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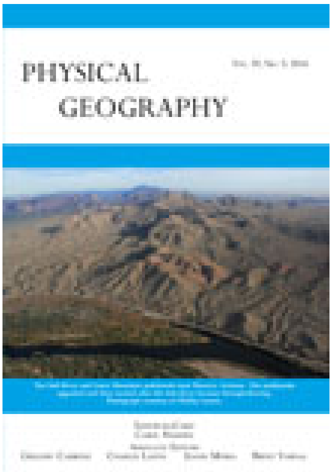

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Postglacial environmental change in the valley of Malye Chily River (the basin of Lake Teletskoye), northeastern Russian Altai

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Postglacial environmental change in the valley of Malye Chily River (the basin of Lake Teletskoye), northeastern Russian Altai

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The evolution and current state of landscapes around Lake Teletskoye have not previously been studied in detail. In the valley of the Malye Chily River, which flows into Lake Teletskoye, the timing of dam failure and draining of two moraine-dammed lakes has been identified. Botanical analysis, ash content determination, and radiocarbon dating of two peat profiles provide insight into postglacial evolution of wetlands related to this landscape. We found clear evidence of the disappearance from the peat of higher vascular species that, today, grows mostly in the plains of Siberia. Correlation of the data obtained with the accepted chronology of the Holocene events in the Russian Altai suggests the following stages of postglacial environmental change in the Malye Chily River valley: (1) the continuation of the Late Würm glaciation degradation (before 7000 cal. yr BP); (2) Holocene Climate Optimum (7000–5000 cal. yr BP); (3) Akkem cooling (5000–4200 cal. yr BP); (4) warm period (4200–3700 cal. yr BP); and (5) Historical cooling (3700–1600 cal. yr BP).

Keywords: Russian Altai; Holocene; Lake Teletskoye; moraine; glacier; botanical analysis of peat; radiocarbon dating

Introduction

The Russian Altai is a territory of natural contrasts. It is practically the north of Inner Asia in "miniature." Here, the contrast of hydrological and thermal regimes, including humid and semi-arid features, can be observed. Therefore, the response of landscapes to short-term changes of climate in the Holocene was different for various parts of the Russian Altai (Chernykh, Galakhov, & Zolotov, 2013; Ivanovsky, 1967). This has made it difficult to reconstruct a general scheme of Holocene events for the whole territory of the Russian Altai.

Knowledge of climate change in the Holocene in the Russian Altai has been based mainly on fluctuations of glaciers, including the position of terminal moraines and dates of organic residues in glacial deposits from the inner parts of the mountain system. As a result, a scheme characterizing the periods of principal Holocene events was developed, mostly for the southeastern and central parts of the Russian Altai. A recent review presented the last variant of the scheme (Agatova, Nazarov, Nepop, & Rodnight, 2012).

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Peat deposits of bogs are traditional sources of information about environmental changes in paleogeographical studies. The inner parts of the Russian Altai experience little precipitation and low temperatures, unfavorable conditions for bog development. For example, at the Kosh–Agach weather station, the annual precipitation is only 110 mm and the mean annual air temperature is −6.7 °C (Sevastyanov, 1998). Currently, in the Russian Altai, few examples exist that characterize continuous evolution of individual landscapes supported by the data from peat profiles.

Recently, some bogs have been found in peripheral parts of the Russian Altai that are slightly warmer and more humid. For instance, we found peat deposits of up to 2 m thick in the middle mountains, located in the west of the Russian Altai (Chernykh et al., 2013). In the northeast, in the river valleys of low mountains, thick peat deposits reaching 7 m in depth have been studied (Inisheva et al., 2011).

Results obtained from our study of peat deposits from the middle mountains of the northeastern part of the Russian Altai are presented in this paper for the first time. Paleogeographical studies to date have largely been confined to a period of the last glaciation and its scope in the lake depression. The last postglacial period and further evolution of the landscape adjacent to Lake Teletskoye, the largest lake in the Russian Altai, have not been previously studied, most likely because it is a hard-to-reach territory.

Data obtained recently indicates that glaciation has had a significant effect on landscape evolution in the study area (e.g., Budnikov & Rudoy, 2009; Rudoy, 2013). During the final period of the last glaciation (about 12,000 yr ago), most of the area adjacent to Lake Teletskoye was occupied by glaciers and periglacial lakes (e.g., ice-dammed, moraine-dammed, thermokarst lakes). Lacustrine–glacial deposits and related peat deposits, yet to be studied and interpreted, have been found in some places to the west of Lake Teletskoye (Rudoy, 2013).

The retreat of glaciers in the region was accompanied by vigorous meltwater erosion and active tectonic movements (Novikov, 2004), which strongly transformed late glacial landscapes and destroyed glacial deposits in most of the topography. In the area contiguous to Lake Teletskoye, the range of dissection exceeds 1000 m (Procsyuk, 1978). The latest data indicates the young age of the Lake Teletskoye depression. Perhaps, even in the Middle Pleistocene, the depression was occupied by an erosional valley formed in the zone of an incipient fault (Novikov, 2004).

Currently, active erosion makes the area well drained, even with a higher amount of precipitation. Hence, very few areas in the depression and the basin of the Lake Teletskoye are favorable for the accumulation of organic matter and formation of peat.

Study area

Lake Teletskoye, with a surface area of 227.3 km^2 and a maximum depth of 323.3 m, is one of the deepest freshwater bodies in Russia and the largest in the Russian Altai (Selegei, Dehandschutter, Klerks, & Vysotsky, 2001; Selegei & Selegei, 1978; Figure 1). Lake Teletskoye, often called the “small Baikal,” is located in the northeast of the Russian Altai. This area belongs to the Northeastern physiographic province, called the Priteletskaya (Procsyuk, 1978; Samoilova, 1990).

The annual total radiation in the area is 85 kcal/cm^2. The average temperature is −12 to −7 °C in January, and + 16 to + 12 °C in July. The average annual precipitation ranges from 800 to 1000 mm. Precipitation is at a minimum in winter (February) and maximum in summer (July–August). Rainfall precipitation is 71% of the average

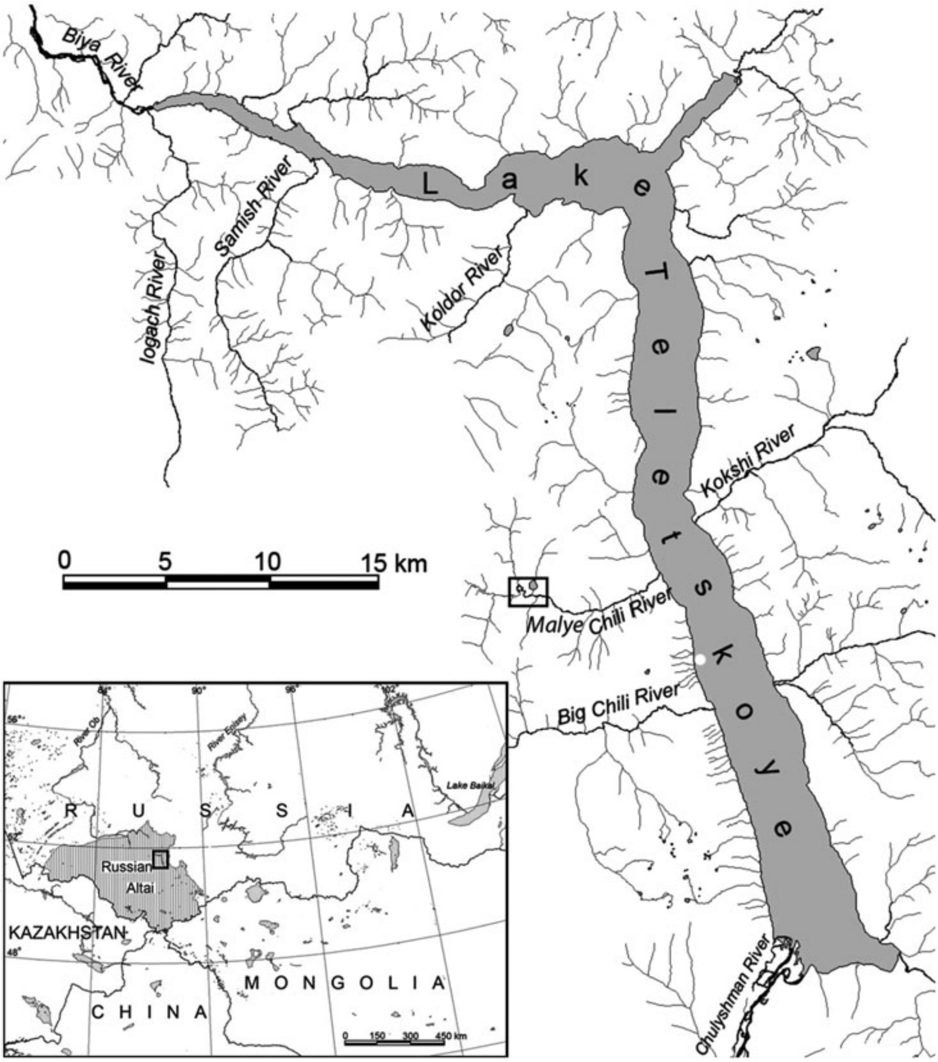

Figure 1. Location of the study area in Central Asia.

annual amount, while solid precipitation is 21% and mixed precipitation is 8%. Snow depth can reach 80–140 cm (Sevastyanov, 1998).

Mountain taiga landscapes occupy the largest area within the ridges surrounding the lake. Forests in the mountain taiga are fir-pine (*Pinus sibirica* and *Abies sibirica*). In the upper part of the forest belt, the forests are composed entirely of the Siberian pine. Here, the mountain soils are typically brown (cambisols), podzolic, and shallow.

Our study sites were in the Malye Chily River valley, which enters Lake Teletskoye from the west (Figure 1). The moraine dam splits the valley into two parts. The upper part of the valley (Archa River valley) is wide and waterlogged, whereas the lower part is narrow (Figure 2). The dam created a large lake in the Malye Chily River valley, with numerous bays in the valleys of its tributaries. Further, the dam's incomplete breakthrough created a vast wetland. A second, smaller lake was formed in the valley of an unnamed stream to the north of the dam. Part of the second lake still exists as Lake Ezhilyukel.

Lake sediments are present on the surface near the river channels. In particular, in the mouth of Yaryshkol River (200 m from its confluence with Archa river), their apparent thickness is not less than 1.5 m (Figure 3). Deposits consist of gray-brown silt with sand inclusions. In the upper part, soil formation takes place. The deposits contain horizontally bedded wood fragments. The thickness of lacustrine silt deposits allows us to argue that a large dammed lake existed in the valleys of Archa River and its tributaries. Vysotsky (1997), who did not visit this place, believed that the lake was formed because of tectonic damming, which was also responsible for the formation of a flat waterlogged bottom of the valleys upstream Malye Chily River (Yaryshkol and Archa Rivers).

In 1998, we visited this hard-to-reach territory for the first time. Our interest in the landscapes and its evolution was stimulated, in particular, by the diversity of mire types in this rather small mountain territory.

Our field observations showed that a dam in the valley was a moraine (Figure 2). The loamy-bouldery moraine (Figure 4) is embedded into the bedrock (shale) of the surrounding valley slopes. Interestingly, the well-rounded erratic boulders of the moraine are granitoid by content, similar to those of the Altyntu Mountains to the south. In its lower part, the moraine has washed out and consists of bouldery sand and gravel deposits. The contact of the moraine with the original slopes is sharp. The original slopes of the valley are composed of greenschist and unrounded (sharp-edged) products of weathering (Chernykh, Zolotov, & Balykin, 2007). Glacial deposits from other sites to the west of Lake Teletskoye have been described by Rudoy (2013).

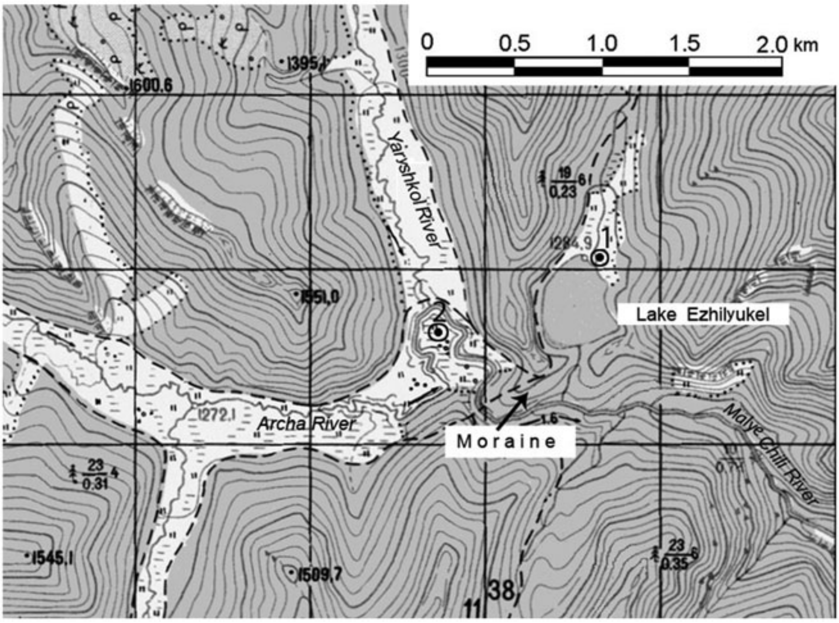

Figure 2. Profiles in the Malye Chily valley. Legend: (1) symbol for lake deposits, (2) symbol for moraine, and (3) location of Profiles 1 and 2.

Figure 3. Lacustrine silt deposits in the Yaryshkol River valley, Russian Altai.

The formation of the moraine dam in the valley was probably associated with the maximum of the last glaciation (Late Würm). This idea is supported in general for the surroundings of Lake Teletskoye by Novikov (2004): "… most likely that the sites of the change of the gently sloping valley to the V-shaped one correspond to the margins of Late Pleistocene glacial maximum advance."

It seemed obvious, even during the first visit to the Malye Chily River valley, that we had found valuable material for studying landscape evolution in the region. The timing of partial or complete draining of the lakes and mire formation particularly attracted our interest. The influence of natural conditions on the succession of bog vegetation and, perhaps, on the environment of surrounding landscapes, was of interest as well. In 2007, we returned to investigate the Malye Chily River valley.

Methods

Sampling

First, we studied the whole waterlogged territory in the Yaryshkol and Archa River valleys. Upstream, peat thickness decreases. In sites adjacent to river beds, lacustrine silts

Figure 4. Loamy-boulder moraine in the Malye Chily River valley, Russian Altai.

are found at the surface. Two profiles in lacustrine-boggy deposits were constructed in locations with maximum peat thickness (Figure 2).

Profile 1 (51°32′48.8″ N, 87°33′25.3″ E, 1295 m asl) was excavated on the lake terrace in the north of Lake Ezhilyukel, which is 100 m from the shoreline and equidistant from the steep slopes of the valley (Figure 5(a)). The surface is occupied by sedge-sphagnum bog with rotundifolious birch (*Betula rotundifolia* – cop1) or dwarf birch. Cover of mosses reaches 100%, including sphagnum (95%) and higher vascular plants (within 30–40%). Bushes of rotundifolious birch are attributed to peat hillocks. Sedges dominate: *Carex pauciflora* (cop2), *Carex rostrata* (cop2), and *Carex canescens* (sp). Cranberries are abundant: *Oxycoccus microcarpus* (cop1) and *Oxycoccus palustris* (sol). Other species occur sporadically and mostly on the periphery, including *Veratrum lobelianum, Parnassia palustris, Menyanthes trifoliata, Comarum palustre,* and *Deschampsia caespitosa*. The profile was made to a depth of 200 cm. At a depth of 190 cm and lower, peat was underlain by loamy-pebbly lacustrine deposits.

Profile 2 (51°32′26.3″ N, 87°32′43.1″ E, 1274 m asl) was excavated in the Archa River valley, opposite the confluence of the Archa River with the Yaryshkol River (Figure 5(b)). In this place, the Archa River makes a loop. The surface has a hilly microrelief (up to 50 cm) with an undershrub-sedge-sphagnum bog. Trees are rare here, with *Picea obovata* (sp), *P. sibirica* (sp), *Pinus sylvestris* var. *nana* (un), and *Betula pubescens* (sol), and with *B. rotundifolia* (cop1) shrubs up to 50 cm in height. Cover of mosses and lichens reaches 100%; sphagnum is about 80%; hypnum (*Polytrichum* sp., *Pleurozium schreberi*), growing mostly on the hillocks, makes up 15%; reindeer moss (*Cladina* sp.) comprises 5%; and higher vascular plants cover 30%. Sedges dominate – *C. pauciflora* (cop2), *Carex limosa* (sp), and *C. rostrata* (sp) – and cranberries (*O. microcarpus* (cop2)) are abundant. Other undershrubs (*Andromeda polifolia* (sp),

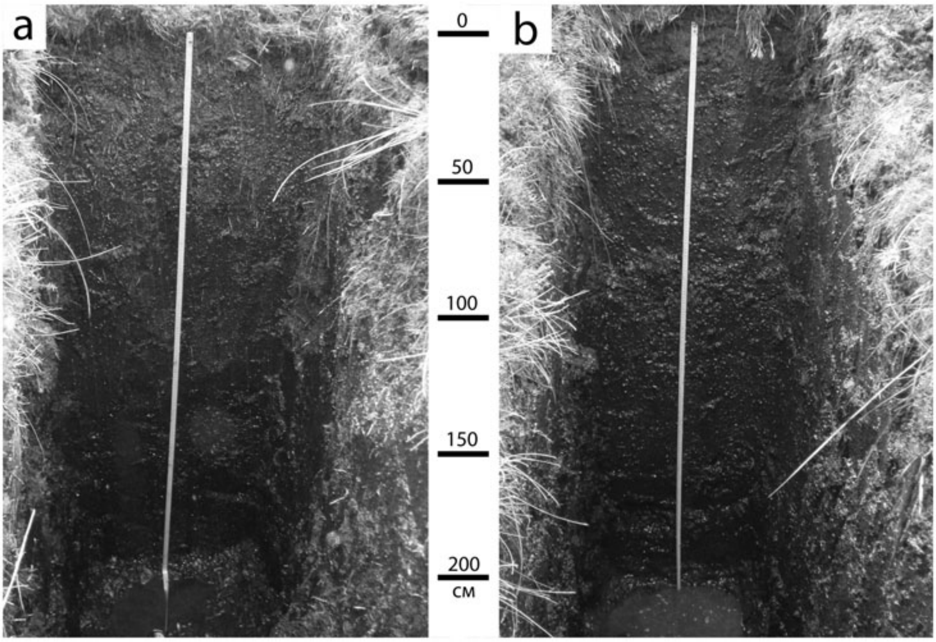

Figure 5. (a) Profile 1 and (b) Profile 2. Profile locations are shown in Figure 2.

Vaccinium myrtillus (sp), *Vaccinium vitis-idaea* (sol)) grow on the peat hillocks and stretched hummocks but are scarce. Some small, flat hollows (*mochazhina*) are filled with shallow water. The profile was excavated to a depth of 200 cm. At a depth of 180 cm and lower, peat was underlain by loamy-pebbly lacustrine deposits. Peat thickness decreases in all directions. Along the banks of Archa River, lacustrine silts are found at the surface.

Botanical analysis of peat

Peat cores of 10 cm (0–10, 10–20, etc.) were sampled across the whole width of the peat profiles for the botanical analysis. Peat samples were studied by A.V. Grenaderova using microscopic methods (botanical analysis of peat), consistent with a standard procedure in the Russian telmathology (Largina, 1977).

Determination of ash content in peat samples

Ash content (A^z) was defined in the Laboratory of Biogeochemistry, (Institute for Water and Environmental Problems, Barnaul) with the use of the melting pot method (Lishtvan & Korol', 1995). To conduct the analysis, 10-cm (0–10, 10–20, etc.) peat cores were sampled across the whole width of the peat profile.

Radiocarbon dating

Two peat samples were selected from each profile for radiocarbon dating. Dates were determined in the Institute for History of Material Culture of the Russian Academy of Sciences, St. Petersburg by G.I. Zaytseva. The number of available samples was limited by the funding available.

Results and discussion

Sample ages and comparison of modern and paleobotanical data

In Profile 1, the first date, of 7860 ± 280 yr BP (Le-9140), was from the base of the peat deposit at a depth of 187–183 cm. The second date, of 2760 (160 yr BP (Le-9138), was from the samples taken from a depth of 47–43 cm where *Sphagnum* peat was dramatically replaced by *Eriophorum*.

In Profile 2, the sample from 177–173 cm was dated to 5600 ± 270 yr BP (Le-9143), and the date from 120–110 cm to 4130 ± 90 yr BP (Le-9142). The first of these specimens was taken from the profile base, while the second was taken from the mid-part of the profile, which had high-ash content.

Profile 1 (Lake Ezhilyukel terrace)

The date from the profile bottom indicates that formation of the mire began about 8000 years ago. This process appears to have continued without significant interruption up to the present. Profile 1 is located on the opposite shore from the dam of the lake (Figure 2). The sharp boundary between lake deposits and peat clearly indicates the beginning of peat accumulation after the partial emptying of the lake. If mire formation had resulted from lake water-level rise, the peat would be underlain by the buried soil or deposits of another origin. In that case, the boundary with peat would have been smoother.

Such ancient peat deposits are extremely rare, not only in the Russian Altai, but also across the mountain belt of the south Siberia. Typically, the peat profiles are indicative of the middle and late Holocene or show the alternative layers of peat and mineral deposits of glacial, fluvio-glacial, or lake origin. The date obtained from the profile allowed us to characterize the rate of peat accumulation in different periods of the Holocene. In the lower and middle part of the profile, at depth of 187–47 cm, it averages 0.28 mm/year; in the upper profile (47–0 cm), it slowed to 0.16 mm/year. Knowing the rate of peat accumulation makes it possible to roughly date layers and define the time of appearance (not earlier) and disappearance (not later) of plant species in different layers of the profile.

Profile 1 indicates that peat, which lies directly on lake deposits (ash content $A^z = 73.4\%$) at a depth of 190–175 cm, is composed mainly of sphagnum, with a botanical composition characterized as transition-moor. Here, the content of sphagnum reaches 85–90%; they are presented by sections *Acutifolia* and *Cuspidata*, and the ash content ($A^z = 12.9\%$) is relatively low for initial stages of mire formation, even though it corresponds to the fen peat (Tyuremnov, 1976). The dominant in mass sect. *Acutifolia* is probably the oligomesotrophic species *S. warnstorfii*, and in the sect. *Cuspidata*, the oligotrophic *S. balticum;* the first section occurs throughout the profile, and the second one disappears above the horizon and appears again only in the uppermost parts of the profile (Figure 6).

This situation apparently exists at the periphery of a clean, mesotrophic lake, in the shallows, where a poor, low-moor sphagnum miry fen was formed with the involvement of higher vascular plants, such as mesotrophic *P. sibirica*, and *C. rostrata* and mesoeutrophic *Carex cespitosa, Scirpus sylvaticus,* and *Thelypteris palustris.* It should be noted that the latter two species were not found in present-day vegetation of this area during the field research in 2005–2007. Although *S. sylvaticus* is common in the Russian Altai (Krylov, 1929; Timokhina, 1990), it occurs at the very periphery, neither

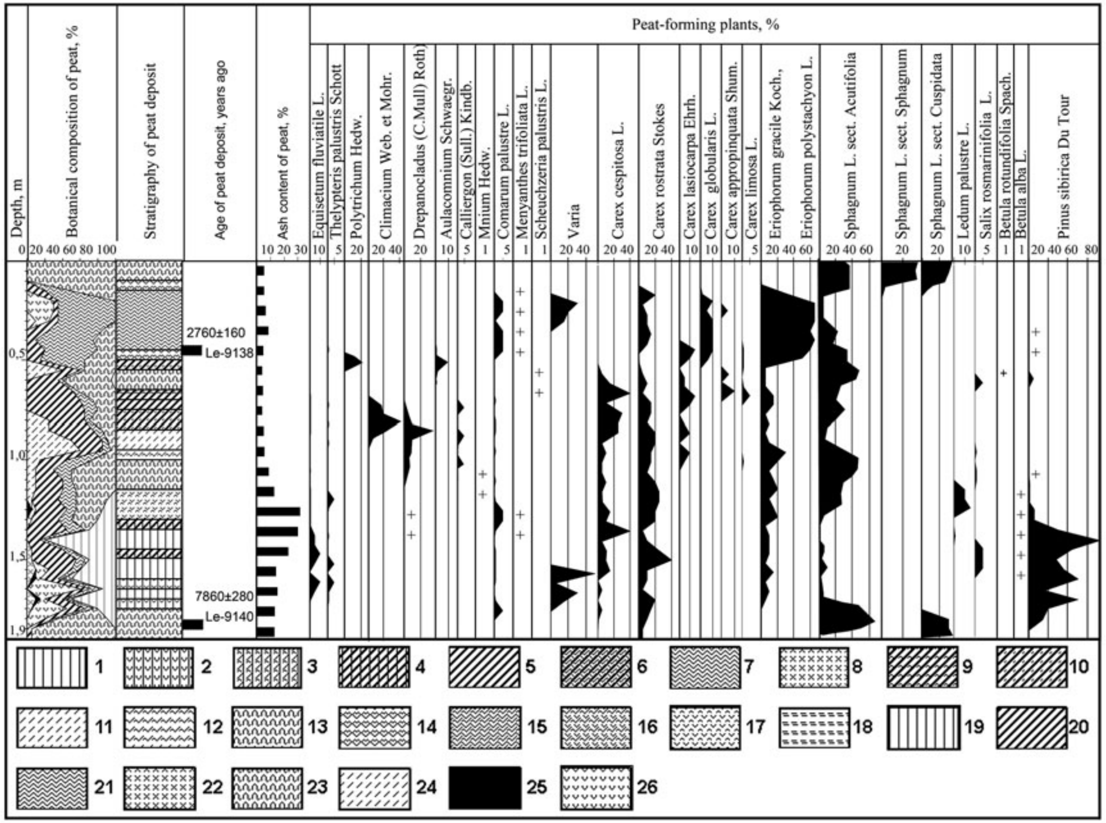

Figure 6. Diagram of the stratigraphy of Profile 1, showing stratigraphy, peat-forming plants, and ash content of the peat deposit. Symbols 1–17 represent peat species: 1 – wood, 2 – wood-grass, 3 – wood-moss, 4 – wood-sedge, 5 – sedge, 6 – sedge-*Eriophorum*, 7 – *Eriophorum*, 8 – *Equisetum*, 9 – sedge-*Sphagnum*, 10 – sedge-*Hypnum*, 11 – *Hypnum*, 12 – moss, 13 – *Sphagnum*, 14 – *Eriophorum*-*Sphagnum*, 15 – *Eriophorum*-moss, 16 – grass-moss, 17 – grass-*Sphagnum*. Symbol 18 represents clay. Symbols 19–26 represent peat-forming plants, including 19 – trees and shrubs, 20 – *Carex*, 21 – *Eriophorum*, 22 – *Equisetum*, 23 – *Sphagnum*, 24 – *Hypnum*, 25 – *Thelypteris*, 26 – varia grass (*C. palustre*, *S. sylvaticus*, *Calamagrostis langsdorffii* and grass high degree of decomposition).

rising high nor penetrating deep. To an even greater degree, the situation is typical for *T. palustris*, which is found only in the northern and western boundaries of the Altai (Shmakov, 2005). Thus, both of these plants are mainly species of the plains in Siberia, where their natural habitats cover areas of forest-steppe, subtaiga, and southern taiga. The extinction of species from the local flora was apparently associated with environmental changes and the natural succession of communities towards oligotrophication. The formation of sphagnum peat is not characteristic of the initial stages of low moors. Usually, such a situation develops under the cold weather conditions of the northern taiga and tundra in plains or highlands on the shores of kar or moraine-dammed lakes poor in mineral salts. It can thus be assumed that similar conditions were present at this location during the Boreal Holocene period.

The sharp decline in the botanical composition of sphagnum to 5% (175–150 cm, $A^z = 12.9$–13.9%) is likely indicative of warming (Holocene Climate Optimum). Here, peat is composed of wood grass and wood, with a 45–85% share of grass and up to 50% of wood. Among the grass, the sedges dominate (20%); there is a considerable quantity of *Equisetum* – up to 10%. (In the modern flora, *Equisetum* is present as a mesoeutrophic *E. fluviatile* and mesotrophic *E. palustre*). In addition, the peat contains *Eriophorum* – up to 15% (in the modern flora, *Eriophorum* is present as mesotrophic *E. gracile* and *E. polystachyon*) – and mesotrophic *C. palustre* – up to 5%. The increase in the share of the above-mentioned *S. sylvaticus* (10%) and *T. palustris* (5%) is observed. These changes indicate an increase in water content and community trophicity in that period and, most likely, a shore sedge-herb low forest (*P. sibirica*). A bit changed, this community existed for almost the whole Holocene Climate Optimum, as shown by wood, wood-grass, and wood-sedge peats at a depth of 175–130 cm.

At a depth of 150–140 cm, the peat includes angular and poorly rounded fragments of clay shale, which make up the surface of the slopes adjacent to the wetland. The occurrence of these inclusions indicates a significant change in the wetland development. At the same time, the ash content increases ($A^z = 22.9$–29.8%) at a depth of 150–130 cm. At this depth are numerous pieces of bark and wood; and, here, alongside with *Pinus*, *Salix,* and *Betula* sect. *Albae* appear (in modern flora it is *B. pubescens*, a typical species of swamp forest and low forest). The peat becomes wood and wood-sedge, which implies an increasing role of sedges. These facts are indicative of an event that drastically changed the local environmental conditions.

Based upon the nature of mineral inclusions (poorly rounded pebbles with silt; as in surrounding slopes, pebbles are shale by content), it appears that the level of Lake Ezhilyukel rose and intermittent re-flooding of the previously dewatered sites took place, probably during a high-water period, since the site is located within the delta of the stream that flows into the lake. Higher lake levels may have been caused by climate change towards higher humidity and the subsequent increase of influent flow. An increase in precipitation would also have contributed to slope processes, such as landslides. Numerous mud trays are found on the surrounding slopes (Figure 7), and their influence is obvious in peripheral parts of wetlands. Further evidence of slope processes is the presence of gravel and large wood remains among lake pebbles and mud. These materials could have entered the lake only with large flow.

The high lake level probably remained unchanged for a long time, and the fall of the lake level was supposed to have been gradual. Warm and humid conditions (Klimenko, 2009) in the mid-Holocene (Holocene Climate Optimum) favored higher productivity of vegetative communities. As a result, the mire changed rather quickly from a low-moor eutrophic to a transition-moor mesotrophic stage. Thus, at a depth of

Figure 7. Traces of debris flow on the slopes and in the valley near Profile 1.

130–100 cm, with a gradual reduction of the ash content from 31.4 to 8.3%, sphagnum increases up to 50%; moss increases up to 65%; the peat becomes grass-sphagnum and sphagnum; and the typical mesooligotrophic species *Carex lasiocarpa* and *Menyanthes trifoliatea,* and oligomesotrophic *C. limosa* appear. In contrast to lower layers, the share of arboreal species decreases sharply. Starting from the depth of 130 cm, the share of hypnum mosses, which appeared sporadically before, grows (5–10% at 130–115 cm, 10–15% at 115–100 cm). Judging from the rate of peat accumulation, this horizon (130–100 cm) refers to the end of the Holocene Climate Optimum, the beginning of the Akkem cooling when the warm and humid climate became colder and drier (Klimenko, 2009).

Basically, the presence of a large proportion of herbaceous plants, with a high degree of decomposition in peat, and the high degree of decomposition peat itself (up to 65%) is indirect evidence that a warm and humid climate existed during this period and contributed to the digestion of organic matter that is characteristic of the Holocene Climate Optimum.

Higher in the profile, at a depth of 100–40 cm, the peat is transition mesotrophic ($A^z = 4.2–5.4\%$), with layers of the high-moor oligotrophic peat (80–70 cm, $A^z = 3.6\%$; 60–50 cm, $A^z = 3.7\%$). For example, starting from the depth of 65 cm, the peat contains the mesooligotrophic *Carex globularis*. Climate fluctuations of the Akkem cooling, the beginning of the Historical cooling, and the warm period between them were not distinctly reflected in the ash content of peat deposit of Profile 1 because the transition-moor bog was less dependent on the surrounding landscapes than the low-moor bog.

However, botanical composition of peat changed greatly. The Akkem cooling resulted in the extension of a cold period, the accumulation of snow, and, consequently, in more prolonged and intensive floods as well as a pulse water regime all year round that is favorable for the formation of floodplain hypnum bogs and fens. The increase in the share of hypnum mosses (from 15 to 65%) up to formation of *Hypnum* low-moor peat at a depth of 95–85 cm, replacing *Sphagnum* transition-moor peat, vividly illustrates this tendency.

In the warm period, after the Akkem cooling, the share of sedges grew notably (up to 60–65%) up to formation of sedge peat low-moor by botanical composition at a depth of 75–70 cm. In addition, at this time (75–65 cm), the degree of decomposition in herbaceous plants increases (*Eriophorum*, up to 15% of peat), which is typical for the warm periods.

The beginning of the Historical cooling, with more distinct boreal conditions and natural succession, decreased the share of sedges up to 30–35% and increased sphagnum within 50% (65–50 cm). At a depth of 55–50 cm, the prevalence of hypnum mosses (up to 40%) provides evidence of a dynamic water regime during the cooling that probably occurred in the end of the early phase of the Historical stage. In the second half of the Historical cooling (second and last phases), the long-term flooding of bogs, most likely caused by a rise in water level of the lake, took place. *Eriophorum* peat at a depth of 45–15 cm and the eutrophication ($A^z = 6.3–8.2\%$; low-moor peat) at a depth of 40–20 cm are indicative of cooling. It is also supported, for example, by the appearance of eumesotrophic *Carex diandra*. This event is marked by the second date (2760 ± 160 yr BP), taken from a depth of 43–47 cm.

In Western Siberia in the second half of the Holocene, the temperature drop during the cooling was followed by a small increase in precipitation and by the rise of water levels in lakes (Galakhov, Gubarev, & Nazarov, 2010). The rise of lake levels was facilitated by low evaporation as well.

The Historical stage of cooling (3700–1600 BP) comprises three phases, namely the advance of glaciers and two warmings. In the Russian Altai, the glacial repeated advance during the Historical stage is recorded in many glacier regions (Agatova et al., 2012; Chernykh et al., 2013; Ivanovsky, 1967).

As compared with previous periods, relatively frequent fluctuations of temperature and precipitation during the Historical stage of cooling did not extensively affect the formation of the bog. In particular, warming is not noted, and the Historical stage itself can be stratigraphically divided into early (early phase) and late (second and last phases).

Natural succession would have contributed to the oligotrophication of the bog. The growth of the peat deposit and the downcutting of draining streams would gradually have reduced the influence of groundwater and surrounding landscape on the wetland, so that the layer corresponding to the warming before the Aktru cooling is not clearly distinguished in the profile. Only the tissues of herbaceous plants of high degree of decomposition (up to 30%), with a peak at a depth of about 20 cm, are indicative of the warming.

Directly under the modern vegetation (20–0 cm) *Eriophorum-Sphagnum*, *Sphagnum* (up to 100%) transition-moor ($A^z = 5.0–5.1\%$), peat occurs. In the upper profile, the diversity of sphagnum increases. From the depth of 45 cm, the dominant across the profile, sect. *Acutifolia,* is supplemented with oligomesotrophic *S. girgensohnii*. From the depth of 15 cm, the oligotrophic representatives of sect. *Sphagnum (S. magellanicum)* and *Cuspidata (S. angustirolium)* appear, and at a depth of 10 cm, they prevail together with the species of sect. *Acutifolia*. By botanical composition, the upper 10 cm of peat refer to a high-moor type. According the rate of peat accumulation, the layer of 13–0 cm is related to the Aktru cooling.

In general, an interesting pattern is observed from the bottom to the top of the profile as we approach modern times. The peat loses the vascular plants that are considered in Siberia to be mostly species of the plains. Many of them are not only absent in the modern flora of the area under study, but are rare in the Altai Mountains in general. These are mesoeutrophic *S. sylvaticus* (180–145 cm ≈ 7680–6430 ± 280 yr BP), *T. palustris* (180–40 cm ≈ 7680 ± 280–2450 (160 yr BP), and mesooligotrophic *Scheuchzeria palustris* (70–50 cm ≈ 3750–3040 ± 280 yr BP). The change of natural conditions, as well as the wetland self-development, suggest that flora of the study area was gradually losing the elements from the plains.

Vegetation in the present stage of development can be characterized as a transition mesooligotrophic sedge-sphagnum bog with dwarf birch (Lapshina, 2003). Among sphagnum, the oligotrophic *S. angustifolium* and *S. magellanicum*, and the oligomesotrophic *S. girgensohnii* and *S. warnstorfii* dominate. Of higher vascular plants, the oligotrophic *C. pauciflora* and *O. microcarpus,* the mesooligotrophic *B. rotundifolia* and *O. palustris*, and mesotrophic *C. rostrata* and *C. canescens* species prevail. This bog, close to a high-moor type, characterizes the final stage of its natural succession in conditions of mountain taiga.

Profile 2 (Archa River valley)

The Archa valley is located approximately 20 m below the Lake Ezhilyukel depression. The date obtained from the profile allowed us to characterize the rate of peat accumulation at different periods of the Holocene. In the lower and middle part of the profile, at a depth of 120–177 cm, it averages 0.43 mm/year, in the upper (0–120 cm) it averages 0.28 mm/year.

The date of 5600 ± 270 yr BP from the depth of 173–177 cm is close to the time of the emptying of the lake in the Archa valley (Figure 8). Profile 2 is located directly upstream of the dam, probably in the deepest part of the dammed lake. The sharp replacement of lake deposits with peat at a depth of 180 cm indicates a complete emptying of the lake and the beginning of mire formation.

Thus, the formation of the mire here began about 2000 years later than in Lake Ezhilyukel. By that time, climate was warming (Holocene Climate Optimum) and primary succession in the shallow lake basin took place, from the typical low-moor stage by coastal aquatic plants represented by horsetails (probably *Equisetum fluviatile* and *E. palustre*), fern (probably *T. palustris*), and *C. palustre*. The loam, with the inclusion of plant remains mentioned, occurs at a depth of 200–180 cm ($A^z = 74.5–77.6\%$). Because of the warmer climate, the productivity of communities was obviously higher than that at the beginning of the mire formation in the Lake Ezhilyukel depression (Boreal Holocene period). At a depth of 180–170 cm, the peat is mainly *Equisetum*.

Later, natural succession from the typical low moor towards the transition and high-moor stages appears to have been recurrently interrupted. This is shown by variations of ash content and of botanical composition of peat. An increase in the ash content of peat is interpreted as an increase in the influence of ground and surface water on the water regime.

At the end of the Holocene Climate Optimum, hypnum mosses appear in Profile 2, and their role is even more significant than in Profile 1. Their share at a depth of 170–145 cm is 20–30%. Here, wood-moss, moss, and grass-moss peat supplemented with sphagnum were formed (15–40%).

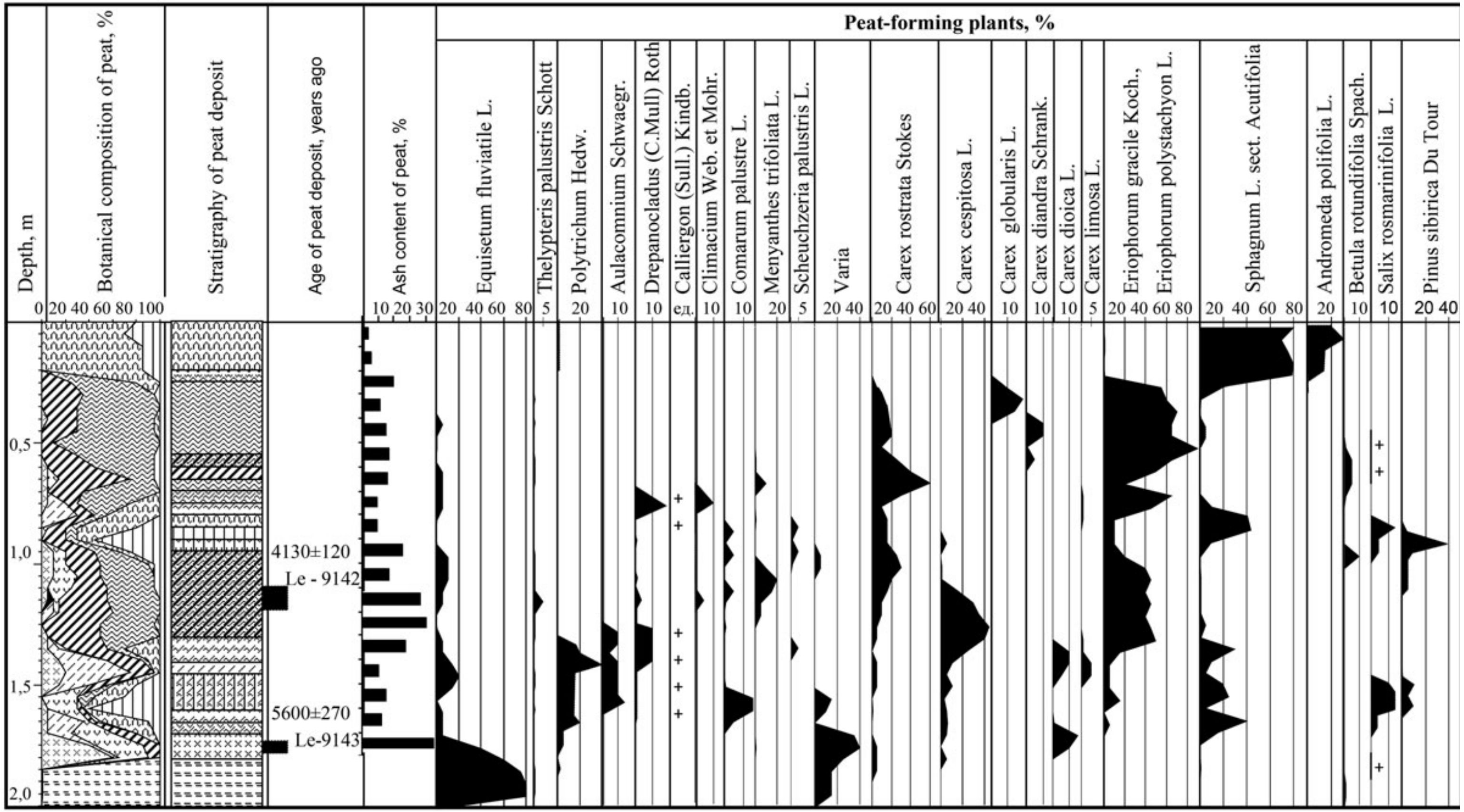

Figure 8. Diagram of the stratigraphy of Profile 2 shows stratigraphy, peat-forming plants, and ash content of the peat deposit. Symbols for peat composition and stratigraphy are the same as in Figure 6.

The larger share of hypnum mosses at that time shows the greater influence of the flooding regime. Sphagnum prefers more stable mineral and water conditions. Profile 2 is located in the valley of a larger stream, near the confluence of the largest of its tributaries, and is within the larger wetland.

In other words, the bog of Profile 2 was initially more hydrologically dependent on the surrounding landscapes and the landscapes of the Archa River basin as a whole. In addition, it is likely that temperatures were cooler at the end of the Holocene Climate Optimum than in the middle, since in Profile 2, at a position with less thickness of peat and time of bog development than in Profile 1, the botanical composition shows the predominance of mosses.

As in Profile 1, the Holocene Climate Optimum in Profile 2 is characterized by the presence of the tissues of herbaceous plants with a high degree of decomposition (up to 40%) in peat, which is indicative of the warm and humid climate at that period.

The beginning of the Akkem cooling, as in Profile 1, resulted in the sharp increase of the proportion of hypnum mosses from 25% (145–160 cm) to 55% (145–140 cm) and the drop of sphagnum from 25 to 5%. As in Profile 1, this appears to be due to more pronounced and prolonged spring floods and the dynamics of the hydrological regime during the year.

In contrast to Profile 1, in Profile 2, a sharp increase of peat ash content, from 10.2% (150–140 cm) to 27.6% (140–130 cm, moss peat), took place at the beginning of the Akkem cooling. This is explained by the difference in the profile's location, and hence the conditions for peat formation. Surface and ground waters had a much stronger effect on the bog in Profile 2.

Another characteristic feature of hydrological regime change is the increase in peat of mesoeutrophic *C. cespitosa*, the typical species of fens and wet meadows with unstable water regimes. Thus, at a depth of 170–145 cm, the share of this species does not exceed 5%, while at the beginning of the Akkem cooling, the proportion of *C. cespitosa* in *Hypnum* peat increases up to 10–15% (145–140 cm). Further, a sharp increase of *C. cespitosa* up to 30% (sedge-*Eriophorum* peat) at a depth of 130–110 cm is accompanied by a growing ash content ($A^z = 36.5–40.8\%$). This is comparable only with the initial stages of the lake overgrowth at a depth of 180–170 cm (*Equisetum* peat, $A^z = 45.4\%$).

Some decrease in the ash content up to 17.3% (110–100 cm) may correspond to the warm period after the Akkem cooling, and further growth at a depth of 100–90 cm ($A^z = 25.6\%$, wood-grass and sedge-*Eriophorum* peat) may correspond to the early phase of the Historical stage.

In botanical composition, the end of the Akkem cooling, the warm period (second dating of 4130 ± 90 yr BP from the depth of 110–120 cm) and the beginning of the early phase of the Historical cooling are similar, since the layer of is composed of 130–95 cm sedge-*Eriophorum* peat.

Further growth of peat and the cutting of Archa River are likely to have reduced the impact of the flooding regime. This would have led to a consistent increase in the proportion of sphagnum to 10% (95–90 cm), 15% (90–85 cm), and 50% (85–80 cm), accompanied by a significant fall of ash content (A^z=9.4–9.3%, 90–70 cm; the average share of sphagnum is 33.6%). In general, the increase in the proportion of sphagnum and, to a lesser extent, hypnum mosses, indicative of the trophicity reduction, was followed by a decrease in ash content. According to the rate of peat accumulation, the 95–80 cm layer corresponds to the end of the early phase of the Historical cooling and subsequent warming.

The beginning of the second phase of the Historical cooling is characterized by an increase in the proportion of hypnum mosses up to 30% (80–75 cm, moss peat), and then *Eriophorum*, with 45% at 75–70 cm and 65% at 70–65 cm, which points to flooding as the moisture increased. Flooding is evidenced by the increased ash content from the depth of 70 cm.

The second warming is indicated by sedge peat (60%, *C. rostrata*, at 65–60 cm). The beginning of the last phase of the Historical cooling is indicated by the repeated increase of water content and the predominance of mesotrophic cotton grass (*Eriophorum gracile, E. polystachyon*), with 50% at 60–55 cm depth and 60–90% at 55–25 cm. A community dominated by cotton grass lasted almost until the end of the warming before the Aktru cooling, and then the growth of the peat deposit and streams down cutting again favored oligotrophication.

The upper part of the profile at a depth of 25–0 cm shows the predominance of sphagnum of sect. *Acutifolia.* The oligotrophic *A. polifolia* in the upper 20 cm is up to 30%, while all kinds of sedge and cotton grass disappear. The ash content drops in the horizon of 20–10 cm to the level corresponding to the transition mesotrophic bog ($A^z = 5.9\%$), and in the upper layer of 10–0 cm, to the raised oligotrophic bog ($A^z = 3.3\%$). According to the rate of peat accumulation, the layer of 22–0 cm refers to the Aktru cooling.

Modern community (undershrub-sedge-sphagnum bog with dwarf birch and low forest) should also be described as oligotrophic. It is dominated by oligotrophic (*C. pauciflora, O. microcarpus*, and *A. polifolia*), mesooligotrophic (*B. rotundifolia, V. myrtillus*, and *V. vitis-idaea*), and oligomesotrophic (*Carex limosa and P. sylvestris* var. *nana*) species, under the subordinate role of the mesotrophic ones (*C. rostrata*, *P. obovata*, *P. sibirica*, and *B. pubescens*).

Here, as in the first profile, at the approach to the present, a number of species of vascular plants, mostly known from the plains, absent in the modern flora of the study area, and rare in the present-day Russian Altai mountains, disappeared. Thus, in the following depth intervals, such species as mesoeutrophic *T. palustris* (195–190 cm (lacustrine loam) and 165–25 cm (peat) ≈ before 5600 ± 270 yr BP to 920 (90 yr BP) and mesooligotrophic *S. palustris* (135–80 cm ≈ 4600 ± 270 to 2880 ± 90 yr BP) occur. In our opinion, this phenomenon occurred for the same reasons as in the profile on the terrace of Lake Ezhilyukel.

Attempt to establish connections with the Altai Holocene chronology

The results presented in this paper are the first attempt to present the chronology of the Holocene events for the surrounding area of Lake Teletskoye (north-eastern part of the Russian Altai). Despite the limited input data (only materials from two peat profiles were processed), the results agree well with findings from other parts of the Russian Altai. The recent results for the Russian Altai were given by Agatova et al. (2012), and results for the southwestern part of the Russian Altai (Kholzun Ridge) were presented by Chernykh et al. (2013). The latter ones form the basis of the Holocene periodization given below.

Before 7000 cal. yr BP

This period appears to have been a continuation of degradation of the Late Würm glaciation (Boreal Holocene period). Our results do not allow us to describe this time in detail. It probably involved both warm and cold periods. The radiocarbon date of 7860

± 280 yr BP from the bottom of the profile on the Lake Ezhilyukel terrace and the composition of *Sphagnum* peat lying directly on the lake deposits indicate relatively cold conditions at the time. The flora of the study area already included the species of the plains: mesoeutrophic *S. sylvaticus* and *T. palustris.*

7000–5000 cal. yr BP

This period is characterized by the highest Holocene temperatures (Holocene Climate Optimum) and is revealed throughout the Northern Hemisphere in close temporal boundaries: 8000–5000 cal. yr BP (Wick & Tinner, 1997); 7000–6000 cal. yr BP (Davis, Brewer, Stevenson, & Guiot, 2003); and 7450–5650 cal. yr BP (Joerin, Nicolussi, Fischer, Stocker, & Schlüchter, 2008). Our study area was also likely to have been warm enough for the initial overgrowth of a shallow lake in the Archa valley. The overgrowth occurred via the typical stage of low-moor as evidenced by the shoreline plants represented by horsetail (apparently *Equisetum fluviatile* and *E. palustre*), *T. palustris,* and *C. palustre*. The date of 5600 ± 270 yr BP records the time of this overgrowth, characteristic of warm conditions. At that time, the most abundant were *S. sylvaticus* (up to 15%) and *T. palustris* (up to 5%). In the next period, the first species was absent, and the second occurred sporadically because of the cooling and drying of the climate (Klimenko, 2009).

The warm conditions of the Holocene Climate Optimum are supported by botanical composition of peat and the high degree of its decomposition. The humidity in this period is evidenced by the nature of peat inclusions. The depth of 150–140 cm in Profile 1 in the Lake Ezhilyukel terrace contains numerous inclusions of pebbles, crushed shale from the surrounding slopes, and large plant residues. Thus, the environmental changes, as reflected in the deposits, were probably common to the whole area, with notable periodic flow increase and intensification of slope processes.

5000–4200 cal. yr BP: Akkem cooling

The beginning of the Akkem cooling in the both profiles is characterized by the increase of hypnum mosses content up to Hypnum peat, formed under high water content, and feed water salinity. Such a change, in our view, indicates a high level of fluctuation in the water regime. Water levels were higher during floods, and the duration of floods was longer due to the prolonged cold season. In Profile 2, this eventually led to the formation of *Eriophorum* peat.

In this period, the mesooligotrophic *S. palustris*, peculiar to the flooded miry bogs, appears in Profile 2. The area of this species in Siberia stretches from subtaiga to northern taiga; single findings were in the forest-steppe zone and mountains of Southern Siberia (Krasnoborov & Korotkova, 1988). It penetrates farther north than *T. palustris* and *S. sylvaticus*; therefore, the occurrence of *S. palustris* during the Akkem cooling is associated with its boreal nature.

4200–3700 cal. BP (Agatova et al., 2012). The warm period before the Historical cooling stage. The study area at that time is dated by 4130 ± 90 yr BP; the date was obtained from a sample of peat at a depth of 110–120 cm in the Archa valley. This period cannot be clearly identified from the data on the profiles. In Profile 1, it shows the increase of sedges proportion in peat and the degree of its decomposition, while in Profile 2 a slight decrease in peat ash content is presented.

3700–1600 cal. BP: Historical cooling

This time period was the Historical cooling, with the Löbben and Göschener phases of glacier advance, according to the Alpine chronology (Maisch, Wipf, Denneler, Battaglia, & Benz, 1998; Wilhelm, 1975). This period of contrasts is divided into three phases of glacier advance with the following peaks: the early phase, at 3100 yr BP; the second phase, at 2500 yr BP; and the last phase, at 1600 yr BP (Chernykh et al., 2013). The early phase of the Historical cooling in our study area is close to the cooling episode of 3700–3300 cal. yr BP given by Agatova et al. (2012), and the last phase in our area is close to the proper Historical cooling stage of 2300–1700 cal. yr BP given by Agatova et al. (2012). The maximum extent of glaciers of the second phase in Agatova et al. (2012) falls on the warm stage before the Historical stage of cooling (3300–2300 cal. yr BP). Thus, the cooling and warming phases of the Historical stage did not coincide in different parts of the Russian Altai.

The latest date (2760 ± 160 yr BP), obtained from the Profile 1 on the terrace of Lake Ezhilyukel probably belongs to the second phase of the Historical cooling. The increase of precipitation and water content at the beginning of this phase probably resulted in the increase of residual cotton grass and sedge.

At the beginning of the early phase of the Historical cooling, *S. palustris* appears in Profile 1, while in Profile 2, it appeared about 1000 years earlier, i.e., during the Akkem cooling. It is of interest that, in both profiles, the occurrence of S. *palustris* signified the formation of *Eriophorum* peat, indicating increased water content in the already developed transition bog and the formation of the miry bog. Because of the specific location of the Archa River valley, the suitable conditions for this species had developed earlier.

During the Historical cooling, in Profiles 1 and 2, *S. palustris* disappeared at one time (the end of the early phase – the beginning of the warming) and, in Profile 1, *T. palustris* disappeared at the end of the second phase (the beginning of the warming). The disappearance of these species was probably due to frequent fluctuations in humidity and temperature in the Historical stage, and hence, to changes to the water content and mineral nutrition of bogs. In Profile 2, *T. palustris* disappeared in the warm period immediately prior to the Aktru cooling. This is probably due to the position of Profile 2 inside a larger wetland of a considerable age, which provided a more stable water regime, a variety of ecotypes, and ultimately greater independence of flora.

Thus, the main reason for the disappearance of the three species from the flora of the region was frequent and relatively short fluctuations in atmospheric humidity and temperature, as well as the evolution of surrounding landscapes. Recolonization of these species, which are mostly found in the plains, did not take place because of the isolation and scarcity of ecotopes in the mountains as compared with the plains.

1600 cal. BP (AD 400): AD 1200

The warm period before the Aktru cooling is not clearly identified in Profiles 1 and 2. At that time, there were watered cotton-grass bogs, which, by the end of the period, began to evolve towards oligotrophication. In Profile 1, the warming is indicated only by the tissues of grasses of high degree of decomposition (varia) with peak (up to 30%) at a depth of about 20 cm.

AD 1200–1850: Aktru cooling or Little Ice Age

In both profiles, this period is presented by *Sphagnum* peat and it is not differentiated into phases.

The recent events, including those associated with the Aktru cooling and the earlier warming, did not produce a clear expression in the profile stratigraphy. In our opinion, there may be two reasons. First, these were smaller (both in amplitude and duration) temperature variations in comparison with the previous periods. Second, in the self-development of wetlands, wetlands had achieved a transition mesotrophic and raised oligotrophic stages, which were less environment-dependent.

Conclusions

(1) Two profiles of lacustrine-boggy deposits were investigated: the first is in the Archa valley, the second is on the terrace of Lake Ezhilyukel. Peat samples were taken from each profile for botanical analysis, and a radiocarbon date was obtained for each profile. The analysis suggests that Lake Ezhilyukel was partially emptied about 8000 yr BP. The complete emptying of the lake in the Archa valley occurred around 6000 yr BP.

(2) Botanical analysis of peat from both profiles revealed an interesting pattern. At the approach to the present, higher vascular plants considered species of the plains in Siberia, disappeared. Most of them are not only absent in the modern flora of the study area but are rare in the Russian Altai in general. This may serve as a confirmation of strong fluctuations of temperature and atmospheric humidity in the second half of the Holocene, which caused the flora to gradually lose the species of the plains.

(3) Based on the comparison of our results and conclusions based on other parts of the Russian Altai, we attempted to link our findings with the accepted chronology of the Holocene events in the region. Our preliminary results suggest the following stages of postglacial environmental change in the Malye Chily River valley: (1) The continuation of the Late Würm glaciation degradation before 7000 cal. yr BP; (2) Holocene Climate Optimum (7000–5000 cal. yr BP); (3) Akkem cooling (5000–4200 cal. yr BP); (4) warm period before the Historical cooling stage (4200–3700 cal. yr BP); and (5) Historical cooling, which according to our data from other parts of the Altai took place 3700–1600 cal. yr BP. More recent events, including those associated with the cooling in the Aktru cooling and the earlier warm period, were not clearly reflected in the profile stratigraphy.

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