Quaternary International 623 (2022) 159–168

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

The Early Neolithic–Middle Bronze Age environmental history of the Mamakan archaeological area, Eastern Siberia

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ARTICLE INFO

Keywords:
Middle Holocene
Lake Baikal Region
Human–environment interactions
Palynology
Charcoal analysis
Scots pine spread

ABSTRACT

This study presents the first radiocarbon-dated palynological record from a peat section (57°49′10.03"N; 114°03′31.37"E, 251 m above sea level) in the Mamakan area located in the lower Vitim River valley, about 350 km northeast of Lake Baikal. While the area is particularly renowned for its numerous multi-layered Upper Palaeolithic (ca. 50,000–14,000/10,000 cal yr BP) archaeological sites with rich cultural assemblages, there is also evidence for human occupation during the Mesolithic–Neolithic–Bronze Age period (ca. 14,000/10,000–3000 cal yr BP). However, the absence of accurately dated palaeoenvironmental records does not allow discussion of prehistoric human–environment interactions in this area. The records of pollen, spores and other non-pollen palynomorphs (NPPs) from the Mamakan site presented in this article document changes in the vegetation and climate of the study area between 6570 and 3630 cal yr BP. From 6570 to 6200 cal yr BP the vegetation around the site was dominated by sparse forests of mainly spruce and larch, indicating that the permafrost layer was located relatively close to the surface. Fir was part of the forest communities in habitats with a milder microclimate and a deeper permafrost layer. Around 6200 cal yr BP Scots pine started to spread across the study area. Until 4670 cal yr BP it dominated the pollen spectra of the Mamakan record, indicating warmer conditions. Climate cooling and higher soil moisture is indicated by the spread of Siberian pine and Siberian dwarf pine at the expense of Scots pine between 4670 and 3840 cal yr BP. From 3840 cal yr BP the Mamakan record suggests a landscape opening associated with the spread of *Sphagnum*-dominated bog vegetation and an increase in the occurrence of wildfires (3870–3820 cal yr BP), which were either natural in origin or caused by human activities. The spread of Scots pine paralleled by a decline in dark conifers (spruce and fir) and larch in the Lake Baikal Region (LBR) has been linked to a 'hiatus' in the Cis-Baikal archaeological records of the Middle Neolithic (6660–6060 cal yr BP). Around the Mamakan site this vegetation change occurred comparatively late, about 600 years later than in the regions around and east (e.g. Lake Baunt area) of Lake Baikal. The Mamakan pollen and NPP records, together with the available archaeological data, suggest that the environmental conditions in the lower Vitim River area may have sustained the hunter-gatherer lifestyle also during the 'hiatus' interval.

1. Introduction

The history of the Holocene natural environment in the Mamakan area of the northern Lake Baikal Region (LBR) (Fig. 1), which is known for its rich archaeological records, is still poorly understood. There are over 50 archaeological sites along the lower Vitim River traversing the Patom Plateau (Fig. 1A). The major archaeological sites in the Mamakan area, such as Avdeikha, Bolshoy Yakor I and II, Invalidny I–III, Kovrizhka I–V and Mamakan I–VI (Fig. 1B), contain over 30 stratified cultural layers associated with the Upper Paleolithic (ca. 50,000–14,000/10,000 cal yr BP), Mesolithic (ca. 14,000/10,000–8000 cal yr BP) and Neolithic (ca. 8000–5000 cal yr BP) periods (Ineshin and Tetenkin,

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https://doi.org/10.1016/j.quaint.2021.12.006
Received 14 July 2021; Received in revised form 8 December 2021; Accepted 9 December 2021
Available online 10 December 2021

2010; Henry et al., 2018; Tetenkin, 2018). A series of radiocarbon (^{14}C) dates from dwellings of these sites (Ineshin and Tetenkin, 2010) indicate periods of human activity at 22,300–15,000, 13,000–11,000 and 9000–6000 cal yr BP (throughout this paper calibrated ^{14}C ages in years before present, i.e., cal yr BP, are presented, if not stated otherwise).

The site Bolshoy Yakor I (57°49′23″N, 113°58′41″E; Fig. 1B), located at an altitude of 255 m above sea level (a.s.l.) and discovered in 1995, is the most informative and well-studied one in the northern LBR (Ineshin and Tetenkin, 2010). The uppermost cultural layers within the sediments of subaerial genesis were attributed to the Neolithic and Bronze Age (ca. 5000–3000 cal yr BP) and the lower cultural layers were deposited during the Lateglacial (ca. 15,000–13,500 cal yr BP). The stratigraphy and cultural and faunal assemblages of this archaeological site indicate various episodes of short-term to relatively long-term occupation (Ineshin and Tetenkin, 2010).

To date, only few low-resolution landscape and climate reconstructions covering the time span from the end of the Last Glacial Maximum (LGM) to the beginning of the Middle Holocene are available from the Mamakan area. A tundra-steppe landscape was reconstructed in the area for the Lateglacial and Early Holocene based on the scarce presence of arboreal pollen identified in contemporaneous sediments (Ineshin and Tetenkin, 2010). Anthracological studies indicate a predominance of shrubby willow and dwarf birch during the same time span (Henry et al., 2018). The remains of large and small mammals recovered from archaeological cultural layers and natural sediment sequences also indicate that during this period the area was inhabited by animals, which are representative for treeless or sparsely wooded landscapes, including tundra-steppe, forb-shrub tundra and forest-tundra (Ineshin and Tetenkin, 2010 and references therein). A few pollen records suggest that in the inner regions of the Patom Plateau Scots pine (*Pinus sylvestris* L.) started to spread at about 3200 cal yr BP, and thus much later than in the regions around Lake Baikal located further southwest (Anderson et al., 2007; Bezrukova et al., 2009; Kobe et al., 2020).

Occupying a vast area in the southern part of Eastern Siberia, the LBR is influenced by air masses from the Atlantic, Pacific and Arctic Ocean as well as by the Asian anticyclone circulation during winter (Alpat'ev et al., 1976; Kostrova et al., 2020). This and the complex topography of the LBR determine the main features of the regional hydrology, mosaic vegetation cover and climatic variability (Galaziy, 1993; Kobe et al., 2020). Palaeoenvironmental reconstructions derived from a ^{14}C-dated pollen record from Lake Kotokel in the Trans-Baikal subregion (Fig. 1) suggest that the Holocene maximal spread of the boreal taiga associated with a warmer and wetter-than-present climate occurred between ca. 10,800 and 7300 cal yr BP (Tarasov et al., 2009). A later pollen-based woody-cover reconstruction (Bezrukova et al., 2010) demonstrates a noticeable decrease in woody cover percentages around the lake ca. 6800–6000 cal yr BP and a regional spread of Scots pine accompanied with insolation-induced changes in precipitation and temperatures. A similar increase in *P. sylvestris* pollen percentages after ca. 7000 cal yr BP was also recorded in the sediment cores from Lake Baikal and the Trans-Baikal area (e.g., Demske et al., 2005; Shichi et al., 2009; Bezrukova et al., 2017). The fact that both millennial trends and centennial variability in pollen percentages and numerical scores of the dominant regional biomes derived from the Kotokel pollen record (Tarasov et al., 2009; Bezrukova et al., 2010) show a striking similarity with oxygen isotope records of the Northern Hemisphere air temperature (Svensson et al., 2008) and the Asian summer monsoon intensity (Yuan et al., 2004) supports the modern observations (Kostrova et al., 2020) and isotope-based climate reconstructions (Kostrova et al., 2013; Harding et al., 2020) showing that the Holocene environments around Lake Baikal were influenced by the North Atlantic and the North Pacific climate systems (Tarasov et al., 2017).

On the other hand, palynological investigations of Holocene peat sediments around Lake Baikal demonstrate that the environment and vegetation of the three different microregions reacted differently to the climatic shifts of the past 7000 years (Bezrukova et al., 2013). Beside of demonstrating the existing interregional variability within the LBR, their study hypothesized that environmental impact on the prehistoric hunter-gatherers of the LBR was strongest in the climatically more sensitive arid microregion to the west of Lake Baikal in comparison to the more humid areas east and south of the lake (Bezrukova et al., 2013). More recent studies comparing results of pollen (Kobe et al., 2020, 2021) and diatom-based oxygen isotope analyses (Harding et al., 2020) from different microregions located north, south and east of Lake Baikal also document a high sensitivity of the entire LBR to both internal and external climate forcing and highlight the influence of site-specific factors on the individual records. These publications thus stress the necessity for obtaining accurately dated multi-proxy records of Late Quaternary climate and environments from the so far poorly studied parts of the LBR in order to test earlier and new hypotheses based on individual sites or/and records. This task also corroborates the aims of the interdisciplinary Baikal Archaeology Project (BAP), which investigates hunter-gatherer culture dynamics in the LBR with a focus on the interval between ca. 8300 and 3500 cal yr BP (Losey and Nomokonova, 2017; Weber, 2020; Weber et al., 2021). One aim of the new phase of this long-term project, which began in 2018, is to search for detailed palaeoenvironmental records representing all geoarchaeological microregions, particularly from the understudied Cis-Baikal area (e.g., Kobe et al., 2020; Weber, 2020).

In this paper we present vegetation and climate reconstructions for the lower Vitim River region on the Patom Plateau, north-eastern Cis-Baikal, based on a new pollen record from the Mamakan sediment section located about 350 km northeast of Lake Baikal (Fig. 1) and in the proximity of the archaeological site complexes Bolshoy Yakor, Invalidny, Kovrizhka, Avdeikha and Mamakan. The results are compared with published vegetation and climate records from the LBR and Central Yakutia and available archaeological records from the study area.

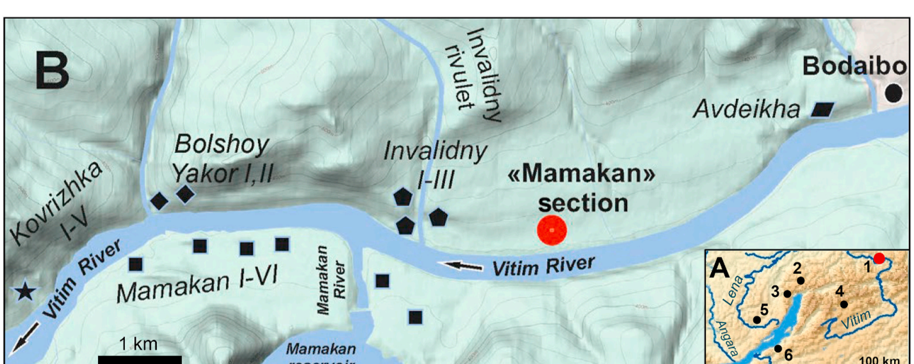

Fig. 1. A – location of the studied Mamakan section (1, red dot) in the northern part of the Lake Baikal Region and positions of the other sedimentary records (black dots) discussed in the text (2 – Ozerny-5, Synnar Range; 3 – Okunaika, Baikalskii Range; 4 – Lake Baunt; 5 – Lake Ochaul; 6 – Lake Kotokel). B – location of the Mamakan sediment section and neighbouring archaeological sites along the lower Vitim River valley. Each site is marked by a corresponding symbol. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Study site and regional setting

The Mamakan sediment section is located near the town of Bodaibo in the Irkutsk region on the Patom Plateau, which has a maximum elevation of 1924 m a.s.l. (Fig. 1). The studied site lies on the right bank of the Vitim River (57°49′10.03″N, 114°03′31.37″E), 1.7 km upstream of Invalidny rivulet (a right tributary of the Vitim River) and 2.2 km upstream of the mouth of the Mamakan River (a left tributary of the Vitim River) (Fig. 1B). The sampled sediment section is located in a swampy part of the Vitim River terrace with a maximum height of 9–14 m above river level (Ineshin and Tetenkin, 2010). The top of the section lies 12 m above and 280 m north of the Vitim River bank.

The regional climate is marked by pronounced continentality (Atlas Zabajkal'ya, 1967). Winters are long and cold and summers are short and warm. Maximum summer temperatures reach up to 40°C and minimum temperatures in winter can fall to −55°C. The mean annual precipitation is 425 mm. The average depth of the snow cover from November to April is up to 60 cm.

According to the botanical zonation, the area belongs to the Patom mountain taiga province (Atlas Irkutskaya Oblast', 2004) dominated by larch (*Larix gmelinii* (Rupr.) Rupr) and Scots pine (*Pinus sylvestris* L.) forests. The partly sparse larch-dominated shrub-moss forests with an understory of Siberian dwarf pine (*Pinus pumila* (Pallas) Regel) are commonly distributed on steep slopes of southern and north-western exposition descending to river valleys or in levelled areas. Flatlands at higher altitudes are mostly occupied by Siberian spruce (*Picea obovata* Ledeb.), Siberian pine (*Pinus sibirica* Du Tour) and fir (*Abies sibirica* Ledeb.) forests and Siberian dwarf pine and heath (*Ledum palustre* L., *Vaccinium uliginosum* L.) shrubs. Birch and larch forests accompanied by Siberian pine generally prevail in the area around the Mamakan site. Spruce grows along the Invalidny rivulet. The vegetation at the Mamakan site is dominated by wet meadows with diverse grasses and herbs.

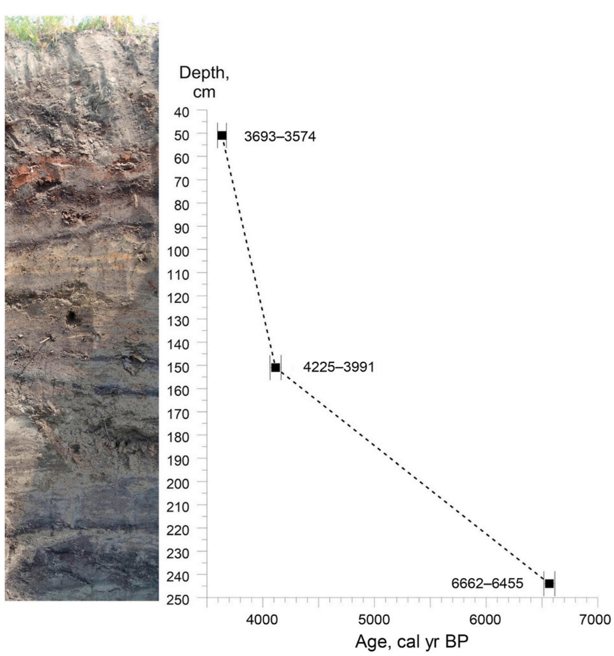

Fig. 2. Photograph demonstrating the Mamakan sediment section along with the position of the three AMS ^{14}C dates (Table 1) and their calibrated age ranges (95.4% confidence intervals) , as well as the resulting age-depth relationship for the studied section (243–50 cm depth).

3. Material and methods

3.1. Study material and age determination

The Mamakan sediment section (Fig. 2) analysed in the current study represents a natural trench that was formed by surface runoff. The upper 50 cm of the 243 cm section were not sampled since the sediments, represented by grey loess-like sandy loams with thin interbeds of light loam, were too loose for secure and contamination-free recovery. The rest of the section is represented by an alternation of peat soils and peat and thin layers of sands of fine to medium size (Fig. 2). A total of 77 sediment samples, each representing 1 cm in depth and 1 cm^3 in volume, were collected for palynological analysis. Between 243 and 175 cm depth samples were collected in 4-cm steps and between 175 and 50 cm depth in 2-cm steps. To determine the sediment age, AMS ^{14}C dating was performed on three bulk sediment samples. Sample preparation including standard chemical pretreatment and graphitisation was carried out at the Center for Collective Use in the Laboratory for Radiocarbon Dating and Electron Microscopy, Institute of Geography, Russian Academy of Sciences (RAS), Moscow. AMS dating was performed at the Center for Applied Isotope Research of the University of Georgia, USA. All ^{14}C ages were calibrated using OxCal v4.3 software (Bronk Ramsey, 1995) and the IntCal20 calibration curve (Reimer et al., 2020). The obtained ages (Table 1) were used to construct an age-depth model for the studied section (243–50 cm depth). The age-depth model is based on linear interpolation between the medians of the calibrated ages and the mid-points of the associated sample depth intervals. Mentioned calendar ages of other, published ^{14}C dates were recalibrated using also OxCal v4.3 software and the IntCal20 calibration curve.

3.2. Palynology

The sediment samples were processed for pollen analysis using standard laboratory methods (Faegri and Iversen, 1989), including HCl to dissolve carbonates and KOH to remove organic and humic materials. Minerogenic material in the samples was removed by density separation using $ZnCl_2$ solution (specific gravity = 2.0 g/cm^3). A 40% HF treatment was also applied to the samples. In order to estimate the concentrations of pollen and spores, a known quantity of exotic *Lycopodium* marker spores (Lyco Batch No 483216: 18,583 spores in one tablet) was added to each sample (Stockmarr, 1971) prior to chemical treatment. The pollen and spores were counted until their quantity per sample reached 500, excluding the added marker spores. Calculation of pollen percentages was based on the sum of arboreal pollen (AP) and non-arboreal pollen (NAP). Percentages for spores of *Sphagnum*, Polypodiophyta, Lycopodiaceae, *Equisetum* were calculated based on the total sum of terrestrial pollen (AP + NAP) and spores taken as 100%. In addition to pollen grains and spores of higher plants, we counted non-pollen palynomorphs (NPPs). Percentages for each taxon were calculated based on the total sum of terrestrial pollen and spores taken as 100%. To calculate taxa percentages and plot the pollen-spores and NPP diagrams, we used the TILIA software version 1.7.16 (Grimm, 2011).

Pollen and NPPs were taxonomically identified with the help of published sources (Lundqvist, 1972; van Geel, 1978; Reille, 1998; Hyde et al., 1998; Tsyganov and Mazei, 2006; Yeloff et al., 2007; Hafellner and Zimmerman, 2012; Demske et al., 2013; Savelieva et al., 2013; van Geel et al., 2016; Ivanova and Ivanova, 2017; Piasai and Sudsanguan, 2018) and a modern pollen reference collection stored at the Institute of the Earth's Crust and the Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, Irkutsk. In addition to pollen and spores, microcharcoal particles of >10 μm in size were counted. At least 200 microcharcoal particles were counted per sample and used as a

Table 1
Radiocarbon dates for bulk sediment samples from the Mamakan sediment section (Fig. 1) used to build the age-depth model (Fig. 2). All samples were AMS-dated at the Center for Applied Isotope Research of the University of Georgia, USA and calibrations were performed using OxCal v4.3 (Bronk Ramsey, 1995) and the IntCal20 calibration curve (Reimer et al., 2020).

Laboratory No.	Depth (cm)	Radiocarbon date (^{14}C BP)	δ13C (‰)	Calibrated age, 95% confidence interval (cal yr BP)	Median of calibrated age (cal yr BP)
8369–$IGAN_{AMS}$	50–52	3400 ± 20	−26.6	3693–3574	3634
8370–$IGAN_{AMS}$	150–152	3750 ± 20	−24.9	4225–3991	4115
8371–$IGAN_{AMS}$	243–245	5765 ± 35	−23.8	6662–6455	6566

proxy for fire activity (Adolf et al., 2017). To calculate microcharcoal concentrations we used *Lycopodium* marker spores (Finsinger and Tinner, 2005).

We used the ratio of AP to NAP as an indicator of forest coverage of the area around the sampling location (Cheung et al., 2014). We also used the ratio of pollen of mesophytic ‘dark coniferous taiga’ trees (Dc = *Picea, Abies, Pinus sibirica*) to pollen of drought tolerant ‘light coniferous taiga’ taxa (Lc = *Larix, P. sylvestris*) as an indicator of relative moisture variability.

4. Results

4.1. Chronology

The obtained calibrated ages of the ^{14}C dates (Table 1) indicate that the studied part (243–50 cm depth) of the Mamakan section was formed between ca. 6570 and 3630 cal yr BP (medians of calibrated age ranges). The constructed age-depth model (Fig. 2) shows that with 4.8 years per cm the sedimentation rate is relatively high in the upper part (243–151 cm) of the section. In the lower part (151–50 cm) it is lower, i.e., ca. 26 years per cm.

4.2. Palynological analysis

The pollen diagram (Fig. 3) is divided into four local pollen assemblage zones (PAZ) Mmk-1–4 and their compositions are described from the bottom up.

In **PAZ Mmk-4** (243–230 cm, ca. 6570–6200 cal yr BP) the spore and pollen concentrations are on average about 4000 palynomorphs/cm^3. The AP percentages are relatively high (i.e., 72%, average pollen percentage values are given throughout the text). Spruce, larch and fir pollen demonstrate highest percentages of the entire record (35%, 14% and 8%, respectively), while Scots pine and Siberian pine show lowest values (19% and 10%, respectively). The pollen abundance of shrub taxa is below 6%, while the contribution of heath and herbaceous taxa is 4%. The spore taxa, mainly ferns (Polypodiophyta) and allies (*Lycopodium clavatum* and *Dyphasium complanatum* (L.) Rothm.), contribute ca. 18% in this zone.

PAZ Mmk-3 (230–172 cm, ca. 6200–4670 cal yr BP) is characterized by an average spore and pollen concentration of 2500 palynomorphs/cm^3. Arboreal pollen taxa still dominate (82%). Scots pine pollen reach highest percentages of the entire record (52%). The zone is characterized by a steady decrease in spruce, larch and fir pollen values to 13%, 5% and 3%, respectively. The values for heath (Ericaceae) and herbaceous (Poaceae, Cyperaceae and *Artemisia*) pollen taxa are low (3%). The percentages of Chenopodiaceae pollen are below 2%. The spore assemblage is still dominated by Pteridophytes.

In **PAZ Mmk-2** (172–94 cm, ca. 4670–3840 cal yr BP) the concentration of spores and pollen is about 5000 palynomorphs/cm^3. High frequencies of AP taxa (81%) and dominance of Scots pine (49%) in the pollen assemblage are noticeable in this zone. Compared to PAZ Mmk-3, pollen percentages of Siberian pine are higher (25%). Pollen percentages

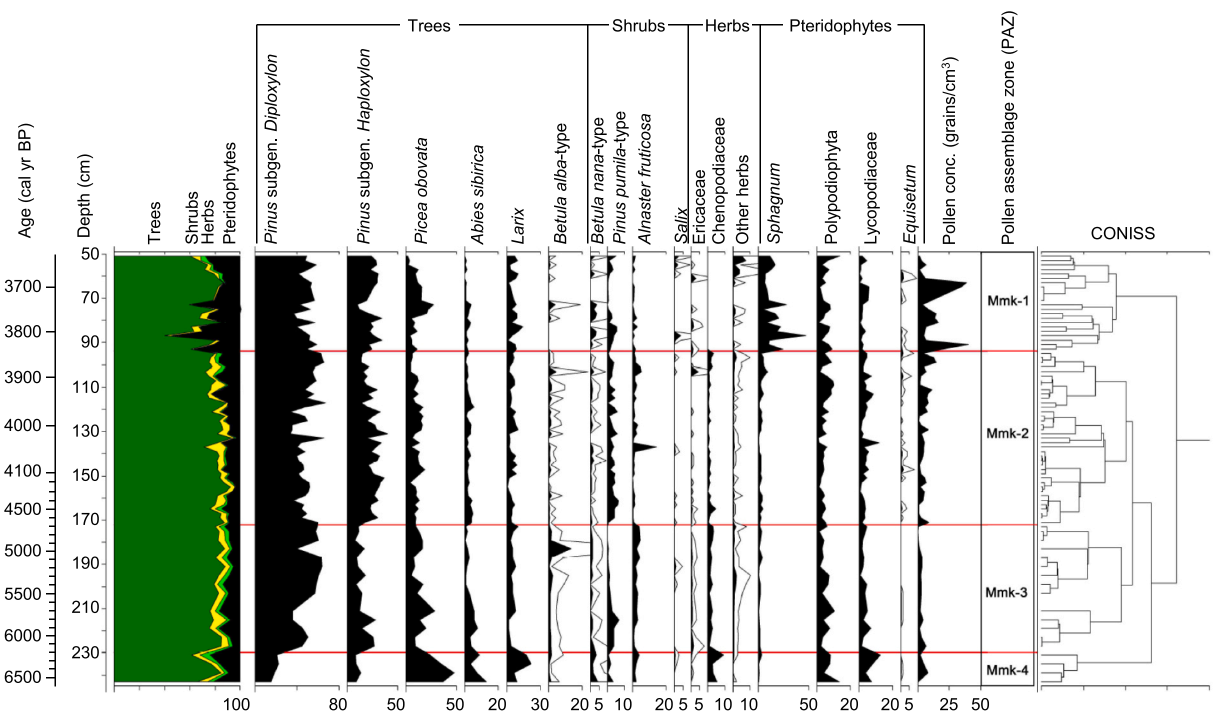

Fig. 3. Percentage pollen and spores diagram of the most abundant taxa from the Mamakan sediment section plotted along depth and age axes.

of spruce, larch and fir are around 10%, 5% and 2.5%, respectively. The pollen spectra demonstrate a steady presence of Siberian dwarf pine (3%). The percentages of spores increase up to 12%, mainly represented by ferns and club mosses (Lycopodiopsida).

PAZ Mmk-1 (94–50 cm, ca. 3840–3630 cal yr BP) is characterized by highest pollen and spore concentrations of about 12,500 palynomorphs/cm^3. The AP percentages decline to 71%. However, average percentages of Scots pine and Siberian pine pollen are more or less comparable to that in PAZ Mmk-2. Fir pollen percentages decrease from 2.5% to 1.4%, whereas pollen percentages of larch increase from 5% to 6.7%. The values for shrub and herbaceous pollen taxa are 3.5% and 1%, respectively. This zone is highlighted by the highest spore abundance (24%) of the entire record. The spore spectra are dominated by *Sphagnum* mosses, which reach highest values (15%) in this PAZ.

4.3. Non-pollen palynomorphs

A number of NPPs (Fig. 4) was microscopically identified and counted along with the pollen and spores of higher plants.The NPP diagram (Fig. 5) is divided into four local zones (Mmk-a–d). For comparison with the pollen record they are described by the defined PAZ.

Mmk-d (243–230 cm, ca. 6570–6200 cal yr BP) shows the presence of spruce and Scots pine stomata and shells of *Arcella gibbosa*. Fungal spores, especially those of Coniochaetaceae and *Sordaria* are abundant.

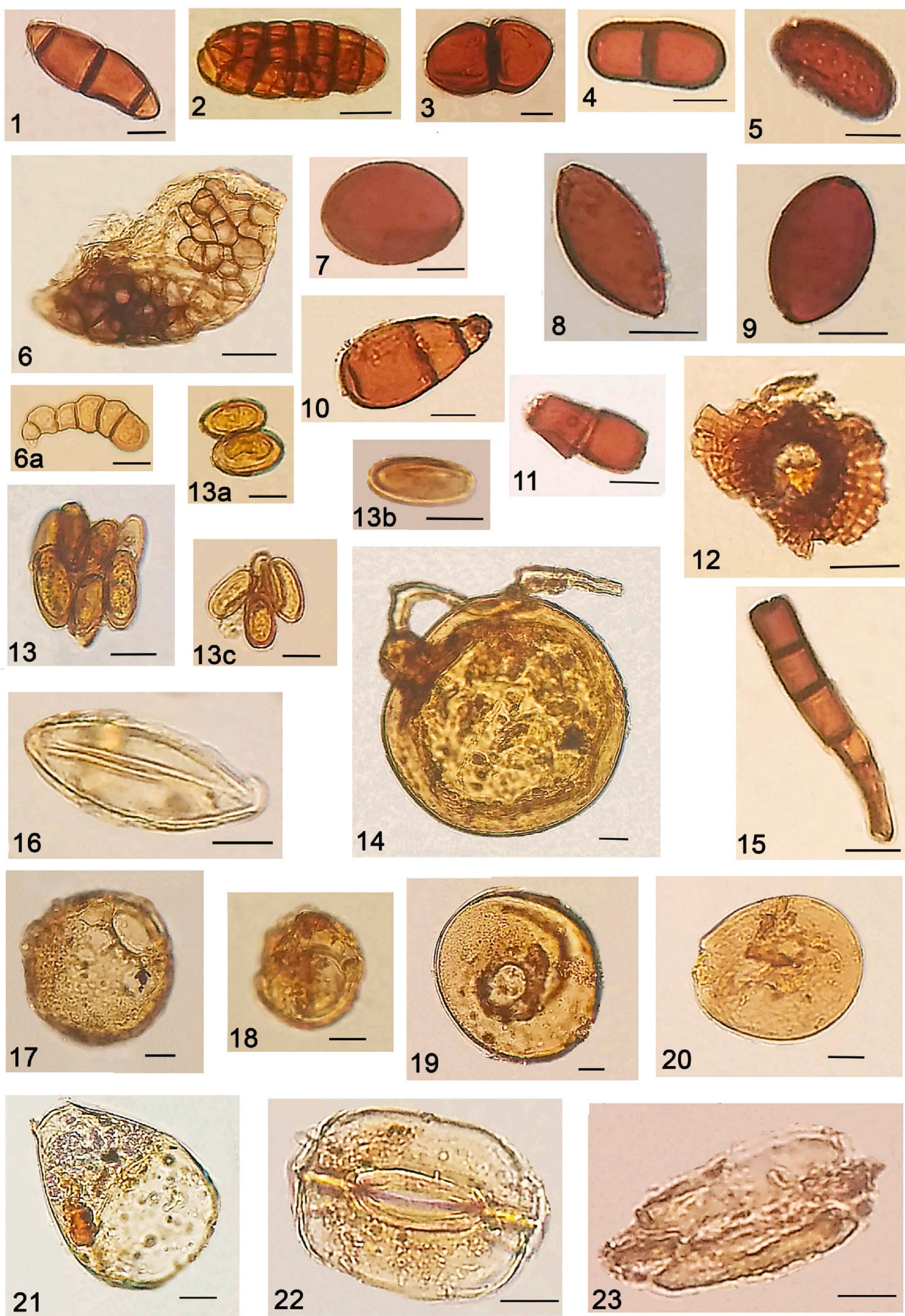

Fig. 4. Photographs of non-pollen palynomorphs (NPPs) commonly observed in the analysed samples from the Mamakan sedimentary section. **Fungi:** 1 – *Meliola*; 2 – *Pleospora*; 3 – ascospora; 4 – *Delitschia*; 5 – *Gelasinospora*; 6 – *Trimmatostroma salicis*; 7 – *Podospora*; 8, 9 – *Sordaria*; 10 – *Trichocladium*; 11 – *Sporomiella*; 12 – *Microthirium*; 13a–c – Coniochaetaceae; 14 – *Glomus*; 15 – *Clasterosporium*. **Algae:** 16 – *Spirogira*. **Amoebae:** 17, 18 – *Centropyxis*; 19 – *Arcella*; 20 – *Assulina*; 21 – *Nebela*. Stomata: 22 – *Pinus sylvestris*-type; 23 – *Larix*.

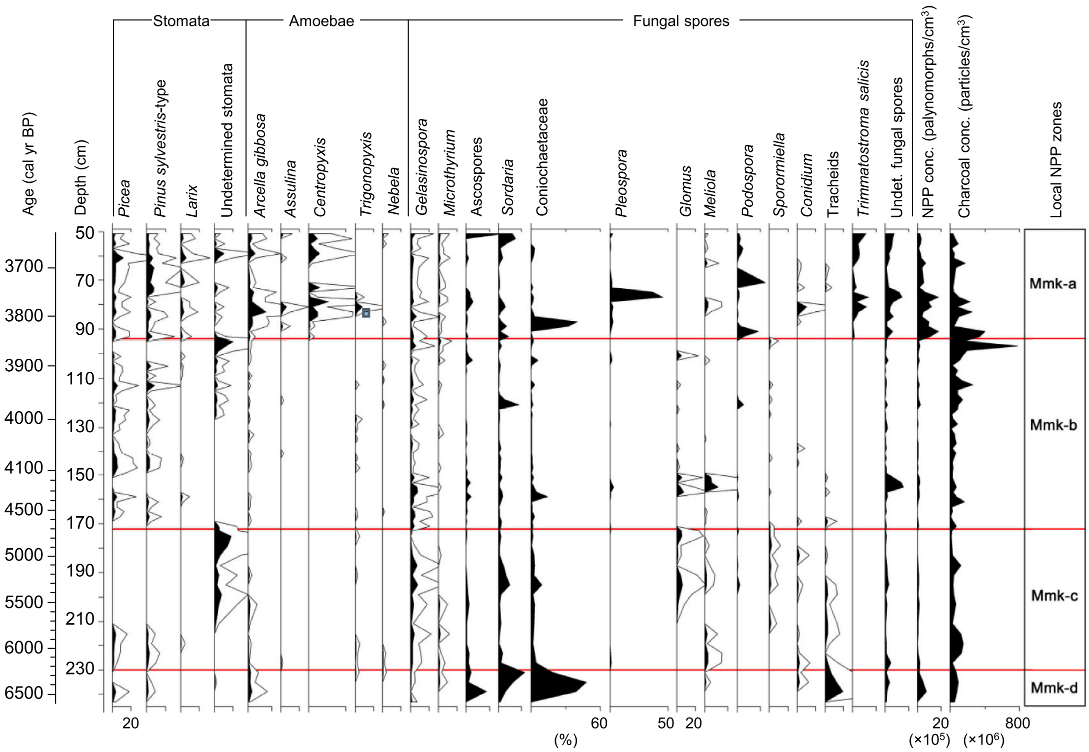

Fig. 5. Percentage non-pollen palynomorphs (NPPs) diagram for the Mamakan sediment section plotted along depth and age axes.

The zone shows high abundance of plant tracheids and charcoal particles (75,500 pcs/cm^3 as average).

Mmk-c (230–172 cm, ca. 6200–4670 cal yr BP) is characterized by the presence of conifer stomata until ca. 5700 cal yr BP. The period between 5700 and 4700 cal yr BP is marked by relatively high frequencies of undetermined stomata and fungal spores of *Gelasinospora, Glomus* and *Sporormiella.* The average charcoal particle concentration is 63,000 pcs/cm^3.

Mmk-b (172–94 cm, ca. 4670–3840 cal yr BP) shows an almost continuous presence of stomata of spruce and Scots pine. Larch stomata also occur more frequently than in Mmk-c. Fungal spores of *Gelasinospora* and *Sordaria* occur throughout the profile, although *Sordaria* occurs less frequent than in Mmk-c. At a depth of 160–150 cm, the record reveals substantial peaks in fungal spores (Coniochaetaceae, *Pleospora*, *Glomus* and *Meliola*) percentages in combination with peak values for charcoal particles (170,000 pcs/cm^3), which are much higher than the average concentration of 94,000 pcs/cm^3.

Mmk-a (94–50 cm, ca. 3840–3630 cal yr BP) is characterized by a continuous presence of spruce, Scots pine and larch stomata with percentages similar to that in Mmk-b. Among the testate amoebae, shells of *Arcella gibbosa, Centropixis* and *Assulina* occur more frequently than in the three lower zones. Spores of fungi, such as *Gelasinospora, Microthyrium, Meliola* and *Trimmatostroma salicis*, are continuously present. The charcoal concentration is 115,000 pcs/cm^3 on average.

5. Discussion

5.1. Regional vegetation and climate history 6570–3630 cal yr BP

Based on a study of the lithology and chronology of the Vitim River terrace complex at a location next to the Mamakan section, (Ineshin and Tetenkin, 2010) dated the transition from floodplain sedimentation to subaerial sediment accumulation. The calibrated ages of two ^{14}C dates (SBRAS-4245, 6095 ± 135 ^{14}C BP and SBRAS-4545, 5945 ± 90 ^{14}C BP) (Ineshin and Tetenkin, 2010) date this transition to around 7300–6500 cal yr BP (sum of 95.4% confidence intervals). By the Middle Holocene glaciers in the area only existed as small mountain glaciers (Margold et al., 2016). Therefore, the amount of meltwater into the Vitim River became much smaller, which was likely the main reason for the change in sedimentation. The studied Mamakan peat section started to form shortly after the recorded onset of subaerial sediment deposition in the Vitim valley (Ineshin and Tetenkin, 2010).

The Mamakan pollen record with a relatively high temporal resolution characterizes the vegetation and climate history of the area between 6570 and 3630 cal yr BP, which covers the second half of the Middle Holocene and the beginning of the Late Holocene (Walker et al., 2012). The pollen record indicates a relatively widespread distribution of boreal forests in the vegetation cover between 6570 and 6200 cal yr BP, with maximum percentages of spruce and larch pollen and a relatively high contribution of fir pollen. The relatively short-distant pollen distribution of these boreal trees implies they grew locally (Heinrichs et al., 2002; Bezrukova et al., 2005; Lozhkin et al., 2007). The ecological-climatic affinities of spruce and larch suggest that the permafrost layer was close to the surface (Bezrukova et al., 2005) and the permafrost thaw in summer provided favourable conditions for their growth. Probably spruce-dominated forests occupied valleys of rivers and streams. As recorded in pollen records from Lake Baikal and Lake Kotokel sediments as well as from peatlands in the north-western and southern mountain periphery of Lake Baikal (Demske et al., 2005; Tarasov et al., 2007, 2009; Bezrukova et al., 2008, 2009), dominance of boreal forests with a significant proportion of spruce was reconstructed for the period 9000–7000 cal yr BP also in these study regions. The wider-than-present distribution of spruce, fir and fern communities around the Mamakan site at 6570–6200 cal yr BP corresponds to the final phase of their maximum spread in the study region. During this period the climate around the Mamakan site was moderately cold and marked by high air and soil moisture. The occurrence of *Arcella gibbosa* valves, Coniochaetaceae, *Sordaria* spores and ascospores supports enhanced moisture availability (van Geel, 1978; Hyde et al., 1998; Reille, 1998; Tsyganov and Mazei, 2006; Hafellner and Zimmerman, 2012).

A significant increase in pollen percentages of Scots pine (threefold) and Siberian pine (twofold) between 6200 and 4670 cal yr BP (Fig. 3) points to their spread at and around the Mamakan site. The pine pollen maximum at 5500–4670 cal yr BP may show the tree's maximum spread in the Mamakan area. Geobotanical studies about Scots pine in the LBR demonstrate that its natural distribution is limited by permafrost (Shumilova, 1960). Therefore, it was suggested that higher-than-present summer insolation during the first half of the Holocene promoted the degradation of permafrost and initiated the spread of Scots pine paralleled by a decline in dark coniferous (Dc) boreal forest taxa at around 7000–6000 cal yr BP, which is regarded as one of the most fundamental changes in the LBR vegetation during the Holocene (Bezrukova et al., 2010; Tarasov et al., 2017; Kobe et al., 2020). The age model of the Mamakan pollen record dates the beginning of the Scots pine spread and the contemporaneous decline in Dc boreal taxa (as reflected by decreasing Dc/Lc ratios; Fig. 6) in the study region to about 6200 cal yr BP. In other regions, such as the eastern coast of Lake Baikal (Tarasov et al., 2009), the area around Lake Baunt (Bezrukova et al., 2017) between the Yuzhno-Muiskii Ridge and the Babanty Mountains (Fig. 1A), in the Verkhoyansk Mountains in Yakutia (Anderson et al., 2007, 2014; Müller et al., 2010) and around the Okunaika peat bog (1450 m a.s.l.) in the Baikalskii Range (Bezrukova et al., 2008) Scots pine spread rapidly between 6800 and 6200 cal yr BP. This suggests a different timing in the vegetation development within this vast region of Eastern Siberia and that the spread of Scots pine and decline of Dc started later in the regions at the northern end (Okunaika peat bog, Baikalskii Range) and north (Mamakan area) of Lake Baikal (Fig. 6). Another pollen record is available from the Ozerny-5 sediment section (56°22′49.1"N, 109°54′09.0"E; Fig. 1A), 370 m from the shore of Lake Bolshoe Inyaptukskoe (Bezrukova et al., 2012). The lake lies in the north-eastern foothills of the Synnyr Range 10 km west of the Inyaptuk summit (2578 m a.s.l.) and between the Baikalskii Range and the Mamakan area (Fig. 1A). This record suggests that Scots pine spread and Dc decline started around the study site at 4500 cal yr BP (Fig. 6). It is possible that this exceptionally late spread is due to effects of the local environmental setting. However, it cannot be excluded that this very late pine spread is due to the age-depth model, which is based on two bulk sediment AMS ^{14}C dates from the lower third of the studied 50-cm-long sediment section covering the last ca. 9000 years (Bezrukova et al., 2012).

The expansion of Siberian pine, which is very sensitive to drier environments (Pozdnyakov, 1983), in combination with the spread of larch, fir and Siberian dwarf pine at 4670–3840 cal yr BP implies a cooler climate than before with enhanced air and soil moisture. The gradual decrease in availability of dry and less cold habitats for Scots pine led to a reduced growth in the study region. However, the persistent presence of Scots pine stomata indicates the continuous presence of this tree in the region. Spores of different fungi, such as *Gelasinospora, Sordaria, Pleospora, Glomus* and mildew (*Meliola*), suggest the presence of herbivorous animals using this site as grazing ground.

In the Baikalskii and Synnyr ranges as well as in the basin of Lake Baunt, Siberian pine was less abundant at ca. 4670–3840 cal yr BP most likely due to a cooler climate at these higher-elevated sites (Bezrukova et al., 2008, 2012). During the uppermost PAZ Mmk-1 (3840–3630 cal yr BP) the Mamakan record shows a phase of significant changes in regional and local vegetation between 3750 and 3680 cal yr BP. Higher AP/NAP values (Fig. 6) and a strong increase in pollen concentration suggest substantial spread of forests around the study site. The increase in AP values appears to be mainly driven by increased Siberian spruce pollen percentages. Furthermore, the Mamakan record reveals the appearance of swampy, *Sphagnum* habitats at the study site from 3840 cal yr BP (Fig. 3). A reason for the development of a swampy environment could be fires that occurred at higher frequencies, which, according to the age model, started ca. 3870 cal yr BP and continued until 3820 cal yr BP as evidenced by maximum concentrations of charcoal particles (Fig. 5). In the Mamakan section, frequent wildfires are indicated by a layer of dark sooty sediment. The fires probably resulted in an accumulation of fallen trees, which hindered drainage at the study site

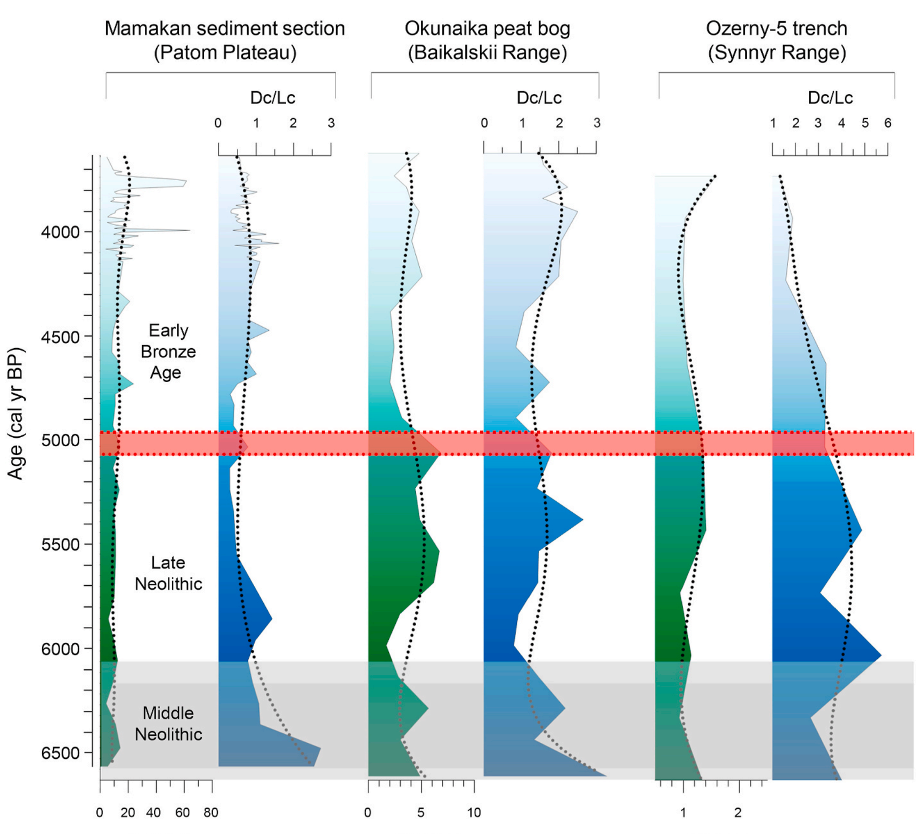

Fig. 6. Summary plot showing centennial variability and millennial-scale trends in pollen-derived indices representing landscape openness (AP/NAP ratios) and relative moisture content (Dc/Lc ratios) for the Mamakan peat section (this study), the Okunaika peat section in the Baikalskii Range (after Bezrukova et al., 2008, Fig. 1A) and the Ozerny-5 trench at the Bolshoe Inyaptukskoe Lake in the Synnyr Range (after Bezrukova et al., 2012, Fig. 1A). The red band marks the transition between the Late Neolithic and the Early Bronze Age and the grey band corresponds to the 'hiatus' in the Middle Neolithic burial record of the Cis-Baikal region (Weber, 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and led to waterlogged conditions. The presence of *Arcella gibbosa, Centropixis, Assulina* and *Nebela* remains in Mmk-a provides evidence for very moist, swampy conditions (Tsyganov and Mazei, 2006). In addition, the appearance of *Trimmatostroma salicis*-type fungal spores (Fig. 5) may reflect the spread of willow communities in moist environments (Ivanova and Ivanova, 2017). The decline of wildfires after 3750 cal yr BP, as indicated by lower frequencies of charcoal particles, could be responsible for locally less swampy conditions providing more favourable conditions for spruce as indicated by increased *Picea obovata* type pollen percentages (Fig. 3).

5.2. Implications for archaeology

The reconstruction of past natural environments and past climate change and the understanding of their possible impact on human population dynamics, cultural traditions and subsistence strategies has been one of the main goals of geoarchaeological studies in the LBR (Tarasov et al., 2007, 2013; Bezrukova et al., 2013; Weber et al., 2013, 2021; Kobe et al., 2020, 2021). One of the aims of past and ongoing archaeological and palaeoecological studies is to understand possible effects of climatic change on hunter-gatherer societies in the region (Tarasov et al., 2017). This is particularly important regarding the documented lack of settlements and burial sites in regional archaeological records during the Middle Neolithic period (6660–6060 cal yr BP) that began with the breakdown of the Early Neolithic Kitoi culture (Weber, 2020; Weber et al., 2021).

Pollen-based vegetation and climate reconstructions from peatbogs and lakes in the LBR (Tarasov et al., 2009; Bezrukova et al., 2010, 2013; Kobe et al., 2020) show that forests gradually spread across the LBR during the Early and Middle Holocene. Consequently, shrub and herbaceous communities decreased, which may have led to a decline in the number of ungulates, which were the main food source for Early Neolithic (ca. 7560–6660 cal yr BP) hunter-gatherer groups (Losey and Nomokonova, 2017). These changes in vegetation may be associated with suggested changes in atmospheric circulation, which resulted in a thicker and longer-lasting snow cover (Kobe et al., 2020). This, in turn, could have led to the documented decline in Early Neolithic hunter-gatherer groups by ca. 6660 cal yr BP (Tarasov et al., 2017), followed by the 'hiatus' in the archaeological records between 6660 and 6060 cal yr BP.

In the Mamakan area, the abundance of mammalian remains in cultural layers from Bolshoy Yakor I implies the dominance of open landscapes during the final Pleistocene/Early Holocene (13,000–8000 cal yr BP) (Ineshin and Tetenkin, 2010). However, the vegetation history in the study area during the first half of the Holocene period remains unresolved (Anderson et al., 2007, 2014). Our new pollen record from the Mamakan site reveals the predominance of forest landscapes in this region between ca. 6570 and 3630 cal yr BP (Fig. 3). The expansion of forest vegetation may have contributed to the decrease of large herbivores serving as the main food source for Early Neolithic hunter-gatherer groups as suggested for other areas in the LBR (Kobe et al., 2020).

Opposed to the Angara River valley and the coastal areas around Lake Baikal in Cis-Baikal (Losey and Nomokonova, 2017; Weber, 2020; Weber et al., 2021), the Mamakan area still lacks a detailed archaeological record of human habitation and subsistence during the Middle Neolithic and Early Bronze Age, 6660–3470 cal yr BP (Weber et al., 2021). Much less archaeological field work has been done in this remote region (Kobe et al., 2021). The available data demonstrates that a higher number of archaeological sites date to the Late Pleistocene and Early Holocene than to the Middle and Late Holocene. However, the documented human occupation at Bolshoy Yakor I, which continued until ca. 6000 cal yr BP, contrasts with the cultural 'hiatus' in the archaeological records from Cis-Baikal during the Middle Neolithic phase (ca. 6660–6060 cal yr BP). The scarce archaeological evidence in the LBR for the Middle and Late Holocene intervals may be correlated with an expansion of pine forests in the area after ca. 7000 cal yr BP, which was a result of the reorganization of the hemispheric and regional climate (e.g., Kleinen et al., 2011; Tarasov et al., 2017; Kobe et al., 2020). In the regions around Lake Baikal and Lake Baunt, this transition in vegetation distribution was dated to ca. 6800 cal yr BP. By contrast, in the Mamakan area the Scots pine spread began several centuries later, i.e., ca. 6200 cal yr BP (Fig. 6). Moreover, the persistent presence of fungal spores (*Microthyrium, Sordaria*) throughout the Mamakan section (Fig. 5) may indicate that the study area was a favoured grazing ground for wild ungulates (Lundqvist, 1972; Blackford and Innes, 2006; Piasai and Sudsanguan, 2018), common prey for Holocene hunter-gatherers in Cis-Baikal (Losey and Nomokonova, 2017). Together, this may indicate that the lower Vitim River area was still favourable for humans during most of the 'hiatus' documented in Cis-Baikal and may have been a refuge for Middle Neolithic hunter-gatherer populations. However, testing this hypothesis in the Mamakan and the Patom Plateau regions requires more archaeological and palaeoecological research on the Neolithic and Bronze Age hunter-gatherer sites there.

6. Conclusions

The Mamakan section discussed in this study provides the first palynological record from the lower Vitim River valley spanning the second half of the Early Neolithic through to the Middle Bronze Age, ca. 6450–3600 cal yr BP. The presented data provides insights into vegetation and climate changes, which allow comparison with the available, still sparse archaeological record from the region. The age-depth model applied to the Mamakan record suggests that the spread of Scots pine accompanied by a decline in Dc occurred in the lower Vitim River mountainous region north of Lake Baikal ca. 6200 cal yr BP, thus about 600 years later than in the Lake Baikal coastal areas east of the lake. This transition from a fir and spruce-dominated to a pine-dominated taiga landscape marks the most fundamental Holocene vegetation change in the LBR and is frequently discussed as a driver of cultural decline during the Middle Neolithic (6660–6060 cal yr BP) as documented in archaeological records from different part of this vast region. We hypothesize that the 'delay' in this vegetation transition may have prolonged more favourable conditions for wild ungulates, which is supported by the record of grazing indicators in the Mamakan section, and thus also for Neolithic hunter-gatherer communities whose subsistence strongly relied on hunting these animals. While in regions like Cis-Baikal no or very limited human presence is registered during the Middle Neolithic, there is archaeological evidence for human activities around the Mamakan site until ca. 6000 cal yr BP. In sum, the current palynological record provides evidence for the continuous presence of grazing animals around the study site and provides an explanation why hunter-gatherer groups were present along the lower Vitim River valley longer than in other parts of the LBR. However, additional palaeoenvironmental and archaeological investigations in the study region are needed to verify these first findings.

Author contributions

Conceptualisation, E.V.B., A.V.T.; Material and data collection, E.V.B., A.V.T.; Methodology, E.V.B., P.E.T., C.L.; Analysis, S.A.R.; Writing (original draft), E.V.B., S.A.R.; Writing (review and editing), C.L., P.E.T.; Visualization, E.V.B., S.A.R, C.L., P.E.T.

Data availability

All raw data supporting the conclusions of this article can be obtained upon request from the corresponding author.

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.

Acknowledgements

The authors are thankful to P.P. Letunova and E.V. Volchatova for NPPs identification and P. Wertmann for the first editorial proofreading of the manuscript. The research was funded by the Russian Foundation for Basic Research (grants 18-59-22003/18, 19-05-00328, RFBR-the London Royal Society 21-55-10001) and was performed in accordance with the state assignment of the Vinogradov Institute of Geochemistry SB RAS (project number: N 0284-2021-0003). This work also contributes to the Ground Check in Northeast Asia (German Archaeological Institute) and the Baikal Archaeology Project. We would like to thank the two anonymous reviewers for the constructive comments and corrections, which helped us to improve the manuscript.

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