunias cochlearioides, Ranunculus sceleratus, Linum, Typha.*

Composition of plant macrofossils in the peat samples characterizes dwarf shrub-moss tundra with dwarf willows and dryads (samples BOB440 p1-p3).

Poorly informative complexes characterizing narrowly local riparian biotopes are recorded in GP2 13/m1, GP2 14/25, GP2 15/26 and BOB440 20/C18, BOB440 20/21. Floodplain forests of spruce and birch with cryophilous elements (*Papaver* sect. *Scapiflora*, *Betula* cf. *nana*) are reconstructed for samples BOB440 20/C19 and GP2 13m/9.

4.3.3. Biochronological significance of the quaternary plant macrofossils

Biostratigraphically significant plant taxa are recovered in Layer 16 (sample 16/C27) in GP2: *Azolla interglacialica, Aracites interglacialis, Myriophyllum spinulosum* (Fig. 10). The remains are in a good state of preservation, megaspores of *Azolla* with preserved glochidia, seeds of *Aracites* with a preserved outer layer of the epidermis. In BOB440, the sample 21/carp contains *Aracites interglacialis, Potamogeton sarjanensis, Carex paucifloroides.*

Azolla interglacialica first appeared in the floras of the Upper Pliocene and became widespread at the Pliocene – Quaternary transition and in the interglacial floras of the Likhvinian type (Velichkevich, 1982; Nikitin, 1970). Single finds of megaspores of Azolla interglacialica have been also mentioned for the deposits of the Mikulinian and other pre-Valdai interstadials.

Numerous remains of *Aracites interglacialis* have been known from the deposits of the Likhvinian optimum on the East European Plain (Dorofeev, 1963; Velichkevich, 1982). There were no finds of *Aracites interglacialis* in the upper horizons of the Pliocene and in the Lower Pleistocene. The species has been also recorded by V.P. Nikitin in the Siberian Mindell-Riss deposits on the left bank of the Ob River near Karga village (Nikitin, 1970) and by S.S. Trofimova in deposits of the Semeika and Chembakchino Formations on the Irtysh River (Kosintsev et al., 2004). This species has never been recorded in the Mikulino interglacial floras (Velichkevich, 1982). *Myriophyllum spinulosum*, a species that first appeared in the Likhvinian, has been known from the interglacial floras of the same age as *Aracites interglacialis* (Velichkevich, 1982; Velichkevich and Zastawniak, 2008).

Potamogeton sarjanensis is a species that appeared in the beginning of the Middle Pleistocene and occurred in interglacial floras of the early Middle Pleistocene (Velichkevich and Zastawniak, 2006).

Carex paucifloroides is a species of the Late Pliocene – Middle Pleistocene. It has never been recorded in the floras later than the Likhvinian interglacial (Velichkevich and Zastawniak, 2006).

Based on the presence of biostratigraphically significant plant taxa, the age of the assemblages GP2 16/C27 and BOB440 21/carp might be determined as the Middle Pleistocene within the Likhvinian interglacial (the last time interval of the Quaternary when the above-mentioned species might co-occur).

4.4. Geochronometric evidence (in a paleontological context)

Luminescence dating results are shown in Appendix B and summarized in Table 3.

Table 3

Luminescence dating results (sample code/estimated age, ka). RGI dates represent average values for three tubes, NL dates show results for each tube (see Appendix B for details).

Locality	Layer	Depth, m	RGI		NL		
			OSL (Q)	IRSL (Fs)	OSL (Q)	IRSL (Fs)	
			2018	2018	2020	2020	
BOB440	21	22.45–22.55	0388/ 109 ± 10	-	-	-	
	21	24.40–24.50	0389/ 124 ± 14	-	-	_	
	22	26.45–26.55	0431a/ 118 ± 12	0431b/ 114 ± 12	_	-	
	21	24.40	-	-	218404/ 165 ± 11	$\begin{array}{c} 218404 \\ 198 \pm 15 \end{array}$	
	21	24.45	-	-	218405/ 162 ± 14	$\begin{array}{c} 218405\\ 183\pm42 \end{array}$	
	21	24.50	-	-	218406/ 169 ± 16	$\begin{array}{c} 218406 \\ 188 \pm 19 \end{array}$	
GP2	12a	25.50	-	-	_	$218416/\ 322.1 \pm 25$	
	12a	25.60	-	-	-	218417/ $323.6 \pm$ 20	
	12a	25.70	-	-	-	218418/ 324.7 ± 28	
	12f	34.05	-	-	-	218410/ 291.7 ± 23	
	12f	34.10	-	-	-	$218411/\ 293.6 \pm 14$	
	12f	34.15	-	-	-	218412/ 298.8 ± 17	
	13a	34.70	-	-	-	218407/ 350.6 ± 18	
	13a	34.75	-	-	-	218408/ 360.0 ± 23	
	13a	34.80	-	-	-	$218409/\ 329.0 \pm 24$	
	13k	41.65	-	-	_	218413/ 392.1 ± 23	
	13k	41.70	-	-	-	218414/ 372.4 ± 19	
	13k	41.75	-	-	-	218415/ 391.9 ± 25	
	13m 13m	43.15 43.20	_	_	_	218419/ >433 218420/	
	13m	43.25	-	-	-	>450 218421/ >483	

OSL dates on Q obtained at BOB440 are at the approximate age limit of the method (109–169 ka). The between-laboratory differences (\sim 38–45 ka) of the OSL dates obtained for the same interlayer within Layer 21 are higher than the difference between the dates obtained for Layers 22 and 21 in one laboratory (\sim 6 ka). A slight depth-age inversion occurs in the middle part of Layer 21 when we compare the OSL dates with the sampling depths.

Despite uncertainties, OSL dates are in good agreement with IRSL dates for the same layers, when obtained in one laboratory. IRSL dating results suggest that BOB440 Layer 22 might have been formed during MIS 5e (114 \pm 12 ka) and the above lying Layer 21 is dated at 198 \pm 15 ka, 183 \pm 42 ka and 188 \pm 19 ka, thus falling into MIS 6.

Thus, both Q and Fs luminescence dating suggest the depth-age inversion within the studied section BOB440. Most probably, this inversion is a result of the admixture of the Middle Pleistocene sediments that have been accumulated in the layer together with plant and animal remains of the Q2 age. Accumulation of large fragments of the allochthonous substrates might have led to incomplete resetting of the luminescence signal prior to deposition.

In GP2, there is also an inversion in Layer 12f (Table 3), but the dates are positively correlated with depths (the Pearson correlation coefficient r = 0.63, p = 0.029) and generally confirm the early Middle Pleistocene age of the layers 13 and 12.

5. Overall view of all proxies deciphering archives of the highenergy depositional environments

In both BOB440 and GP2, the assemblages rich enough for paleoenvironental interpretations have been accumulated in the high-energy depositional environments marked by cross-bedding of sands with gravel interlayers of 'clayey pellets'. In our study, if an assemblage of micromammals is found in an interlayer of 'clayey pellets', the overlying fluvial sediments accumulated in low-energy environments contain the same complexes of micromammals, though in less-concentrated amounts. The presence of reworked fossils from the pre-Quaternary is quite typical of such deposits. However, the closer the assemblage to the time of sediment accumulation, the higher the probability to obtain taphonomically and paleoecologically substantiated inferences for biostratigraphy and geological correlation.

5.1. Reworked pre-quaternary fossils found together with the Middle Pleistocene assemblages

Pre-Quaternary plant remains dating to the Oligocene – Pliocene are present in nearly all samples in both localities (GP2 and BOB440), albeit in different quantities. These remains have a very dark, nearly black color, and differ considerably from the Quaternary plant macrofossils. In GP2, the quantity of the pre-Quaternary plant remains is rather low in the Chembakchino layers (Tobolian Horizon), but increases with depth (from sporadically found single seeds in the Chembakchino Fm to 0–8% of identified taxa in the deposits of Semeyka Fm (Shaitanian Horizon) and 29% of the taxa in the sample 16/27 from Layer 16 tentatively considered as sands of the Talagaika Fm (Talagaikian Horizon of the early Middle Pleistocene). These data are in agreement with previous results (Kaplyanskaya and Tarnogradsky, 1974) suggesting the presence of plant macrofossils from the Turtas Fm, Upper Oligocene, in the Semeyka and Talagaika Formations of the Middle Pleistocene in the upper reaches of the Irtysh River.

In BOB440, pre-Quaternary plant taxa constitute 24–29% of samples taken from diagonal sands, but they are lacking in the samples p1-p3 from the fragments of allochthonous peat. Other pre-Quaternary fossils include lignitized wood and a single tooth of *Carcharias* sp. Collectively, these results suggest the increased concentration of paleoenvironmental information from different periods within one unit (Khashgort diagonal sands). Comparison of the last-occurrence data for each identified taxon (Fig. 11) indicates the presence of taxa that existed in four different types of ecosystems from the Late-Cretaceous-Oligocene marine to the Oligocene-Neogene, Neogene and Middle Pleistocene terrestrial and freshwater environments.

In BOB440, the Middle Pleistocene age of the Quaternary assemblages is confirmed by the evolutionary level of arvicolines (presence of *D. simplicior* and *M. n. lidiae*) and by the presence of biochronologically

informative plants: *Carex* cf. *paucifloroides* the latest occurrence of which is correlated with the panultimate interglacial, not later than the Alexandrian stage (Velichkevich, 1982, 2006) and *Aracites interglacialis*, a stenochronous species for the Likhvinian (= Tobolian, Alexandrian, or Holsteinian) interglacial stage (Velichkevich, 1982, 2006; Field et al., 2017). These biochronologically informative groups of arvicolines and plants differ significantly in their ecology. Therefore, inferences from this relocated material must be viewed with caution.

5.2. Multi-proxy analysis of the Middle Pleistocene paleoarchives

5.2.1. BOB440 as a mixed archive of the Middle Pleistocene environmental chanage

The Middle Pleistocene complexes of fauna and flora in BOB440 suggest the existence of 1) a cold terrestrial environment with tundralike vegetation and 2) interglacial environment inferred from the analysis of plant macrofossils.

Ecological structures of the arvicoline fauna and plant macrofossil assemblage from the peat samples are quite similar and include both moss remains and *Lemmus sibiricus*, an inhabitant of moss habitats. Dwarf willows recovered in the peat samples are also known to be a food resource for *Dicrostonyx*. Insect remains were not found in samples p1-p3, however, their structure in samples taken from sands enclosing the fragments of peat is also indicative of a cold climate that might be used as an indirect evidence of their relation to the same ecosystem as arvicolines and plants from peat samples.

The ecological structures of the arvicoline and insect assemblages from all over the Khashgort diagonal sands and plant macrofossils from allochthonous peat consistently suggest much colder conditions than today in the study area and open habitats with mostly shrubs and mosses in the ground cover (Fig. 11).

Geochronometric data suggest that the Khashgort sand unit exposed at BOB440 might have been formed at the Middle to Late Pleistocene transition (169–109 ka based on Q and 198–114 ka based on Fs (Table 3)). This would mean, the comprising Middle Pleistocene fauna and flora might represent either i) remains of a transitional ecosystem synchronous to the end of MIS 6 – beginning of MIS 5 or ii) re-deposited mix of a periglacial complex of fauna and flora and an interglacial flora of unknown late Middle Pleistocene age.

5.2.2. GP2 as a fluvial sequence reflecting environmental fluctuations in the late Middle Pleistocene

Biochronological and paleoecological interpretation of the late Middle Pleistocene sequence in GP2 is shown on Fig. 12.

The lower part of the section GP2 (Layers 14–15, Semeyka Fm) yields no micromammals and is characterized by less informative plant and insect assemblages suggesting a riparian biotope (Fig. 12, II, III, samples 14/25, 15/26).

The assemblages from Layer 16 are sufficiently rich suggesting relatively mild conditions similar to that of modern taiga (Fig. 12, II, III, samples 16/C27). These complexes might be correlated tentatively with the Talagaika Fm due to their position under the clays of the same color and structure as those in Layer 15. However, the presence of stenochronous plant species of the Likhvinian interglacial (*Aracites inter-glacialis, Myriophyllum spinulosum*) and two molars of arvicolines (*Lemmus* cf. *sibiricus, Microtus* sp.) close to those obtained in the abovelying strata might suggest that Layer 16 was accumulated later, probably as a tributary alluvial fan at the mouth of an adjacent ravine, a hypothetical channel of a paleotributary.

The base of the Chembakchino Fm (Layer 13m) is characterized by a suite of paleontological proxies obtained from different lithological units that, however, yield micromamals of the same evolutionary level (samples 13m/1 and 13m/9) and provide environmental reconstructions that are consistent with each other and suggesting environmental conditios colder than today in that area (open landscapes close to tundra or forest tundra in the paleoassemblages (GP2, Layer

13m) vs. middle taiga subzone of modern taiga zone in present time (Ilyina et al., 1985). Thus, based on micromammals, insects and plant macrofossils we can consider the assemblages from Layer 13m as transitional from cold conditions of the Shaitanian time (correlated with MIS 12, Semeyka Fm) to milder conditions of the early Tobolian time (correlated with MIS 11, Chembakchino Fm).

If we exclude the inconsistent IRSL dates (Layer 12f, samples NL21840-NL21842 (Table 3)), the estimated age of the sequence would rather fall within the interval from MIS 11 to MIS 9 that fits well the stratigraphic positioning of Layers 13-12 within the Tobolian Horizon. However, based on arvicoline remains, we cannot confirm the existence of completely interglacial environments during the sediment formation. The fauna indicates periglacial conditions and open landscapes. The ancestors of extant species occurring in modern tundra constitute large parts of these communities, the taxa confined to the habitats with herbaceous and moss ground cover prevail. The taxonomic composition does not vary significantly with depth, the variation in the ecological structure does not exceed the expected level of ecological successional changes within one ecosystem. If we accept geochronometric dating results, the assemblage 13d with a single find of Lagurus might be indicative of the maximum of the MIS 11 and 12f is a transition to the stage MIS 10 (that is also indirectly confirmed by the change from a fluvial (Layer 13) to lacustrine type of sedimentation (Layer 12). However, taking into account the depth-age inversion at the level of 12f, we cannot exclude that the sequence 13m-12f might have had accumulated during a shorter time interval (e.g., 88-700 years based on the highest known rates of fluvial sediment accumulation (Ferring, 1986; Sedláček et al., 2016)).

Thus, both geochronometric dating and biostratigraphic relative dating based on arvicolines confirm a late Middle Pleistocene age of the layers 13m–12f and the positioning of the sequence at the base of the Tobolian Horizon. However, the upper age limit for the sequence is not exact and correlation with particular oxygen-isotope stages has yet to be proven.

6. Conclusion

The sequence BOB440 is a mixed paleoarchive that comprises fossil remains of the taxa indicative of 1) warm marine environments in the Late Cretaceous - Oligocene, 2) warm terrestrial/riparian environments in the Oligocene-Neogene, 3) interglacial floras with stenochronous Middle Pleistocene taxa, 4) very cold environments with small mammals of the Middle Pleistocene age and cryoxerophiles and cold-tolerant taxa among plants and insects. All paleontological proxies are confined to the layers of obliquely-bedded sands of the Khashgort complex. Classification of plant and animal remains recovered in Khashgort sands based on the last known occurrence of each taxon allows correlating the faunas and floras with the geologic time scale. However, comparison of the results obtained for plants and animals suggests that all paleontological remains are allochthonous and might not be used as signals for geological correlation. OSL and IRSL dates obtained in two laboratories suggest either MIS 5 or MIS 6 age for the deposits. Despite considerable variation, this time interval is highly probable for the Khashgort unit. The high-energy depositional environment might be correlated with sea level rise during MIS 5e. However, precise geochronometric investigation is necessary for exact dating of the Khashgort sands. Until it is done, alternative hypotheses of the origin of the unit remain plausible.

The sediments of the Chembakchino Fm (Tobolian Horizon) and the underlying Semeyka Fm (Shaitanian Horizon) in GP2 yield the assemblages of plant and animal remains indicative of the environmental change from tundra-like landscapes at the Shaitanian-Tobolian transition (MIS 12 – MIS 11) to non-analogous open patchy landscapes with highly productive moss and herbaceous vegetation during the Tobolian period. Correlation with particular oxygen isotope stages based on paleontological data is problematic, and the obtained IRSL dates allow no clarification due to their considerable variation. The admixture of

allochthonous fossils in the Tobolian deposits in GP2 is minor and includes single seeds of pre-quaternary age and single teeth, not older than the early Middle Pleistocene. Analysis of the ecological structure of the micromammal assemblages in the sequence from GP2 13m to GP2 13d might represent ecological successional changes of the periglacial ecosystem with different types of a non-analogous fauna from a colder Shaitanian stage to the warmer Tobolian period, most probably prior the onset of the interglacial conditions. Comparison of the micromammal assemblage GP2 13d with other Middle Pleistocene localities in the north of West Siberia allows distinguishing two evolutionary levels: the early and late Tobolian faunas with *D. simplicior* and *D. henseli*, respectively.

The allochthonous fossils comprised in alluvial sediments have no apparent startigraphical significance. However, biochronological studies on particular taxonomic groups may reveal the problems to be solved in regional biostratigrahic frameworks and, hopefully, suggest the ways to solve them. The highly eroded sequences of the upper parts of the Tobol and Chembakchino Formations in most of exposures available for the study, the lack of micromammal-bearing sequences with reliable geochronometric data, and the uncertain differentiation of the MIS 8 and MIS 6 deposits result in the poor resolution of paleontological records of the very end of the Middle Pleistocene in the north of West Siberia. Some of these problems are regional but others might concern the entire northern Eurasia, e.g., the problem of distinguishing MIS8 and MIS 6 deposits. To address the latter problem, the studies on arvicoline key lineages widely distributed in the periglacial northern Eurasia during the late Middle Pleistocene are crucial, especially those with the high rates of morphological evolution during this period: genus Dicrostonyx (Smirnov et al., 1986, 1997), Alexandromys oeconomus (Lemanik et al., 2022), and species that became extinct (Markova and Borodin, 2022).

Despite the extremely high rates of reworking, the records of environmental change have been preserved in alluvial sequences. The problem of re-deposition can be overcome by multi-proxy approaches to the analysis of fossils. When the assemblages are rich enough, micromammals and plant macrofossils provide good resolution for biochronological inferences from the fossil record preserved in mixed alluvial archives of the lower Ob and Irtysh Rivers. The data on insects provide additional information to characterize habitat, landscape, and climate characteristics. The choice of methods depends on the type of depositional environments in a particular localitiy and in the study area as a whole. We hypothesize that the approaches used here can be applied to the areas and time intervals, for which a combination of high-energy fluvial environments, extensive distribution of moss cover and cold temperatures provide a chance for accumulation of the Quaternary archives.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

CRediT authorship contribution statement

Aleksandr V. Borodin: Supervision, Conceptualization, Investigation, (all stages of the research), Project administration, Writing – original draft, preparation. Evgenia A. Markova: Investigation, (analysis of micromammals), Formal analysis, Writing – original draft, preparation, Visualization. Sergey E. Korkin: Investigation, (field research), Writing (geological descriptions and stratigraphic interpretations), Writing – original draft. Svetlana S. Trofimova: Investigation, (paleocarpological analysis), Formal analysis, Writing – original draft, preparation, Visualization. Evgeniy V. Zinoviev: Investigation, and Writing (paleoentomological analysis and sections on invertebrates), Formal analysis, Writing – original draft. Vladimir A. Isypov: Investigation, (field research), Visualization. Lidia E. Yalkovskaya: Investigation, (field research, paleontological preparation). **Redzhep N. Kurbanov:** Investigation, (geochronometry), Writing (sections on OSL/IRSL dating), Writing – original draft.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2023.07.009.

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