Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Russian Geology and Geophysics 52 (2011) 458–465
RUSSIAN GEOLOGY AND GEOPHYSICS
www.elsevier.com/locate/rgg

Palynological study of Lake Kotokel' bottom sediments (*Lake Baikal region*)

E.V. Bezrukova [a,*], P.E. Tarasov [b], N.V. Kulagina [c], A.A. Abzaeva [a], P.P. Letunova [a], S.S. Kostrova [a]

[a] *A.P. Vinogradov Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, ul. Favorskogo 1a, Irkutsk, 664033, Russia*
[b] *Freie Universität Berlin, Habelschwerdter Allee 45, Berlin,14195, Germany*
[c] *Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, ul. Lermontova 128, Irkutsk, 664033, Russia*

Received 25 September 2009; received in revised form 4 May 2010; accepted 31 August 2010

Abstract

Pollen and AMS ^{14}C analyses of bottom sediments from the upper nine meters of the Lake Kotokel' section were carried out. The regional climate and landscape dynamics during the Late Glacial and Holocene has been reconstructed with an average time resolution of ~120 years. It is shown that the climatic conditions in the Kotokel' basin during Termination I (~15.5–11 ka) were characterized by short drastic changes resulting in the reorganization of landscapes and vegetation. Five short (400–1200 years) intervals have been recognized: 15.5–14.7, 14.7–14.3, 14.3–13.2, 13.2–12.5, and 12.5–11.7 ka. In the early Holocene (~11 ka), the climate became less continental and stayed such till ~7 ka. Later on, it again became more continental, which led to a significant decrease in average annual precipitation and winter temperatures and an increase in average summer temperatures. The pollen record from Lake Kotokel' agrees with the general climatic trend for the Northern Hemisphere. The amplitude of vegetation and climatic variations during the Late Glacial is best expressed as compared with the previous regional pollen records. This is probably because the ecosystem of the small lake localized deep inside the continent, at the boundary of two large ecotones (forest and steppe), is highly sensitive to moisture deficit.

The new dated detailed pollen record from the Lake Kotokel' bottom sediments might be regarded as a key section for the reconstruction of variations in regional vegetation and climatic dynamics for the last 15–15.5 kyr. The results obtained refined the kind of changes in regional vegetation, and the reliable age model permitted intra- and interregional correlations of environmental changes.

Keywords: pollen analysis; lacustrine sediments; Termination I; Holocene; landscape dynamics; climate changes; Transbaikalia

Introduction

Paleoclimatic, especially palynological, records for intracontinental regions are important for understanding the past climatic changes on the Earth and estimating the sensitivity of the regional ecosystems to future climatic variations. Pollen records for the key object of northern Central Asia—bottom sediments of Lake Baikal and its basin peat bogs—showed the general tendency of the response of the regional vegetation to the global climatic changes in the Late Glacial and Holocene (Bezrukova et al., 1991, 1996, 2008a; Bradbury et al., 1994; Demske et al., 2005; Horiuchi et al., 2000; Takahara et al., 2000; Tarasov et al., 2007). But some of the pollen records are of low temporal resolution (Bezrukova et al., 1991; Bradbury et al., 1994); the others are of poor chronological control (Bezrukova et al., 1996) despite the obvious progress in absolute dating (Krivonogov et al., 2004). Some records lack part of the Late Holocene information (Demske et al., 2005) or show only the dynamics of few abundant pollen taxa of tree and shrub flora determined up to the genus, which significantly reduces the reliability of paleoreconstructions (Horiuchi et al., 2000). Moreover, the reconstruction of the Late Glacial paleoenvironment by the Baikal pollen records was difficult because of the small amount of pollen and spores in the sediments accumulated in that epoch (Tarasov et al., 2007). The low content of organic material in the sediments complicates a reliable chronological control of the reconstructions, which makes one to search for new objects of study. For this purpose we decided to use the recently obtained palynostratigraphic sequence of the bottom

* Corresponding author.
E-mail address: bezrukoba@igc.irk.ru (E.V. Bezrukova)

1068-7971/$ - see front matter © 2011, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.rgg.2011.03.008

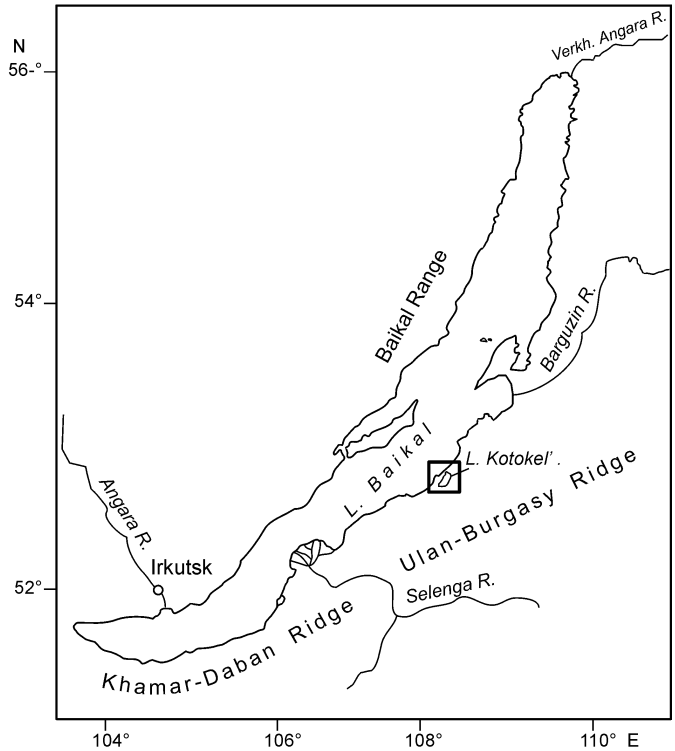

Fig. 1. Geographic location of Lake Kotokel'.

sediments of Lake Kotokel', dated at >15 ka (Bezrukova et al., 2008b). The lacustrine sediments of such small lakes are unique environmental archives. The above lake is shallow and might have existed as an isolated system at least since the Late Pleistocene (Khlystov et al., 2008; Korde, 1968; Krivonogov and Takahara, 2003; Urabe et al., 2004).

In that epoch, a thick layer of organic mud accumulated, which is reliably dated by the AMS ^{14}C method. The localization of the Kotokel' basin in the zone of interaction of three largest systems of atmospheric circulation (Asian anticyclone, Westerlies, and Pacific monsoon) with forest-steppe and steppe landscapes makes the basin ecosystem highly sensitive to climatic changes. In this paper we reconstruct the vegetation and climate of Lake Kotokel' and its basin, based on the detailed pollen stratigraphy of its sediments, and compare them with those in other regions of Siberia. We also discuss the environmental dynamics in East Siberia in relation to the climatic changes in the Eurasian mid-latitude regions.

Statement of the problem

The first core of the lacustrine bottom sediments, ~550 cm in length, was obtained by Vipper (1962) in 1960 and studied by radiocarbon, palynological, and algological analyses with the time resolution of the pollen record of ~300–350 yr. The great error of determination of the ^{14}C age (600–1700 yr) significantly reduced the value of the compiled chronological scale. The later additional results of pollen analysis of the same core (Tarasov et al., 2002) did not differ significantly from the initial ones. New pollen records of the core of the Kotokel' bottom sediments were obtained in 2004–2005. Shichi et al. (2009) reported results of a palynological study of the core performed in 2005. They examined the core with a 20 cm interval, i.e., with a time resolution of ~300 years. The interval of sediments dated at 15 ka was investigated and briefly described (Bezrukova et al., 2008b). The entire sediment core with the lower horizons dated at >47 kyr is considered by Shichi et al. (2009). The time resolution of the record presented here is close to centennial scale. A pollen record of this resolution for the small lakes of the Baikal basin was obtained for the first time. It will help to reveal short-term environmental changes, including the climatic fluctuations in the last transitional period. We use this record to obtain the first semiquantitative climatic parameters for the southern Baikal region.

General description of the study area

Lake Kotokel' (458 m above the sea level) occurs in the west of the Buryatiyan Republic, ~2 km east of the Baikal shore (Fig. 1), and is separated from it by mountains. The lake is almost 15 km in length, ~5 km in width, and 5–6 m in average depth (the maximum depth is ~15 m). In the north of the lake, the waters run off into Baikal through the Istok and Turka Rivers.

The region has a continental climate, with cold winter and moderately warm summer. The average January temperature is about –20 ºC, the average July temperature is +16 ºC, and the average annual precipitation is ~400 mm (Galazii, 1993). West-directed wind prevails in the region. July and August are the most humid months, when the westward air transfer weakens and the meridional air circulation and cyclones at the Polar front are activated. Cyclones bring warm and humid air from the southeast and cause heavy rains.

The modern vegetation of the Baikal shore and Kotokel' basin is represented by boreal coniferous and leaf forests. The forests around the lake are dominated by Scots pine *Pinus sylvestris*, larch *Larix sibirica*, and birch *Betula* with admixture of *Duschekia fruticosa* (Galazii, 1993). Siberian pine *Pinus sibirica*, fir *Abies sibirica*, and spruce *Picea obovata* are not found in the Kotokel' basin but grow on the ridge slopes a few kilometers east of it. The local communities on the lake shore abound in littoral-aquatic vegetation *Sparganium*, *Phragmites*, and *Nuphar*. The swamped sites are covered with grasses *Calamagrostis*, sedges *Carex limosa*, *C. rhynchophysa*, and *C. lasiocarpa*. Birch *Betula* sect. Nanae, marsh tea *Ledum palustre*, and cranberry *Oxycoccus palustris* occupy the lower stage between the second barrier beach and swamped sites.

Materials and methods

Drilling. In summer 2004, the upper beds of the lacustrine sediments were drilled at a water depth of ~4 m, using a

Livingston-type piston corer. The core was undisturbed. The upper 470 cm were dark gyttia. Below (470–700 cm), there is a less compact and light gyttia. The bed in the range 700–900 cm is formed by muddy clays.

Sampling. The core was sampled in the laboratory at the Institute of Geochemistry, Irkutsk. For pollen analysis we used 130 wet sediment samples 1.5 cm^3 in volume.

Pollen analysis. Extraction of pollen and spores was made by the standard technique (Berglund and Ralska-Jasiewiczowa, 1986). The results of analysis are presented on a pollen diagram (Fig. 2). The percentage of pollen taxa was calculated from the total content of pollen grains, except for aquatic pollen. The abundance of aquatic pollen and spores was evaluated relative to the total amount of all pollen and spores. With regard to the changes in pollen stratigraphy, six local pollen zones were recognized on the diagram. The age of the boundaries between the pollen zones and palynologically studied levels in the core was determined by the interpolation between the dated horizons.

Radiocarbon dating. We obtained three AMS ^{14}C dates for the gyttia layer: 6070 ± 60 (Beta-207356), 10,680 ± 40 (Beta-209638), and 11,670 ± 60 (Beta-207357) (Bezrukova et al., 2008b; Shichi et al., 2009). The radiocarbon age was converted into the calibrated age, using the CalPal program (Danzeglocke et al., 2008). The age model constructed by three dates (Bezrukova et al., 2008b; Shichi et al., 2009) suggests the continuous accumulation of sediments, which is confirmed by their lithology. The chronology of vegetation and climatic variations reported below is based on this model.

Typification of vegetation. The diverse pollen taxa were divided into types following the classification proposed by Tarasov et al. (2007). Then, the dynamics of forest, tundra, and steppe types of vegetation was used for the additional description of environmental and climatic changes responsible for the predominance of this vegetation in the Kotokel' basin (Fig. 3).

Results

Pollen stratigraphy. Compositional changes in pollen spectra permitted us to recognize six pollen zones: Ktk1-1–Ktk1-6 (Fig. 2). The description of the zones is made from bottom to top.

Ktk1-6b—Chenopodiaceae–Poaceae–Artemisia (900–860 cm, ~15.5–14.7 ka). The spectra are dominated by herb pollen (60–85%), mainly wormwood *Artemisia*, grasses Poaceae, and sedges Cyperaceae. Pollen of shrubs *Betula* sect. Nanae and willow *Salix* amounts to 20 and 15%, respectively. Pollen of *Pinus sibirica* and *Pinus sylvestris* present in great amounts was, most likely, wind-blown from other areas.

Ktk1-6a—Salix-Betula sect. Nanae–Artemisia (860–830 cm, ~14.7–14.3 ka). The boundary between Ktkl-6_b and Ktkl-6_a is characterized by the increased amount of shrub pollen—*Betula* sect. Nanae and *Salix*, with its predominance in the spectra of the Ktkl-6_a subzone. At the boundary with the Ktkl-5 zone, there is a peak of the hygrophyte pollen—*Alisma* and *Sparganium*.

Ktk1-5—Larix–Abies sibirica–Picea obovata (830–770 cm, ~14.3–13.2 ka). The spectra are dominated by the pollen of arboreal plants, mainly spruce (25–75%), but there is also abundant pollen of fir (1–6%) and larch (up to 1–5%).

Ktk1-4—*Picea obovata*–*Betula* sect. Nanae–*Duschekia fruticosa* (770–720 cm, ~13.2–12.5 ka). Transition to this zone is marked by a significant reduction of the arboreal pollen, especially spruce and fir, and increase in the amount of pollen of shrubby alder and shrubby birch.

Ktk1-3—*Betula* sect. Albae–*Betula* sect. Nanae (720–650 cm, ~12.5–11.7 ka). The amount of shrubby alder and spruce pollen is reduced. The spectra are dominated by pollen of shrub birch (up to 60%).

Ktk1-2—*Abies sibirica*–*Betula* sect. Albae (650–410 cm, ~11.7–7.0 ka). The zone is characterized by a significantly lower abundance of shrubby-birch pollen and higher percentage of tall birch pollen. The spectra are dominated by pollen of arboreal plants, mainly *Betula* sect. Albae (55–67%). The content of *Abies sibirica* pollen is still high (1–3%).

Ktk1-1_b—*Pinus sylvestris* (410–160 cm, ~7.0–2.7 ka). The spectra are dominated by pollen of arboreal plants (78–90%), mainly pine (60–75%).

Ktk1-1_a—*Larix*–*Betula* sect. Nanae–*Pinus sylvestris* (upper 160 cm, ~2.7–0 ka). The spectra are significantly richer in pollen of larch, pine, and both types of birch.

Discussion and interregional correlations

Vegetationi and climatic dynamics in the Kotokel' basin in the Late Glacial and Holocene. We used the terms “the Oldest Dryas”, “Bölling”, “Alleröd”, and “Younger Dryas” in terms of climatic stratigraphy, implying corresponding climatic (Wohlfarth, 1996; Yu and Eicher, 2001) rather than chronostratigraphic (Mangerud et al., 1974) events. We agree with Wohlfarth (1996) that these terms are of broad use in literature and the sequence of the above climatic events is not disputed. We also use the term “Bölling–Alleröd”, not separating these interstadials because of the insufficient number of dates for the obtained paleoclimatic record and the impossibility to recognize reliably the stadial event between them at this stage of research.

The Ktk1-6_b spectra formed mainly in mineragenic clayey sediments poor in organic matter at ~15.5–14.7 ka. The predominance of arboreal pollen and the low pollen abundance in the sediments suggest the existence of open landscapes with prevailing steppe herbage-goosefoot-wormwood associations. Sedge-grass and dwarf birch associations might have formed the vegetation of the swamped lake shores. Moreover, the swamp must have been localized much closer to the drilling point than now because the sedge and grass pollen is a local element of the spectra and is not spread for great distances (Bezrukova, 1999). Judging from the abundance of sedge and grass pollen (most likely, grass pollen is dominated by *Phragmites* and *Calamagrostis*, which, along with several

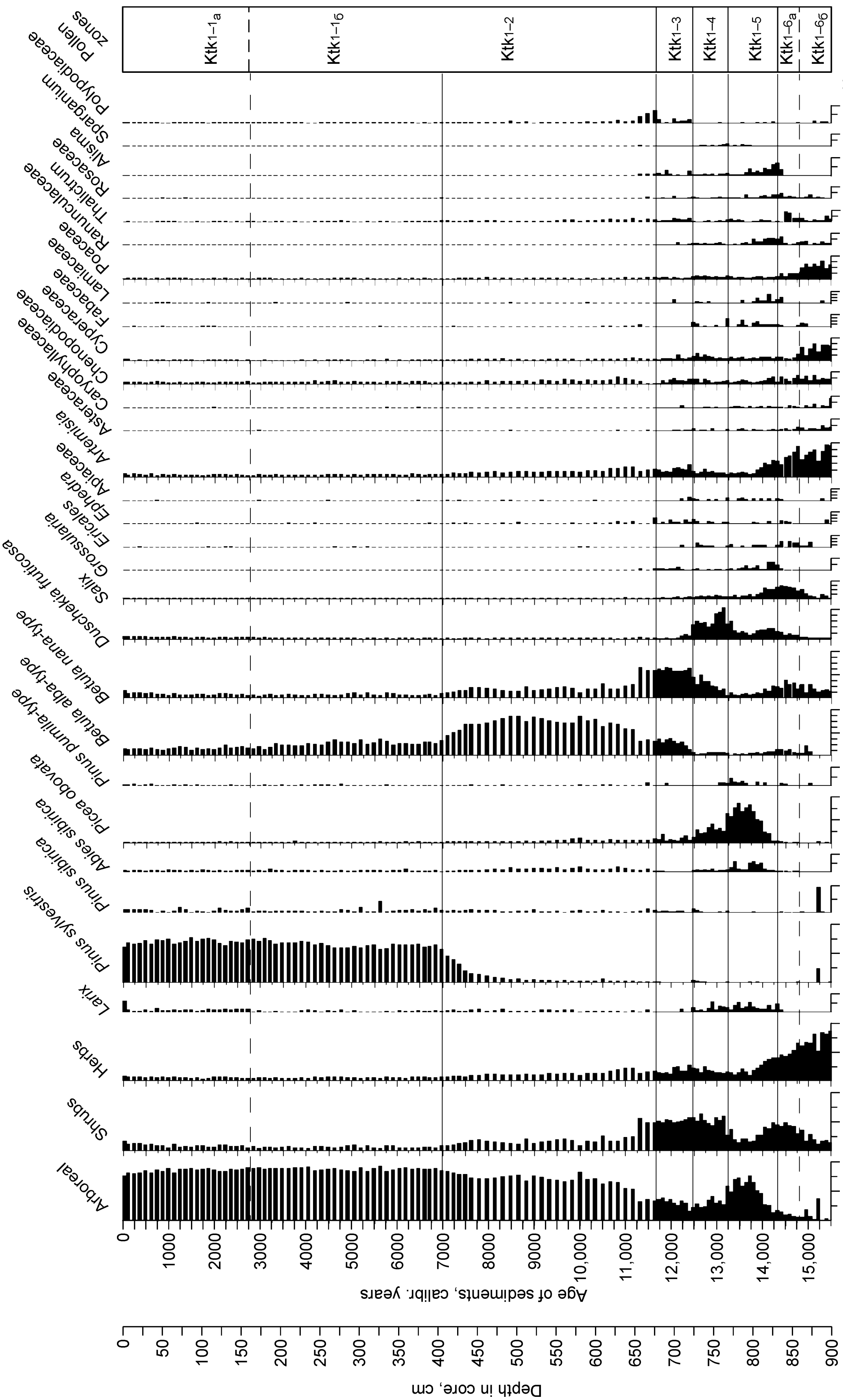

Fig. 2. Spore–pollen diagram of the Kotokel' bottom sediments, core Ktk1.

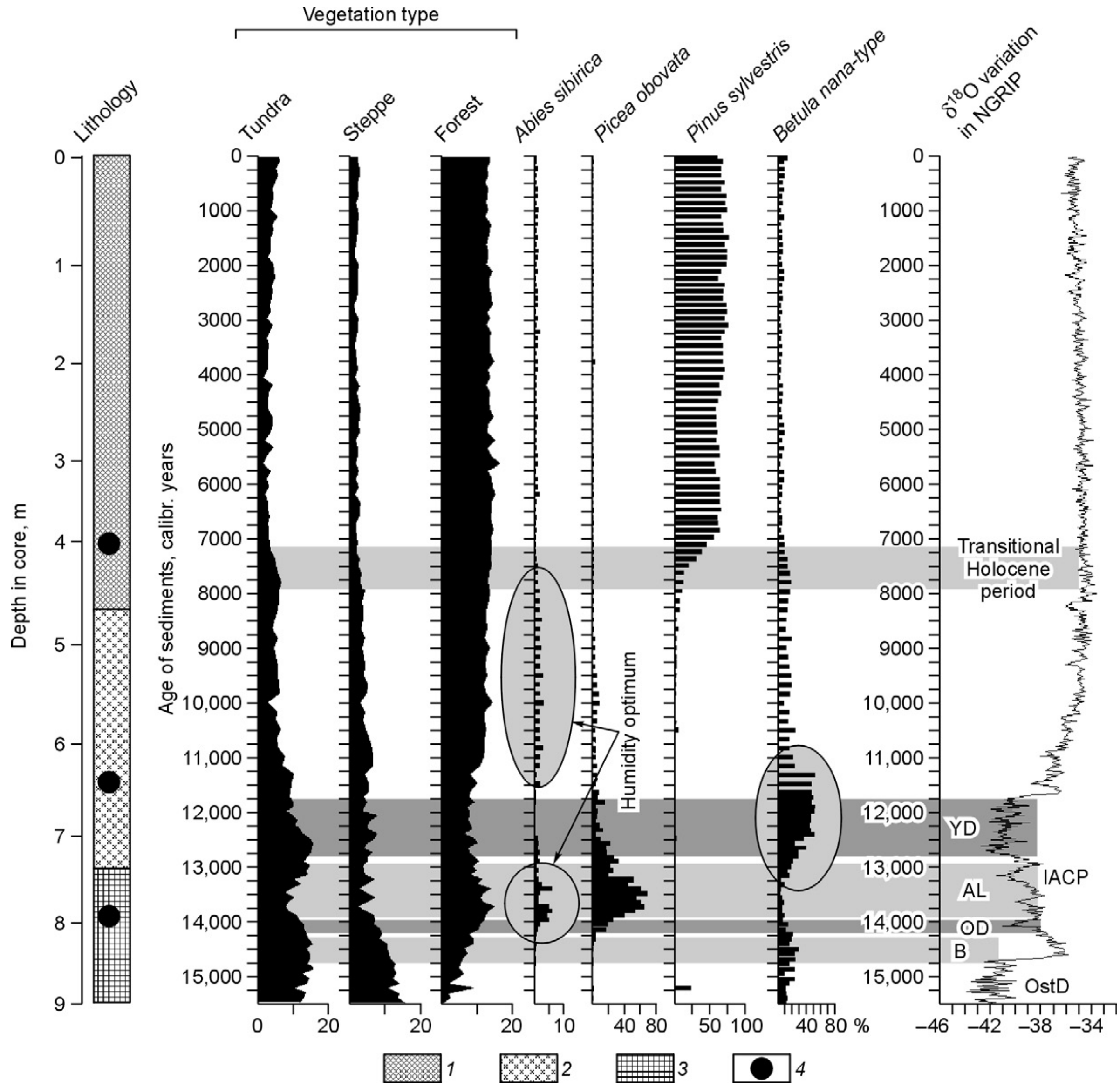

Fig. 3. Dynamics of vegetation types in the Kotokel' basin for the last 15.5 kyr. *1*, dark, almost black, gyttja; *2*, lighter and more compact gyttja; *3*, muddy clays; *4*, position of dated levels in the core. Late Glacial stadials and interstadials: YD, Younger Dryas; IACP, cold period in the Alleröd; AL, Alleröd, OD, Old Dryas; B, Bölling, OstD, Oldest Dryas.

sedge species, form the lake shore vegetation), the lake water level at that time was much lower than today. The available pollen and lithological data point to an arid cold climate and permafrost in tundra and steppe landscapes (Fig. 3). According to the age model of sediments, this stage corresponds to the stadial cooling during Termination I—the Oldest Dryas according to the European climatic stratigraphy (Stuiver et al., 1995). The high contents of elements undergoing leaching (Mg, K) in the Baikal sediments older than 14.5 ka (Chebykin et al., 2002) also evidence the existence of open, mainly forest-free landscapes on highly eroded poor soils in cold climate.

At the beginning of the Bölling–Alleröd interstadial warming (~14.7–14.3 ka, Ktk1-6$_a$), willow and mesophytic-herbal associations became more abundant in the lake basin, which evidences that the climate became somewhat warmer. The same is also indicated by the results of reconstruction of the types of vegetation, showing that forest landscapes became more widespread (Fig. 3). The warming seemed to be so serious that favored the rapid spread of spruce and larch forests in the Kotokel' basin and fir forests in its mountainous framing at ~14.3–13.2 ka (Ktk1-5). The peak of larch pollen, usually poorly represented in Siberian sub-recent and fossil pollen spectra, points to the abundance of larch (Bezrukova, 1999). The stable peak of Siberian fir pollen might evidence an expansion of fir forest areas but, most likely, within the mid-mountain belt of the Khamar-Daban and Ulan-Burgasy Ridges. It is unlikely that fir spread toward the lake, but the approach of its areal boundaries to the Kotokel' basin might have favored the transport of large amounts of its pollen into the lacustrine sediments. The abundance of dark-coniferous plants indicates a significant climatic warming. Moreover, the fir abundance indicates that the winter temperatures and the total atmospheric precipitation increased and the climate became less continental. At the same time, similar spread of forest began in the entire Baikal basin (Demske et al., 2005), in Gorny Altai (Blyakharchuk et al., 2007), and in northern Mongolia (Prokopenko et al., 2007). The cooling in the Bölling–Alleröd interstadial (~13.3–13.4 ka) might have been a trigger for the replacement of spruce and fir forests by *shrubby alder* and, later, dwarf birch associations (Ktk1-4). The warming following that short but strong cooling (at ~13 ka) was obviously not so intense to favor the return of dark coniferous plants. Moreover, the Younger Dryas (~12.8–12.5 ka) stadial conditions were favorable for the abundance of shrub birch associations in the lake basin, which were predominant till ~11.7–11.3 ka. Such great vegetation changes might have been due to the wide spread of permafrost, whose thawing in summer ensured a predominance of dwarf birch associations in the Kotokel' basin. The slight peak of wormwood pollen and the permanent presence of goosefoot pollen argue for the development of steppe plant associations on well-warmed elevated sites with low precipitation. Note that the cooling caused the spread of tundra vegetation and reduction (but not disappearance) of forest plants. Coniferous trees might have remained as isolated islands, as evidenced from the low but constant content of larch and spruce pollen. The available reconstructed parameters of the Younger Dryas climate in South Baikal showed that the average July temperatures might have been 2–3 ºC lower than the modern ones and the average January temperatures, 8–10 ºC lower, whereas the average annual precipitation was ~50–80 mm lower (Tarasov et al., 2007).

In the early Holocene (~11.7–11.3 ka), the tundra and steppe vegetation in the Kotokel' basin was rapidly reduced, and forests, mainly birch ones, began to spread. The period of birch forest predominance lasted till ~7.2 ka (Ktk1-2). The significant reduction in dwarf birch associations and spread of fir forests in the mountainous framing of the basin were the most crucial event in that period. These vegetation changes might have been caused by the global climatic warming and related permafrost degradation, rise of the lake level, and, as a result, flooding of the swamped shores. For the existence, fir needs mild winters and cool summers, a thick snow cover to prevent the soil from deep freezing, much precipitation, and fertile soils with running water flows. This permits us to consider the above period optimal in terms of the above environmental parameters. The period between the maximum fir abundances in Siberia, ~11–6 (7) ka, is regarded as the Holocene optimum (Bezrukova et al., 2005, 2008a,b; Blyakharchuk et al., 2007; Demske et al., 2005; Tarasov et al., 2007). The quantitative paleoclimatic reconstructions for the Baikal basin in this period suggest that the summer temperatures at ~9.5–6 ka were close to the modern ones, the winter temperatures were 3–4 ºC higher, and the average annual precipitation probably exceeded the present-day one by 100–120 mm, with the moisture index being also higher (Tarasov et al., 2007).

The Holocene climatic optimum at ~11–7 ka was also established in the entire North Eurasian area and is associated with the high insolation, termination of the breakup of the Scandinavian ice sheet, and warming in the North Atlantic region (Kutzbach and Gallimore, 1986; MacDonald et al., 2000; Velichko et al., 1997). In the northern Tibetan Plateau, the Holocene climatic optimum is dated to 8–5 ka and is characterized by a high effective soil moisture as a result of snow and glacier thawing. The optimum was so late probably because of the delayed response of the low-latitude oceanic areas to the high-latitude insolation peak, at 9–8 ka (Feng et al., 2006). The Holocene climatic optimum in northern Central China was also at ~10–7 ka, during the maximum activity of the East Asian monsoon, and was characterized by the maximum precipitation in summer (Xiaoqiang et al., 2004).

The drastic increase in the Scots pine pollen content in the Ktk1-1 spectra at ~7.2 ka points to the beginning of pine forest expansion in the lake basin. In recent 7.2 kyr, forest vegetation has been predominant in the basin, with Scots pine, larch, and birch remaining the main taxa. The beginning of pine expansion is considered to be one of the most crucial transitional Holocene periods in the study region. Pine and larch became predominant in the Kotokel' basin vegetation at the same time as the climate in the Baikal basin became more continental (Tarasov et al., 2007).

Despite the almost absolute predominance of pine pollen in the sediments formed in recent ~7.2 kyr, the pollen diagram shows a higher content of larch and Siberian pine pollen in the lacustrine sediments younger than 2.5 ka. This indicates that the vegetation pattern in the Kotokel' basin and the nearby areas again changed. The abundance of larch and Siberian pine increased; moreover, the expansion of larch areas began in the lake vicinity, whereas the expansion of the Siberian pine forests took place, most likely, in the mountain-taiga belt near Lake Kotokel'. The abundance of shrub birch near the lake seems to have increased as well. This is best seen in the surface spectra of the studied sediments. Comparison of the Kotokel' pollen record with the Baikal ones shows a similar event in the Continent and Posol'skaya underwater high records (Demske et al., 2005). The pollen spectra of their cores younger than 2.5 ka show much higher contents of larch, wormwood, and herbs typical of swamped landscapes—Poaceae and Cyperaceae. In climatic terms, this might indicate a still greater decrease in atmospheric precipitation and cooling, especially in summer, which resulted in lower evaporation and the swamping of new areas.

Conclusions

Thus, based on the results of palynological study, we have recognized intervals in the Kotokel' sediment core that reflect the main periods of landscapes, vegetation, and climate in the Holocene and Late Glacial.

The climate in the Kotokel' basin during Termination I (~15.5–11 ka) underwent short-term drastic variations resulting in serious changes in the landscape structure and vegetation pattern. We recognized five short intervals lasting from 400 to 1200 years (15.5–14.7, 14.7–14.3, 14.3–13.2, 13.2–12.5, and 12.5–11.7 ka). In general, the climate in the transitional period remained strongly continental, changing from arid and very cold to more humid and cold and then, to cold, with a high soil moisture.

In the interval ~11–7 ka, the climate in the Kotokel' basin became still less continental. It was characterized by mild winters, cool summers, a thick snow cover, and high annual average precipitation. Later on (~7–2.5 ka), the climate again became more continental, as evidenced from the significant reduction in the average annual precipitation, the growth in average summer temperatures, and the decrease in winter ones. At ~2.5 ka, the climate tendency to become more continental increased and continues today.

The reconstructed changes in the landscape, vegetation, and climatic dynamics in the Kotokel' basin correlate well with the general changes in the Northern Hemisphere environment. The record of the lacustrine sediments shows the highest amplitude of the Late Glacial vegetation and climatic changes as compared with the previous regional pollen records. This is probably because the ecosystem of the small lake localized deep inside the continent, at the boundary of two large ecotones (forest and steppe), is highly sensitive to moisture deficit. Moreover, the dynamics of the Kotokel' environment must have been controlled not only by climate but also by other local factors (geologo-geomorphologic, vegetation, groundwater level, etc.).

The new dated pollen record of the Kotokel' bottom sediments should be considered a key for the detailed reconstruction of the regional vegetation changes and the dynamics of climatic changes for the last 15–15.5 ka. The results obtained permitted us to refine the character of the vegetation changes, and the reliable age model served as a basis for the intra- and interregional correlations between the reconstructed environmental changes. To confirm the spread of fir in one of the Late Glacial interstadials, we need new, reliably dated records for various natural Siberian objects.

We thank S.K. Krivonogov for drilling in the study area, K. Shichi for sediment dating, and O.N. Shestakova for technical preparation of the samples for a pollen analysis.

This work was supported by grant no. 09-05-00123-a from the Russian Foundation for Basic Research, project TA 540/1 from the German Research Foundation, and Baikal Archeological Project.

References

Berglund, B.E., Ralska-Jasiewiczowa, M., 1986. Pollen analysis and pollen diagrams, in: Berglund, B.E. (Ed.), Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley and Sons, New York, pp. 455–484.

Bezrukova, E.V., 1999. The Paleogeography of the Baikal Region in the Late Glacial and Holocene [in Russian]. Nauka, Novosibirsk.

Bezrukova, E.V., Bogdanov, Yu.A., Williams, D.F., Granina, L.Z., Grachev, M.A., Ignatova, N.V., Karabanov, E.B., Kuptsov, V.M., Kurylev, A.V., Letunova, P.P., Likhoshvai, E.V., Chernyaeva, G.P., Shimaraeva, M.K., Yakushin, A.O., 1991. Deep changes of the North Baikal ecosystem in the Holocene. Dokl. Akad. Nauk 321 (5), 1032–1037.

Bezrukova, E.V., Mats, V.D., Letunova, P.P., Nakamura, T., Fuji, Sh., 1996. Holocene peat bogs in Prebaikalia as an object of paleoclimatic reconstructions. Geologiya i Geofizika (Russian Geology and Geophysics) 37 (12), 78–92 (76–89).

Bezrukova, E.V., Krivonogov, S.K., Abzaeva, A.A., Vershinin, K.E., Letunova, P.P., Orlova, L.A., Takahara, H., Miyoshi, N., Nakamura, T., Krapivina, S.M., Kawamuro, K., 2005. Landscapes and climate of the Baikal region in the Late Glacial and Holocene (from results of complex studies of peat bogs). Geologiya i Geofizika (Russian Geology and Geophysics) 46 (1), 21–33 (20–33).

Bezrukova, E.V., Belov, A.V., Letunova, P.P., Abzaeva, A.A., Kulagina, N.V., Fisher, E.E., Orlova, L.A., Sheifer, E.V., Voronin, V.I., 2008a. Peat biostratigraphy and Holocene climate in the northwestern mountain periphery of Lake Baikal. Russian Geology and Geophysics (Geologiya i Geofizika) 49 (6), 413–421 (547–558).

Bezrukova, E.V., Krivonogov, S.K., Takahara, H., Letunova, P.P., Shichi, K., Abzaeva, A.A., Kulagina, N.V., Zabelina, Yu.S., 2008b. Lake Kotokel as a stratotype for the Late Glacial and Holocene in southeastern Siberia. Dokl. Earth Sci. 420 (4), 658–663.

Blyakharchuk, T.A., Wright, H.E., Borodavko, P.S., van der Knaap, W.O., Ammann, B., 2007. Late Glacial and Holocene vegetational history of the Altai Mountains (southwestern Tuva Republic, Siberia). Palaeogeogr. Palaeoclimatol. Palaeoecol. 245, 518–534.

Bradbury, J.P., Bezrukova, Ye.V., Chernyaeva, G.P., Colman, S.M., Khursevich, G.K., King, J.W., Likoshway, Ye.V., 1994. A synthesis of post-glacial diatom records from Lake Baikal. J. Paleolimnology, No. 10, 213–252.

Chebykin, E.P., Edgington, D.N., Grachev, M.A., Zheleznyakova, T.O., Vorobyova, S.S., Kulikova, N.S., Azarova, I.N., Khlystov, O.M., Goldberg, E.L., 2002. Abrupt increase in precipitation and weathering of soils in East Siberia coincident with the end of the last glaciation (15 cal. kyr BP). Earth Planet. Sci. Lett. 200, 167–175.

Danzeglocke, U., Jöris, O., Weninger, B., 2008. CalPal-2007 (http://www.calpal-online.de).

Demske, D., Heumann, G., Granoszewski, W., Nita, M., Mamakowa, K., Tarasov, P.E., Oberhansly, H., 2005. Late Glacial and Holocene vegetation and regional climate variability evidenced in high-resolution pollen records from Lake Baikal. Global Planet. Change 46, 255–279.

Feng, Z.-D., An, C.B., Wang, H.B., 2006. Holocene climatic and environmental changes in the arid and semi-arid areas of China: a review. The Holocene 16 (1), 119–130.

Galazii, G.I. (Ed.), 1993. Baikal. Atlas [in Russian]. Federal'naya Sluzhba Geodezii i Kartografii.

Horiuchi, K., Minoura, K., Hoshino, K., Oda, T., Nakamura, T., Kawai, T., 2000. Palaeoenvironmental history of Lake Baikal during the last 23,000 years. Palaeogeogr. Palaeoclimatol. Palaeoecol. 157, 95–108.

Khlystov, O.M., Khanaev, I.V., Grachev, M.A., 2008. Evidence of Lowstand of Lake Baikal during the Last Glaciation. Dokl. Earth Sci. 422 (7), 1133–1136.

Korde, N.V., 1968. Biostratigraphy of the Lake Kotokel' sediments, in: Mesozoic and Cenozoic Lakes in Siberia [in Russian]. Nauka, Moscow, pp. 150–170.

Krivonogov, S.K., Takahara, H., 2003. Late Pleistocene and Holocene environmental changes recorded in the terrestrial sediments and landforms of Eastern Siberia and Northern Mongolia, in: Proc. Intern. Symp. 21st Century COE Program, 17–18 March, 2003. Kanazava, pp. 30–36.

Krivonogov, S.K., Takahara, H., Kuzmin, Ya.V., Orlova, L.A., Timothy Jull, A.J., Nakamura, T., Miyoshi, N., Kawamuro, K., Bezrukova, E.V., 2004. Radiocarbon chronology of the Late Pleistocene-Holocene paleogeographic events in lake Baikal region (Siberia). Radiocarbon, No. 2, 745–754.

Kutzbach, J.E., Gallimore, R.G., 1986. The influence of changing orbital parameters and surface boundary conditions on climate simulation for the past 18,000 years. J. Atmos. Sci. 43, 1726–1759.

MacDonald, G.M., Velichko, A.A., Kremenetski, K.V., Borisova, O.K., Goleva, A.A., Andreev, A.A., Cwynar, L.C., Riding, R.T., Forman, S.T., Edwards, T.W.D., Aravena, R., Hammarlund, D., Szeicz, J.M., Gataullin, V.N., 2000. Holocene treeline history and climate change across Northern Eurasia. Quatern. Res. 53, 302–311.

Mangerud, J., Andersen, S.T., Berglund, B.E., Donner, J.J., 1974. Quaternary stratigraphy of Norden, a proposal for terminology and classification. BOREAS 3, 109–126.

Prokopenko, A.A., Khursevich, G.K., Bezrukova, E.V., Kuzmin, M.I., Boes, X., Williams, D.F., Fedenya, S.A., Kulagina, N.V., Letunova, P.P., Abzaeva, A.A., Paleoenvironmental proxy records from Lake Hovsgol, 2007. Mongolia, and a synthesis of Holocene climate change in the Lake Baikal watershed. Quatern. Res. 68, 2–17.

Shichi, K., Takahara, H., Krivonogov, S., Bezrukova, E., Kashiwaya, K., Takehara, A., Nakamura, T., 2009. Late Pleistocene and Holocene vegetation and climate records from Lake Kotokel, central Baikal region. Quatern. Int. 205, 98–110.

Stuiver, M., Grootes, P.M., Braziunas, T.F., 1995. The GISP2δ^{18}O climate record of the past 16,500 years and the role of the Sun, ocean, and volcanoes. Quatern. Res. 44, 341–354.

Takahara, H., Krivonogov, S.K., Bezrukova, E.V., Miyoshi, N., Morita, Y., Nakamura, T., Hase, Y., Shinomiya, Y., Kawamuro, K., 2000. Vegetation history of the southeastern and eastern coasts of Lake Baikal from bog sediments since the last interstade, in: Minoura, K. (Ed.), Lake Baikal: A Mirror in Time and Space for Understanding Global Change Processes. Elsevier, Amsterdam, pp. 108–118.

Tarasov, P.E., Dorofeyuk, N.I., Vipper, P.B., 2002. The dynamics of vegetation in Buryatia in the Holocene. Stratigrafiya. Geologicheskaya Korrelyatsiya 10 (1), 88–96.

Tarasov, P., Bezrukova, E., Karabanov, E., Nakagawa, T., Wagner, M., Kulagina, N., Letunova, P., Abzaeva, A., Granoszewski, W., Riedel, F., 2007. Vegetation and climate dynamics during the Holocene and Eemian interglacials derived from Lake Baikal pollen records. Palaeogeogr. Palaeoclimatol. Palaeoecol. 252, 440–457.

Urabe, A., Tateishi, M., Inouchi, Y., Matsuoka, H., Inoue, T., Dmytriev, A., Khlystov, O.M., 2004. Lake-level changes during the past 100,000 years at Lake Baikal, southern Siberia. Quatern. Res. 62, 214–222.

Velichko, A.A., Andreev, A.A., Klimanov, V.A., 1997. Climate and vegetation dynamics in the tundra and forest zone during the Late Glacial and Holocene. Quatern. Int. 41/42, 71–96.

Vipper, P.B., 1962. The post-glacial history of Transbaikalian landscapes. Dokl. Akad. Nauk 145 (4), 871–874.

Wohlfarth, B., 1996. The chronology of the Last Termination: a review of radiocarbon-dated, high resolution terrestrial stratigraphies. Quatern. Sci. Rev. 15 (4), 267–284.

Xiaoqiang, L., Jiea, Z., Ji, S., Chengyu, W., Hongli, Z., Qianli, S., 2004. Vegetation history and climatic variations during the last 14 ka BP inferred from a pollen record at Daihai Lake, north-central China. Rev. of Palaeobot. Palynol. 132, 195–205.

Yu, Z., Eicher, U., 2001. Three Amphi-Atlantic century-scale cold events during the Bölling–Alleröd warm period. Géographie Physique et Quaternaire 55 (2), 171–179.

Editorial responsibility: A.V. Kanygin