



# Changes of environments and climate during the Late Pleistocene and Holocene reconstructed from aeolian and colluvial deposits of the Zaktui site (Tunka rift valley, Baikal region)



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## ABSTRACT

Integrated study of the multilayer Zaktui site supplied a large volume of paleontological materials and a series of radiocarbon dates falling within the MIS 3–MIS 1 interval. Multidisciplinary data provided evidence of the past dynamics of environments and climate. Paleontological data point to a mosaic structure of landscapes, and suggest a temperate warm and humid climate in the south-western Baikal region during MIS 3 interval, with some regional deviations.

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## 1. Introduction

Recently, investigations of the climate and environmental changes in the Lake Baikal region (Southern Siberia) through the Late Pleistocene–Holocene have been considerably intensified. Palaeoecological data derived from sediments of different genesis including bottom sediments of Lake Baikal and Lake Hovsgol (Karabanov et al., 2000; BDP Members, 2001, 2005; Kataoka et al., 2003; Demske et al., 2005; HDP Members, 2007, 2009; Mackay et al., 2011), and those of small lakes and peat bogs in the same region (Bezrukova et al., 2005, 2008, 2010, 2011, Shichi et al., 2007, 2009; Mackay et al., 2012, 2013), river terrace alluvial deposits (White et al., 2008, 2013; Arslanov et al., 2011), and cultural horizons of archaeological sites (Khenzykhenova and Alexeeva, 1999; Khenzykhenova, 2008; Sato et al., 2008, 2014; Erbaeva et al., 2011; Khenzykhenova et al., 2011). Studies of the cores obtained by drilling in Lake Baikal and Lake Hovsgol revealed the sediments to be heavily compressed, which prevents obtaining paleogeographic reconstructions of a satisfactory accuracy for the Late

Pleistocene–Holocene interval. In dealing with this problem we made recourse to other natural records, such as bottom sediments of small lakes in the vicinity of Baikal and Hovsgol lakes, peat-bog deposits, and sections of subaerial and fluvial deposits.

The position of the Tunka rift valley extending from Baikal to Hovsgol lakes forms a kind of “connecting link” between the North Asian taiga zone and steppe landscapes of Central Asia. This location makes the Tunka rift an important area for analyzing environment and climate dynamics in the Baikal region. One of the key sections of the Upper Pleistocene in the Tunka rift was described at the Zaktui site.

This paper deals with results of integrated research of the Zaktui section. The principal aims of the paper may be stated as follows: (1) to describe the geological and stratigraphical context of the Zaktui site; (2) to present results of the studies of pollen assemblages and theriofauna successions from the Late Pleistocene (MIS 3) to Holocene (MIS 1); and (3) to integrate these new data with key local and regional multi-proxy data on the Late Pleistocene–Holocene climate and environments.

## 2. Locality setting

The Zaktui site (51°42.184' N, 102°39.615' E, 740 m a.s.l.) is at the southeastern end of the Tunka basin (Tunka rift valley), on the

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gently sloping piedmont plain fringing the northern slope of the Khamar-Daban Range (Fig. 1), 80 km south of Lake Baikal. The Khamar-Daban elevation in this region reaches 2700 m, bordering the chain of tectonic depressions of the Tunka rift valley on the south. On the north, the rift valley is bounded by the alpine-type Tunka Range up to 3100 m high.

In the 1960s–1980s, the area near the Zaktui site was actively used as arable land. The farming stopped in the early 1990s, but the plain surface suffered badly from the gully erosion, a dense network of rills and ravines being developed. One of the largest gullies cuts through the entire sequence including loess-like deposits, mostly of colluvial genesis of 5 m thickness overlying the solid rock of the basement. This exposure is known as the Zaktui cross-section.

The basement of the Tunka basin is composed mainly of the Early Paleozoic granitoids and metamorphic rocks. The basin is filled with a series of Oligocene–Quaternary deposits up to 3 km thick. The Cenozoic geology of the Tunka region is dealt with in a number of papers (Ravskii et al., 1964; Mazilov et al., 1972; Adamenko et al., 1975, 1984; Popova et al., 1989; Kashik and Mazilov, 1994; Ufimtsev et al., 2002, 2003, 2004a,b; Hase et al., 2003). In the Tunka basin, several stratotype sections of Cenozoic stratigraphic units were described (Logachev, 1958a, b; Florensov, 1960), including recent investigations (Shchetnikov and Ufimtsev, 2004; Shchetnikov et al., 2009, 2013) (Shchetnikov et al., 2012).

During the Late Pliocene–Quaternary, tectonism formed basins that are now filled with coarse clastic materials highly variable in composition. Early and Middle Pleistocene sediments are exposed only occasionally, usually overlain by Late Pleistocene deposits. Three Late Pleistocene sedimentary facies are dominant: boulder–pebble gravels (proluvial, glaciofluvial, and alluvial sediments); alluvial sands; and loess-like sediments with associated slope deposits altered by post-depositional wind processes. The relationship between these complexes, as well as radiocarbon and other chronological data and fauna and flora remains, suggests the onset of the deposition c. 70 ka (Shchetnikov et al., 2012). Glacial deposits and cryogenic material indicate that at times the climate was cool or cold. During the early Late Pleistocene, renewed tectonism caused an increase of the coarse material deposition. The middle Late Pleistocene deposits consist mostly of sandy floodplain alluvium. By the end of the Late Pleistocene–Holocene, alluviation was reduced and gave way to erosion and aeolian deposition.

The Tunka rift valley position, at the center of the continent far away from seas and oceans, accounts for the climate characteristics: its continentality and moderate humidity, with a large proportion of sunny days. The microclimate of the region is largely controlled by topography: the latter is extremely diversified, the relative altitudes exceeding 2 km. The entire region features a relatively cold winter with a small amount of snow, drought-afflicted spring and the first half of summer, while the second half of summer is usually rainy. The precipitation is irregularly distributed over the region. Bottoms of the basins are the least supplied with moisture (less than 300 mm per year), while windward slopes of the mountain ranges obtain as much as 500 mm (Zhukov, 1960). Mean annual temperature is negative (from  $-1^{\circ}$  to  $-9^{\circ}$  C) everywhere in the Tunka rift (Zhukov, 1960). The highest air temperature, occasionally up to  $40^{\circ}$  C, occurs in July–August, and the lowest January (to  $-45^{\circ}$  C).

The vegetation in the Tunka rift valley is rather diversified. The upper part of the forest zone in mountains (1800–1200 m) is dominated by Siberian stone pine (*Pinus sibirica*) and Siberian fir (*Abies sibirica*). Foothills are occupied by mixed forests of Siberian larch (*Larix sibirica*), pine (*Pinus silvestris*), and birch (*Betula*). Siberian spruce *Picea obovata* and poplar (*Populus*) are confined to river valleys. Floodplains in the rift basins are occupied with shrubs (mostly of *Salix*), marshy meadow and wetlands.

### 3. Materials and methods

The mineralogical analysis of the sediments was performed in the Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences (Irkutsk, Russia). First, the samples were sieved, and then the fraction to be analyzed (0.25–0.05 mm) was separated into light and heavy fractions using a heavy liquid (bromoform) with specific gravity of 2.8. The mineral grains were analyzed using an immersion technique. Six samples were analyzed from each layer except for layer 1 (from which 2 samples were taken).

The age of the sediments was determined by  $^{14}$ C. Large mammal bones were dated in the Oxford University (Great Britain) using AMS technique with ultrafiltration, while for dating fossil soils the benzol-scintillation method was used (Institute of Geography RAS, Moscow, Russia). Eight samples were dated.

The pollen diagram was compiled using Tilia 1.5.12 software developed and kindly provided by Dr. Eric Grimm (Illinois State Museum, Springfield, the USA). According to that technique, the general composition of the spectra is counted (arboreal pollen + non-arboreal pollen + spores = 100%), and a proportion of individual components of the pollen assemblage is expressed as a percentage of the total number of counted grains. The Zaktui cross-section was sampled at 10 cm intervals, and 33 samples have been analyzed.

Remains of large mammal fauna were collected directly in the process of excavation. Those of small mammals and birds were mostly recovered by way of wet sieving. In the laboratory, the bones were carefully cleaned and impregnated with glue using standard procedures, and determined to a species level. The total number of faunal remains collected during the excavations is as follows: large mammals – 38, small mammals – 482, and birds – 2.

#### 3.1. Sedimentology and stratigraphy

The recent soil is developed on sandy loam with an admixture of silt, light to dark brown, with occasional lenses of dark humified sandy loam. They are underlain with light brown gravelly sands, showing cross bedding and wavy lamination. The sands, in turn, overlie wavy laminated loess-like sandy loams including thin laminae of non-sorted silty sands, gravel and gruss, with occasional lenses of humified material. The proportion of coarser sands and gravel, as well as angular debris and blocks varying in size, increases towards the base of the sequence.

The upper part of the sequence is exceedingly rich in carbonates, which is a distinctive feature of loess in the Tunka rift (Shchetnikov et al., 2012). In the fine fraction (sand, silt, clay) the size of particles increases noticeably towards the base of the section. Dominance of quartz, plagioclase, and potassium feldspar in the sediments suggests some local sources of those minerals within the area of granitic rock outcrops. A layer-by-layer description, from base to top of the sequence, includes (Fig. 2):

Layer 1. Gray silty sands with gravel and gruss, with interlayers and lenses of brownish-gray loam and inclusions of angular rock debris and blocks. The sand and loam boundary is marked with an ocherous fringe due to iron hydroxides. There is S-like and lens-like lamination. The layer is broken with numerous micro-faults of 6–7 cm amplitude. Colluvial deposits. Total thickness – 1.4–1.7 m.

Layer 2. Cocoa-colored loam and clays with lenses of fine sands and sandy loams, abounding in charcoal fragments. Individual laminae within the sandy loam lenses bear an ocherous fringe. The lower boundary is distinct, uneven. Colluvial deposits. Thickness – 0.3–0.5 m.

Layer 3. Sandy loams with interlayers and lenses of gravelly sands and occasional rock debris and blocks, ocherous due to

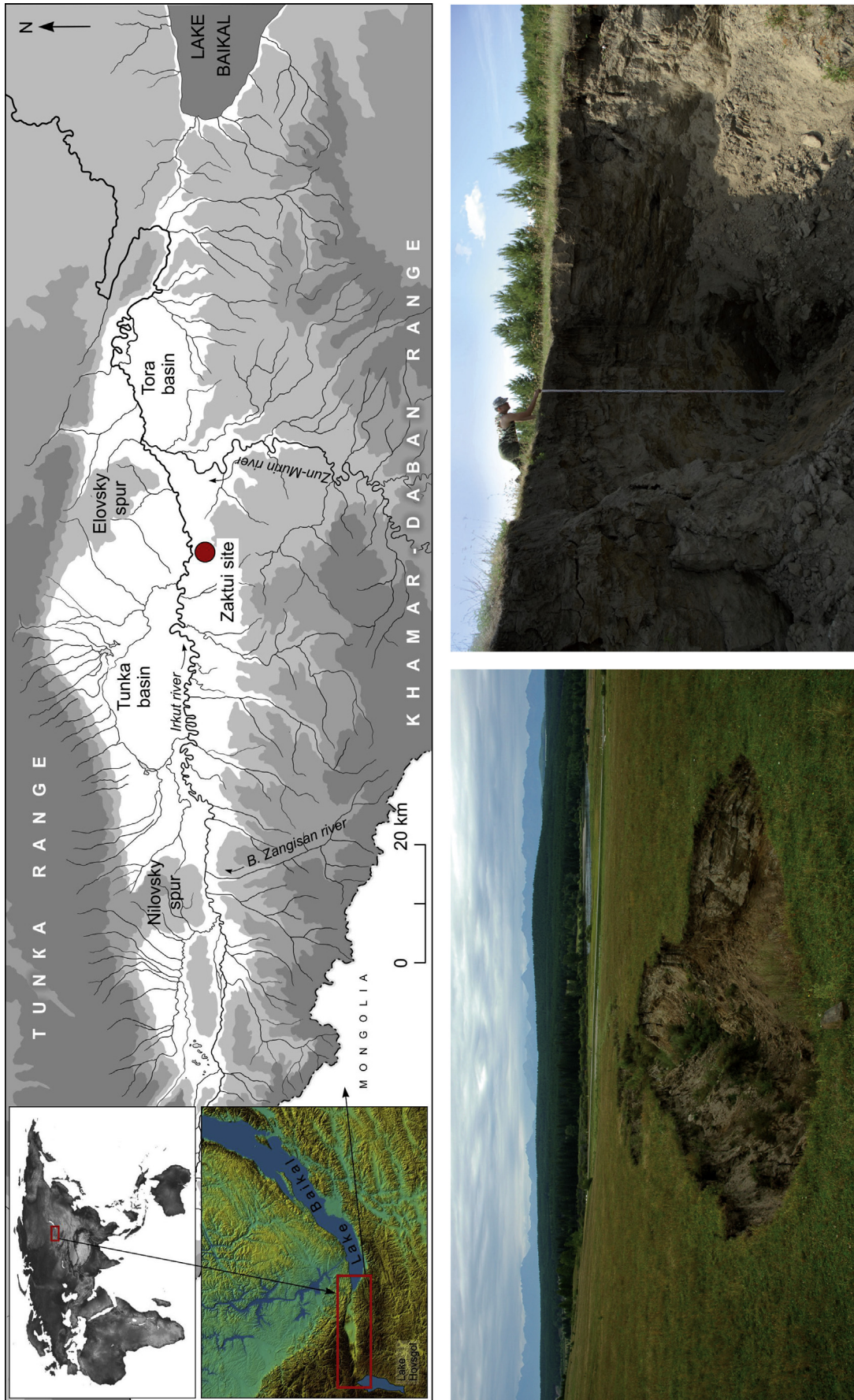


Fig. 1. Location map and general view of Zaktui site.

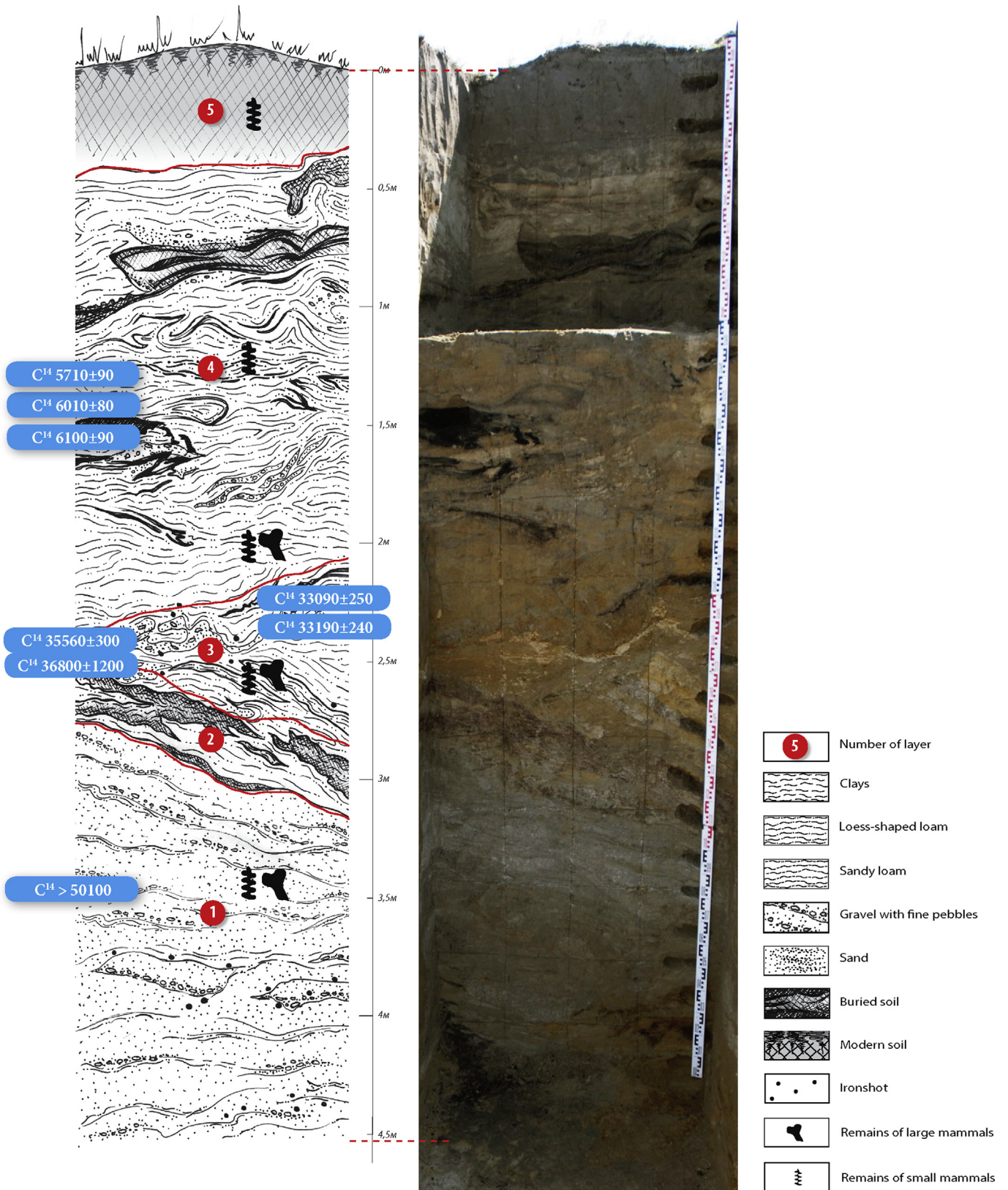


Fig. 2. Lithologic and stratigraphic column of Zaktui site with radiocarbon dating.

saturation with iron hydroxides. The lower boundary is distinct, uneven. The interlayers contain numerous paleontological remains (micro- and megafauna of mammals, fragments postcranial bird skeletons). Colluvial deposits. Thickness – 0.3–0.8 m.

Layer 4. Loess-like sandy loam and silty loam, brown-gray, with interlayers whitish in color due to high content of carbonates, with thin wave-like and lens-like lamination. Fossil soils are present as lenses and interlayers dark brown to black, with abundant

inclusions of charcoal fragments. The soils are heavily distorted by solifluction, folded and disrupted, so that no horizon can be traced. There are numerous inclusions of plant roots and isolated lenses of gravelly sand, with admixtures of angular rock fragments. Spots and laminae of reddish sand saturated with iron hydroxides occur in the lower part of the layer. The boundary with modern soil is distinct, often interrupted due to ploughing. Aeolian-colluvial deposits. Thickness – 1.0–1.8 m.

Layer 5. Silts and sandy loams, dark brown, modern podzolic soil (abandoned arable land). Thickness – 0.2–0.3 m.

The slope deposits are essentially polygenetic. The upper part of the sequence was accumulated with considerable contribution from eolian processes. At depth, clastic material transported from nearby sources by small streams and slope wash becomes dominant.

### 3.2. Geochronology

Fossil soils of layer 4 at a depth of 0.7–2.0 m were sampled and dated by radiocarbon (Table 1). The dates (uncalibrated) – 5710 ± 90 BP (IGAN-4154), 6010 ± 80 BP (IGAN-4153), and 6100 ± 90 BP (IGAN-4155) attribute the soil horizon development to the Atlantic optimum of the Holocene.

**Table 1**  
Details of available radiocarbon dates from deposits of the Zaktui site.

Stratigraphic context	Depth, m	Uncalibrated <sup>14</sup> C yr BP	Method	Material	Identification	Lab ref. no.
Buried soil	0,7 (layer 4)	5710 ± 90	<sup>14</sup> C	Organic remains		IGAN-4154
Buried soil	1,4 (layer 4)	6010 ± 80	<sup>14</sup> C	Organic remains		IGAN-4153
Buried soil	1,4 (layer 4)	6100 ± 90	<sup>14</sup> C	Organic remains		IGAN-4155
Sandy loams	2,3 (layer 3)	33 090 ± 250 <sup>a</sup>	<sup>14</sup> C AMS <sup>b</sup>	Bone	<i>Mammuthus primigenius</i> Blum.	OxA-21014
Sandy loams	2,3 (layer 3)	33 190 ± 240 <sup>a</sup>	<sup>14</sup> C AMS <sup>b</sup>	Bone	<i>Mammuthus primigenius</i> Blum.	OxA-21015
Sandy loams	2,3 (layer 3)	35 560 ± 300 <sup>a</sup>	<sup>14</sup> C AMS <sup>b</sup>	Bone	<i>Crocota spelaea</i>	OxA-19719
Sandy loams	2,3 (layer 3)	36 000 ± 800 <sup>a</sup>	<sup>14</sup> C AMS <sup>b</sup>	Tusk	<i>Mammuthus primigenius</i> Blum.	OxA-88 <sup>c</sup>
Silty sands	2,4 (layer 1)	>50 100	<sup>14</sup> C AMS <sup>b</sup>	Bone	<i>Alces</i> sp.	OxA-25678

<sup>a</sup> Shchetnikov et al. (2012).

<sup>b</sup> Indicates ultra-filtration samples.

<sup>c</sup> Indicates sample with low collagen yield (5.71 mg collagen from 330 mg original weight).

Bone-bearing layer 3 has been also radiocarbon-dated using AMS. The dates (uncalibrated) thus obtained on bones belonging to several mammal species are as follows (Table 1): 33 090 ± 250 BP (OxA-21014), 33 190 ± 240 BP (OxA-21015), 35 560 ± 300 BP (OxA-19719), 36 800 ± 1200 BP (OxA-88\*) (Shchetnikov et al., 2012); all of them fall within a rather narrow interval of the Karginian time (MIS 3). A lower-limiting AMS date (>50100 BP, OxA-25678) obtained on a moose bone from layer 1 suggests an early Karginian age of the layer.

### 3.3. Palynology

The Zaktui section has been sampled for pollen and spore analysis. The abundance of pollen grains in samples is highly variable, with the upper part of layer 1 (at a depth of 3.10–3.85 m) having the least. Some redeposited pollen grains of Pliocene – Early Pleistocene age were recorded in layers 2 and 1. Redeposited grains of *Tsuga*, *Corylus*, *Ulmus*, *Carya*, *Juglans* occur at 3.1 m depth, and those of *Carpinus*, *Tilia*, and *Diervilla* from 4 m downward. In the recent pollen assemblage, tree and shrub pollen constitutes 75% of the total, pollen of herbs and dwarf shrubs accounts for 16%, and spores for 9%. In the AP group, *Pinus sylvestris* pollen is dominant, and pollen of birches, *P. sibirica*, spruce and fir are also present. Non-arboreal plants are represented by Asteraceae, Geraniaceae, Onagraceae, Chenopodiaceae, Brassicaceae, and Ranunculaceae. In

the spore group there are grains of *Botrychium*, Polypodiaceae, and Lycopodiaceae (*Lycopodium clavatum*, *Lycopodium complanatum*, *Huperzia selago*). As follows from the pollen assemblage, the vegetation was dominated by pine forests (middle taiga type) with occasional areas of meadows. Based on the data obtained, 6 pollen complexes were distinguished corresponding to the principal stages in vegetation evolution (Fig. 3).

PAZ 1 (3.1–4.8 m, layer 1). Tree pollen (AP) constitutes 50–75% of the total pollen grain number. This group consists of *Abies*, *Picea*, *Pinus*, *Betula* (including *B. sect. Fruticosae* + *Nanae*), and *Alnus* + *Alnaster*. Of the NAP group, pollen of Ericales, Onagraceae, Caryophyllaceae, *Artemisia*, *Thalictrum*, and *Dryas* have been identified. Proportions of spores are up to 30–50%, Polypodiaceae being prevalent. The region was dominated by open deciduous and coniferous forests. A sizeable amount of *Betula* sect. *Fruticosae* + *Nanae*, *Alnus* + *Alnaster*, *Dryas*, and Polypodiaceae in the pollen assemblages suggests the presence of tundra plant communities in the landscapes under conditions of a rather cool climate. The vegetation was interstadial in appearance, and may be attributed to the beginning of the early Karginian interval (Shichi et al., 2007).

In the upper part of the layer 1 (3.0–3.9 m) the samples are poor in pollen and spores, with only occasional grains of *Picea*, *Pinus*,

*Alnus*, Ericaceae, and Gramineae. Spores are represented by *Botrychium*, Polypodiaceae, and *Diphysastrum alpinum*.

PAZ 2 (2.8–3.1 m, layer 2). AP pollen proportion increases to 80–85%. In this group, *Picea* rises sharply to 45%, while proportions of small-leaved trees (birch, willow), herbs, and spores are noticeably reduced. The warming known as the first Karginian optimum resulted in the taiga forests enlarging their areas and becoming the dominant type in vegetation.

PAZ 3 (2.1–2.8 m, layer 3). Proportion of herb and grass pollen – Chenopodiaceae, Asteraceae, *Ephedra*, *Artemisia* – rises to 50%. The AP group is dominated by *P. sylvestris*, *P. sect. Cembrae*, *Picea*, and *Betula*. Spores are represented by Polypodiaceae, *Botrychium*, *Lycopodium annotinum*, *L. complanatum*, and *D. alpinum*. The vegetation displayed a combination of coniferous forests, steppes, and relatively small areas of tundra communities forming a mosaic pattern. The climate was noticeably drier, although taiga forests persisted in landscapes.

PAZ 4 (1.1–2.1 m, the lower part of layer 4). Tree pollen is dramatically reduced, while that of shrub birches, as well as *Artemisia*, Onagraceae, Caryophyllaceae, and spores of Polypodiaceae gain in abundance. Treeless landscapes, meadow-steppe communities in combination with tundra, become prevalent under conditions of colder climate.

PAZ 5 (0.3–1.1 m, the upper part of layer 4). Proportions of *Pinus*, *Betula*, *Ephedra*, Caryophyllaceae, Asteraceae, *Thalictrum* pollen increase, as does *Sphagnum* spores, up to 15%. Dominant were tundra-

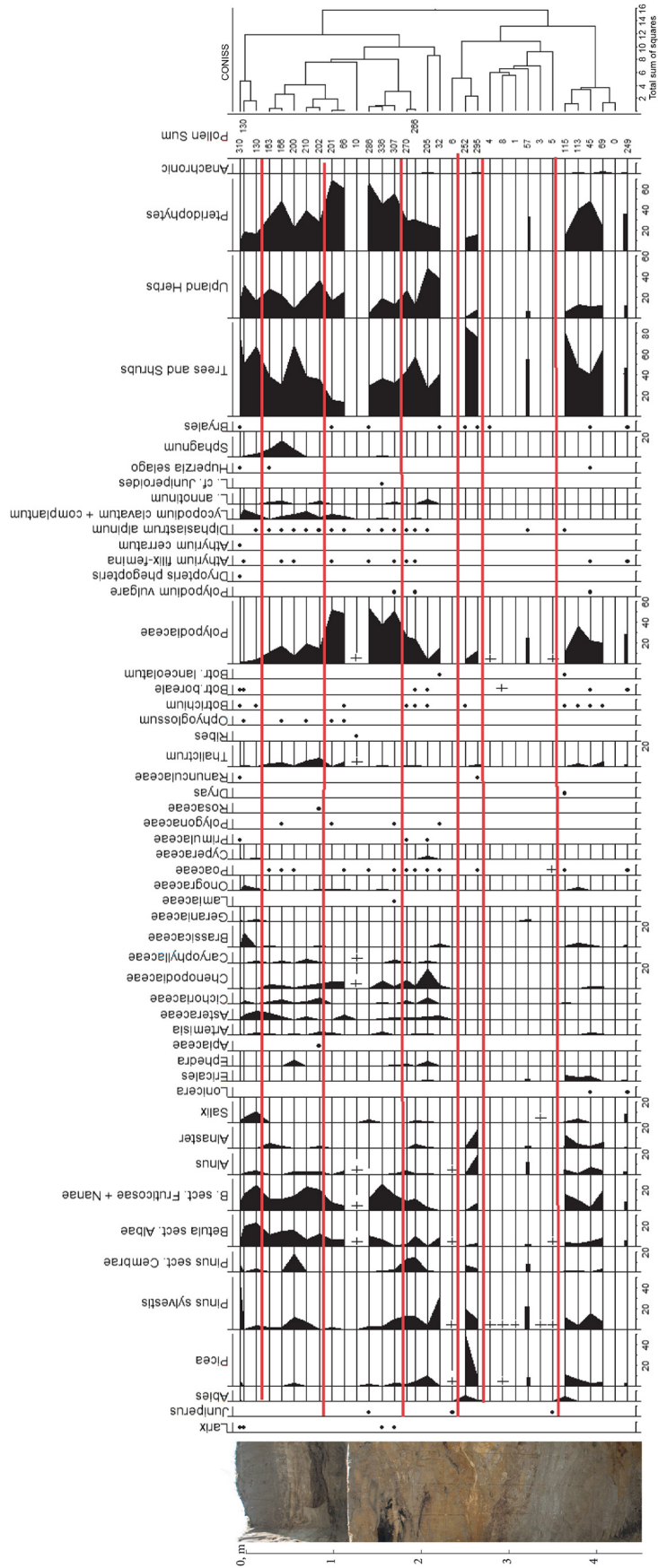


Fig. 3. Pollen diagram of Late Pleistocene sediments, Zaktui site.

steppe landscapes, with small areas of birch forests. The pollen assemblage identified in the sample from the depth of 0.75 m shows a noticeable increase in abundance of spruce and pine, which suggests an enlargement of the taiga forest area and better climate conditions. According to the radiocarbon dates, this pollen assemblage corresponds to the Atlantic optimum of the Holocene.

PAZ 6 (0.1–0.3 m, layer 5). The modern soil yielded pollen assemblages consisting of AP pollen to the extent of 50–65%. Proportion of pine, birch, and willow pollen increases noticeably, while pollen of *Alnaster* and *Ephedra* disappear. Also gaining in importance are Asteraceae, Brassicaceae, and Onagraceae pollen, as well as *L. clavatum* + *L. complantum* spores, although the total amount of spores decreases. Pine-birch forests became dominant, in combination with meadows.

### 3.4. Mammal fauna

During the excavations fossil mammal remains were collected in abundance from all the stratigraphic units of the sequence (Table 2).

**Table 2**  
Species composition of the Zaktui mammal fauna.

Taxon	Number of layer				
	5	4	3	2	1
<b>Insectivora</b>					
1 Soricidae gen. indet.		3/1			
<b>Lagomorpha</b>					
2 <i>Ochotona</i> sp.		8/1	5/1		1/1
<b>Rodentia</b>					
3 Sciurinae gen. indet.		1/1			
4 <i>Spermophilus undulatus</i> Pall.	1/1	7/1	1/1		
5 <i>Cricetulus barabensis</i> Pall.		1/1			
6 <i>Clethrionomys rutilus</i> Pall.		19/3	7/2		
7 <i>C. rufocanus</i> Sundev.		63/13	26/6		1/1
8 <i>Clethrionomys</i> sp.			1/1		
9 <i>Lemmus amurensis</i> Vinogr.		6/2			
10 <i>Lemmus amurensis/Myopus schisticolor</i>		20/5	2/1		
11 <i>Myopus schisticolor</i> Lill.		6/2			
12 <i>Alticola argentatus</i> Severtz.			1/1		
13 <i>Alticola</i> sp.		2/1			
14 <i>Lagurus lagurus</i> Pall.		5/2	1/1		
15 <i>Lasiopodomys brandti</i> Radde		40/12	27/11	1/1	2/1
16 <i>Microtus gregalis</i> Pall.		38/7	12/3	1/1	
17 <i>M. cf. arvalis</i> Pall.		1/1	2/1		
18 <i>M. maximowiczii</i> Schrenck			2/1		
19 <i>M. ex gr. fortis-maximowiczii</i>		1/1			
20 <i>M. agrestis</i> L.		1/1			
21 <i>M. oeconomus</i> Pall.		16/8	17/7		1/1
22 <i>M. mongolicus</i> Radde			2/2		
23 <i>Microtus</i> sp.		96/14	15/6	2/1	
24 Microtinae gen. indet.		13/3	3/2		
<b>Carnivora</b>					
25 <i>Crocota spelea</i> Gold.			1/1		1/1
<b>Perissodactyla</b>					
26 <i>Equus</i> sp.			9/2		
27 <i>Sussemionus</i> sp.			3/1		
28 <i>Coelodonta antiquitatis</i> Blum.			10/3		1/1
<b>Artiodactyla</b>					
29 <i>Capreolus pygargus</i> Pall.			1/1		
30 <i>Cervus elaphus</i> L.			4/1		
31 <i>Alces</i> sp.					1/1
32 <i>Procapra gutturosa</i> Gmel.			1/1		
33 <i>Bison priscus</i> Boj.			2/1		
<b>Proboscidea</b>					
34 <i>Mammuthus primigenius</i> Blum.			3/3		1/1

The lower part of layer 1 yielded a few remains of small mammals (*Ochotona* sp., *Clethrionomys rufocanus*, *Microtus oeconomus*), as well as rare fragments of large mammal bones (*Coelodonta antiquitatis* and *Crocota spelea*). Besides, there were found two remains of *Lasiopodomys brandti*.

In layer 2 there are occasional remains of small mammals (*Spermophilus undulatus*, *L. brandti*, *Microtus gregalis*, *M. oeconomus*) and large mammals (*Mammuthus primigenius*, *Alces* sp.). Two remains of vole (*Microtus* sp.) were also recovered from this layer.

Bone-bearing layer 3 (MIS 3) is distinct for both the most diversified species composition and the greatest concentration of bones. Small mammal remains are found as intact bones, postcranial skeleton fragments, mandibles and separate teeth identified as belonging to *Ochotona* sp., *S. undulatus*, *Clethrionomys rutilus*, *C. rufocanus*, *Clethrionomys* sp., *Lemmus amurensis/M. schisticolor*, *Alticola argentatus*, *Lagurus lagurus*, *L. brandti*, *M. gregalis*, *Microtus cf. arvalis*, *Microtus maximowiczii*, *M. oeconomus*, *M. mongolicus*, *Microtus* sp., and Microtinae gen. indet. Of the listed species, dominant were *L. brandti*, *C. rufocanus*, and *M. oeconomus*.

The large mammal faunal remains included bones of *C. spelaea*, *M. primigenius*, *C. antiquitatis*, *Equus* sp., *Sussemionus* sp., *Cervus elaphus*, *Capreolus pygargus*, *Bison priscus*, and *Procapra gutturosa* (Fig. 4). Dominant are bones of mammoth (3 individuals), woolly rhinoceros (3 individuals), and horse (2 individuals). An AMS date  $35\,560 \pm 300$  BP (OxA-19719) has been obtained on a bone of *C. spelaea*. Bones of two mammoths (*M. primigenius*) of different age were dated at  $33\,090 \pm 250$  BP (OxA-21014) and  $33\,190 \pm 240$  BP (OxA-21015) (Table 1). Of special interest is a unique find of a mammoth calf tusk fragment (Fig. 4) dated at  $36\,800 \pm 1200$  BP (OxA-88\*). Evidently the tusk is at the earliest stage of development. The found fragment is 37 mm long; the size at the base is 8.2/7.1 mm. The enamel about 1.1 mm thick is chipped at the top, so that dentin can be seen. The fragment shows a spiral-shaped curvature, in common with adult mammoth tusks. The back surface has enameled protrusions with tips directed towards the root. Seemingly, the mammoth calf did not begin to use its tusk, as the latter is not worn in use. It is, however, a permanent tusk, so the young mammoth could have been 2 or 3 years old (Shchetnikov et al., 2013).

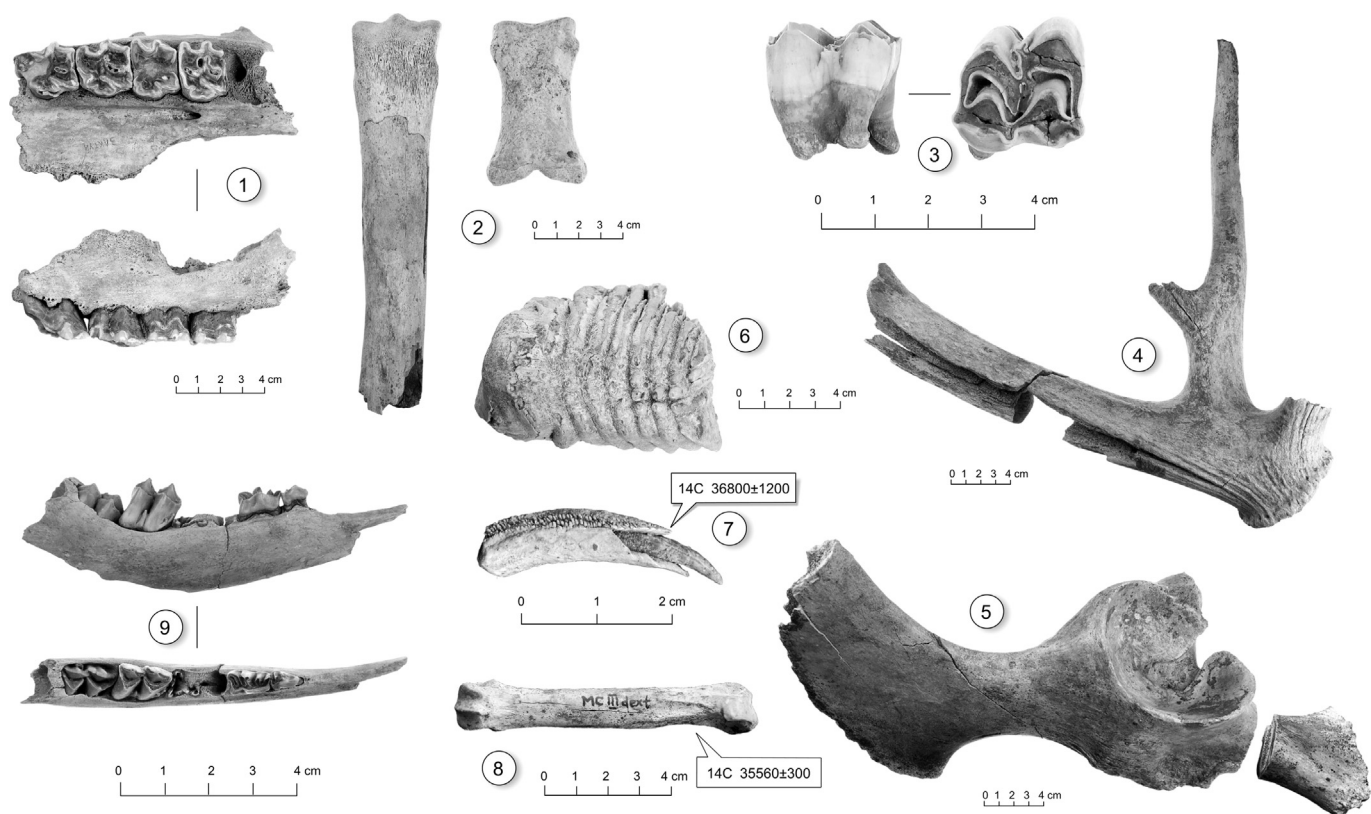
Layer 4 (MIS 1–2) yielded remains of the following small mammals: Soricidae gen. indet., *Ochotona* sp., *S. undulatus*, Sciurinae gen. indet., *C. rutilus*, *C. rufocanus*, *L. amurensis*, *L. amurensis/Myopus schisticolor*, *M. schisticolor*, *Alticola* sp., *L. lagurus*, *L. brandti*, *M. gregalis*, *M. cf. arvalis*, *Microtus ex. gr. fortis-maximowiczii*, *M. agrestis*, *M. oeconomus*, *Microtus* sp., and Microtinae gen. indet. Four species are dominant: *C. rufocanus* and *L. brandti*, and to a lesser degree *M. gregalis* and *M. oeconomus*, the bones of the two last species being less abundant by factor of 1.5. The species diversity increases towards the lower part of the layer. Layer 5 (recent soil, MIS 1) contains remains of *S. undulatus* (1 individual).

## 4. Palaeoenvironmental significance of the Zaktui locality

### 4.1. Palynological data

The most pronounced changes in pollen assemblages of the Zaktui sequence occur at a depth of 2.4 m, approximately at the boundary between layers 2 and 3. The deposits above that boundary formed in a relatively more arid climate than those below. This is indicated by the presence of steppe plant communities, somewhat reduced amount of *Picea* pollen, and a drastic growth of proportion of dwarf birch and herbs (*Ephedra*, Asteraceae, Chenopodiaceae) in the pollen spectra. As follows from studies of bottom sediment in Lake Kotokel (east of Lake Baikal) (Shichi et al., 2009; Bezrukova et al., 2010) and of subaerial deposits in the Fore-Baikal region (Arslanov et al., 2011), a noticeable enlargement of steppe coenosis areas occurred at approximately 32 ka BP, which is in complete agreement with the obtained  $^{14}\text{C}$  dates.

During Karginian time (MIS 3) the environments in the Baikal region were non-uniform (Shichi et al., 2007; Bezrukova et al.,



**Fig. 4.** The bone remains of large mammal fossils of Zaktui site: 1 – fragments of the upper jaw of *Hemionus* aut *Sussemionus*; 2 – limb bones of *Sussemionus*, 3 – the upper molar of *Cervus elaphus*, 4 – a piece of *Cervus elaphus* horn, 5 – the pelvic bone fragment of *Coelodonta antiquitatis*, 6 – fragments of upper molar of *Mammuthus primigenius*, 7 – tusk fragments of a young individual of *Mammuthus primigenius*, 8 – the metacarpal bone of *Crocuta spelaea*. Photos by A. Sizov.

2010; Arslanov et al., 2011; Bezrukova et al., 2011; Sato et al., 2014). Palynological data obtained from the Zaktui section indicate a noticeable expansion of spruce communities before 50 ka, 40–44 ka, and 33 ka. Similar changes in vegetation and climate were reconstructed in the south-eastern Baikal region based on studies of lacustrine and subaerial deposits (Bezrukova et al., 2010; Arslanov et al., 2011; Bezrukova et al., 2011). Taiga forests were dominant in the region during the first Karginian optimum, while taiga in combination with steppe and tundra during the second optimum of the Karginian. Some increase in the taiga forest area was also inferred from pollen assemblages recovered from samples at a depth of 0.75 m, correlatable with relative warming corresponding to the Atlantic optimum of the Holocene.

The uppermost part of layer 1 (to a depth of 4 m) is noted for scarcity of pollen grains and less diversified composition of redeposited pollen grains as compared with the lower part of the layer. Cluster analysis of pollen spectra also implies layer 1 division into two parts.

#### 4.2. Mammal fauna

The species composition of mammal fauna recovered from layer 1 suggests taiga, forest-steppe and meadow steppe landscapes were widespread during the layer deposition. That is in a reasonably good agreement with data indicating an interstadial type of vegetation dominated by open small-leaved and coniferous forests under conditions of cool climate. A find of woolly rhinoceros is indicative of open grasslands, and the presence of *L. brandti* of dry steppe spots on south-facing slopes with *Artemisia* communities.

Occasionally found mammal remains in layer 2 may be interpreted as evidence of meadow, meadow-steppe and taiga

landscapes at the time of layer deposition. The presence of Brandt's vole strongly suggests dry steppe biotopes persisting on the southern slopes of the Tunka rift basin.

A rich species composition of the mammal remains recovered from layer 3 points to the dominance of open landscapes (dry steppes, meadow steppes, meadows) and the proportion of taiga forests was reduced to 1/3. Both paleozoological and palynological data indicate a mosaic structure of landscapes of that time. Mammal species composition in layer 4 attests to the dominance of taiga forest massifs (42%) and steppes (37%), with a lesser proportion of meadows (19%) confined to river valleys and negligible participation of nival species (2%). A single remain of *S. undulatus* found in layer 5 points only to the presence of meadow-steppes, agreeing with palynological data on the prevalence of pine-birch forests in combination with meadow landscapes.

#### 5. Conclusions

The palynological, paleontological, and geochronological data obtained by integrated studies of eolian and colluvial deposits of the Zaktui sequence provided a means of understanding specific features of environments and climate evolution through the second half of the Late Pleistocene and Holocene (MIS 3–1). The spruce forest expansion occurred at the Karginian (MIS 3) optimum. Taiga forests were dominant in the region during the warm phase at the first half of the Karginian time, while taiga in combination with steppe and tundra dominated during the second Karginian optimum.

Noteworthy is a general trend towards increasing aridity in the second half of the Karginian, marked by widespread steppe and tundra biocoenoses. This is in agreement with the studies of the

Lake Kotokel bottom sediments (Shichi et al., 2009; Bezrukova et al., 2010) and of subaerial deposits in the Fore-Baikal region (Arslanov et al., 2011). The paleontological data suggest that the tundra biotopes were practically absent from the region at the second half of the Karginian interval, although pollen spectra indicate the presence of such plant communities. This phenomenon could be explained by the local-landscape zonal structure. The tundra landscapes occurred widely above the forest boundary in the mountains bordering the Tunka rift. Their lower boundary line was previously at a much lower height, approaching the Zaktui deposit by no more than a few kilometers. We think this is the explanation for the lack of evidence of the nival small mammal species, which do not tend to migrate over long distances, and for some finds of cryophyte pollen in the deposits of the Karginian cold intervals.

During the MIS 3 interval, the environments underwent essential transformations, relative warmings being repeatedly replaced with sharp coolings. On the whole, both the species composition of mammal fauna and palynological data points to a mosaic structure of landscapes. As follows from the palynological analysis of the deep-sea drill cores obtained from the Baikal bottom sediments (BDP Members, 2001, 2005) the early Karginian time was also marked by an expansion of forests due to climate warming and increase of humidity in the Fore-Baikal region. From the mid-Karginian time, according to the same source of data, steppe plant communities gain in importance and reach their maximum at the early Sartanian cooling (MIS 2). Our results are in reasonable agreement with those data.

During MIS 2, marked by cold extremely continental climate with a pronounced rainfall deficiency, the Tunka valley landscapes were dominated by tundra-steppe with small areas of birch forests. That agrees with the published results of studies performed on the Baikal (BDP Members, 2001, 2005) and Kotokel cores (Nakamura, 2009; Shichi et al., 2009; Bezrukova et al., 2010). Since the beginning of MIS 1, the climate noticeably improved. The formation of paleosol horizon (recorded in the section at a depth of 0.7–2.0 m) may be correlated with the Atlantic optimum of the Holocene characterized by an expanding range of taiga forests in the region and increasing proportion of *Picea* communities.

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