This article presents new interdisciplinary observations relating to environmental changes in the Bolshoe Inyaptukskoe Lake Basin, North Baikal Plateau. A column taken from a loam/turf deposit at 1320 m above sea level is shown to reflect changes in vegetation and climate over the last 8–9 thousand years through its palynology, radiocarbon chronology, and the count of charcoal particles. The chronology of the reconstructed changes in the vegetation around the Ozernyi-5 trench agrees well with existing regional and global climatic trends. However, the local processes also show their own peculiarities. The discrepancies are associated with the elevation and the altitude of the site.

Keywords: Siberia, North Baikal Plateau, high resolution pollen record, vegetation and climate changes, Middle Holocene, Late Holocene.

Introduction

It is well known that the vegetation of the Baikal region, which includes the North Baikal Plateau, was highly susceptible to global and regional climate changes during the Holocene and responded to them rather rapidly (Bezrukova, 1999; Demske et al., 2005; Tarasov et al., 2007; Tarasov, Bezrukovka, Krivonogov, 2009). It has been also demonstrated that climatic changes in this territory occurred almost synchronously with the climate...
oscillations of the Northern Hemisphere (Prokopenko et al., 2010). Until recently, no continuous, dated, high resolution pollen records of environmental changes have been obtained for the mountainous part of the North Baikal Plateau. This region presents itself as a large inland system of medium-sized mountains and flat-topped ridges with contrasting relief, flora, and climate, and a complex glacial history.

This article presents the first results of palynological study of loose mineral and organic (peat) sediments from the basin of Lake Bolshoe (Great) Inyaptukskoe located on the North Baikal Plateau. The results are unique for the region due to the fine-grained selection of samples which makes it possible to read pollen changes with a 180 year resolution on average. Such detailed information makes it possible to trace environmental variations beyond the regional level, to trace local vegetation changes (Kuoppamaa, Goslar, Hicks, 2009; Schlütz, Lehmkühl, 2007), and to establish the causes of these changes as either climatic or anthropogenic. The impact of anthropogenic factors is not analyzed in full here. Instead we focus on the way that major climatic changes were manifested in a peculiar way in mountainous areas.

**Description of the study area**

The Ozernyi-5 trench (56°22'49.1" N; 109°54'09.0" E) was located at the northeastern foothills of the Synnyr Ridge in the central portion of the North Baikal Plateau – a part of the Baikal Mountains lying between the Stanovoi Highland and the Lena and Vitim river valleys. The highest peak of the North Baikal Plateau is Mount Inyaptuk; it reaches 2578 m asl. Bolshoe Inyaptukskoe Lake lies 10 km west of the peak. In the 19th–20th centuries, a camp of Evenki reindeer-herders was situated on its western shore; and in the mid-20th century, a settlement of geologists was built there (Kharinsky, 2010). The Ozernyi-5 trench was dug on the northeastern periphery of the former reindeer-herding camp, 370 m from the lake shore.

This region has a continental climate. The annual temperature varies from −5 to −12 °C and the winters are cold and long. Temperatures in January average −30 °C. The daily temperature drops below zero until May. Summers are short and moderately warm. At the elevation of 500–600 m, the mean July temperature does not exceed +14 °C, while the growing season lasts for less than 90 days (Atlas..., 1967). Most precipitation falls in July and August as well as in the first half of the autumn. In mountainous areas, the average annual precipitation exceeds 500 mm while in the intermontane basins, it is 300–350 mm. The thickness of snow cover fluctuates markedly: from 20–30 cm to 180–200 cm in areas near Lake Baikal. The main air currents are western. In summer and autumn, the effect of northwestern winds increases. The North Baikal Plateau is situated in the zone of discontinuous permafrost (Baikal..., 1993).

The diversity of plant communities on the North Baikal Plateau is determined by zones which vary by altitude. Mountain taiga (larch and pine-larch forests), subalpine (larch forests with dark conifers and Siberian dwarf pine), and mountain tundra zones are characteristic of this region (Zony..., 1999).

The Ozernyi-5 trench was placed within the subalpine larch forest belt in the Olokit River valley, near Bolshoe Inyaptukskoe Lake (Fig. 1). The valley floor consists of a wetland covered with dwarf birch and tussock meadows. The slopes of the southern and western exposures are covered by subalpine larch open woodlands with dark conifers and Siberian dwarf pine (Fig. 2). Alpine tundra plant communities (primarily, dwarf birch with lichen)
Vegetation near the Ozernyi-5 trench is part of the valley wetland system with hummocks covered by ground birch (*Betula rotundifolia* Spach), isolated larches (*Larix dahurica* Laws.), golden rhododendron (*Rhododendron aureum* Georgi), bilberry (*Vaccinium uliginosum* L.), white arctic mountain heather (*Cassiope tetragona* (L.) D. Don), crowberry (*Empetrum sibiricum* V.N. Vassil.), and lingonberry (*Vaccinium vitis-idaea* L.). Lichen grows above the soil surface of hummocks. Hollows between the hummocks are occupied by willows (*Salix arctica* Pall., *S. bebbiana* Sarg., *S. coasia* Vill., *S. divaricata* Pall., and others) and by tussocked cotton grass or grassy sedge bogs on permafrost-affected meadow soil.

**Materials and methods**

The trench was dug near Ozernyi, an abandoned settlement built by geologists, at an elevation of 1320 m asl in the Olok River valley. The trench was 50 cm deep and was composed primarily of loam sediments with turf in its upper part. A damp site was chosen near to an alpine lake with the expectation that it would better preserve a local pollen signature. Further, the trench was placed near a camp once used by reindeer-herders with the hope that we would pick up a signature of pollen associated with the concentration of a large number of domestic animals once held there. This methodology of site selection was developed in Scandinavia, where pollen samples are taken 6–50 m away from a geoarchaeological object (Aronsson, 1991; Räsänen, Froyd, Goslar, 2007).

**Pollen analysis.** One sample was taken from every centimeter of the column creating an archive of 50 samples. To extract pollen and spores in the laboratory, 1 cm³ of undried sediment from each layer was processed using a standard process using hydrofluoric acid followed by acetolysis (Faegri, Iversen, 1989). Before the start of the procedure, two tablets of *Lycopodium clavatum* marker spores (18,584 grains per tablet) were added to each sample in order to control the pollen concentration (Maher, 1981). Pollen grains and spores were counted until either their total number, or the quantity of the *Lycopodium* markers reached 1000. The count of naturally-occurring *Lycopodium* spores was excluded from these totals. The relative percentage of all pollen-bearing taxa was calculated relative to the total count of pollen coming from terrestrial species. The percentages of spores from fern, moss, and club moss were calculated relative to the total count of both pollen grains and spores in each sample. At the same time, the number of charcoal particles was counted from the same prepared samples. The counts of each charcoal microparticle were calibrated to the size of 30 microns in diameter (the approximate size of a grain of the *Lycopodium clavatum* marker) (Innes, Blackford, Simmons, 2004). We did not carry out an inventory of different sizes of charcoal.

**AMS dating.** Two bulk AMS dates were obtained from samples taken from the depths of 19 and 32 cm at the Ångström laboratory at Uppsala University in Sweden. The first was taken from the bottom of the layer composed of light gray loam. The second, from an isolated black loam layer. The uncalibrated radiocarbon dates for these samples are 5935 ± 36 (Ua-38926) and 7005 ± 40 (Ua-38927), respectively. The dates when calibrated using CalPal software give the values of 6764 ± 50 (68 % confidence limit: 6713–6814 calibrated years) and 7858 ± 56 (68 % confidence limit: 7801–7914 calibrated years) (Danzeglocke, Joris, Weninger, 2011). Only the calibrated dates are cited from this point forward.

**The alternation of light and dark conifer taxa.** Light conifers are represented by *Pinus sylvestris* and *Larix*. The group of dark conifers includes *Pinus sibirica*, *Abies sibirica*, and *Picea obovata*. Given the different ecological (edaphic and climatic) needs of these two groups of arboreal species, changes in the counts of their pollen are thought to point to changes in the continental climate (Bykov, 1960; Koropachinsky, Vstovskaya, 2002). This is usually interpreted as a change in the relative humidity or as a change in the difference between the mean temperatures in summer and winter.
Results

Chronology. In order to reconstruct the rate of change in the occurrence of plant taxa in the Ozernyi-5 trench, and to assess the chronology of pollen zones, a linear interpolation was made between the two calibrated dates. The age of the top sample was set at zero. The dates below the lowest dated sample were extrapolated. To generate a more reliable chronology of changes in the either the regional or local pollen signatures, events were correlated to other paleogeographic events which were known to cause drastic climatic changes in the Northern Hemisphere. The date of their appearance and their duration serve as additional time markers. Our age model suggests that the bottom level of the trench may have formed before 9 ka BP (Fig. 3).

The assessment of accumulation rates between the dated horizons indicates a marked decrease in the upper layer (0–19 cm) when compared to the lower layer (19–32 cm). This may be due to landscape or to environmental factors which favored the quite rapid formation of a black and then gray-yellow loam before 6.7 ka BP, and then the accumulation of a light-yellow loam with a very low content of organic matter from ca 6.7 to 4 ka BP. The upper 12 cm layer of turf may also have accumulated gradually, because it was formed during the Neoglacial cooling after 4 ka BP.

Palynostratigraphy. The pollen diagram has been divided into three local pollen zones (OZY) on the basis of changes in the counts of various individual taxa and the sum total of the pollen of light and dark coniferous species. These changes were identified visually. The zones are numbered starting from the top. The lower zone is subdivided in two subzones (Fig. 3).

OZY-36 (50–32 cm, > 9–7.8 ka BP). Most of the spore-pollen spectra (SPS), 18 of 29 samples, within this subzone contain less than 100 pollen grains. In nine spectra, the total sum of pollen and spores does not exceed 100. Although the relative quantity of individual taxa for these SPS have been calculated and indicated by dots in the graph, they cannot be used reliably to reconstruct the vegetation history. Generally speaking, SPS from the 50–30 cm interval of the trench (> 9–7.8 ka BP) are dominated by *Sphagnum* and *Lycopodium* spores including the modern tundra species *Lycopodium pungens*. In the arboreal group, spruce (*Picea obovata*) and Siberian pine (*Pinus sibirica*) are especially common. Grains of dwarf birch (*Betula nana*) type are dominant amongst the shrubs. Herbaceous plants are mostly represented by the pollen of Asteraceae, Brassicaceae, and Geraniaceae. Charcoal is scarce in this subzone.

OZY-3a (32–20 cm, ~ 7.8–6.8 ka BP). In the SPS of this subzone, the number of calculated pollen grains varies from 150 to 1000 making it possible to consider all spectra as significant and therefore allowing us to reconstruct the plant communities. Arboreal pollen dominates (56–72 %) with Siberian pine and Scotch pine (*Pinus sylvestris*) being most common. However, spruce and Siberian fir (*Abies sibirica*) are also well represented. Amongst the shrubs, the pollen of dwarf birch dominates with a small quantity of shrub alder (*Duschekia fruticosa*). The quantity of *Botrychium, Polypodiophyta*, and *Lycopodium clavatum* pollen reaches its highest level in the history of the formation of the Ozernyi-5 trench. The concentration of pollen and spores in the sediments of this subzone varies greatly, but generally remains within 400 to 56,000 grains per 1 cm³. The number of charcoal particles increases near the upper boundary of the subzone.

OZY-2 (20–14 cm, ~ 6.8–4.3 ka BP). Here, there is a relative abundance of pollen from spruce, larch (*Larix* sp.), Siberian fir, and dwarf birch. The pollen from wormwood (*Artemisia*) reaches its maximum. The concentration of pollen and spores increases sharply, reaching 32–62 thousand grains per 1 cm³. The sediments of this subzone contain the maximum number of charcoal fragments.

OZY-1 (12–0 cm, ~ 4.3–0 ka BP). The unique quality of the spectra of this subzone is a sharp decrease in the amount of spruce and dwarf birch pollen and an increasing number of pollen from Siberian pine, Scots pines, and willow (*Salix*). The spores of spike moss (*Selaginella selaginoides*) are always present. The pollen of sedge (*Cyperaceae*) dominates the group of herbaceous plants. The concentration of pollen and spores reaches its maximal here. The counts of the number of charcoal particles gradually decrease.

The proportion of dark and light coniferous taxa. The gray area at the bottom of Figure 4 marks the insignificant spectra counts. The reconstructions here should be regarded as tentative. The diagram is divided into three zones which represent noticeable differences in the proportion of dark and light coniferous taxa. SPS formed greater than 9–7.8 ka BP are dominated by pollen of dark conifers (spruce and Siberian pine), although the meaning of the total counts of pollen from each group is highly ambiguous. The relative quantity of pollen from dark conifers remains high (65–85 %) in the period from around 7.8–4.3 ka BP. In the sediments accumulated over the past 4.3 thousand years, the dark conifer counts gradually decrease from 60 % to 50 %. This is especially visible in the most recent centuries.

Interpretation and discussion

The results from the Ozernyi-5 sequence suggest that the changes in the plant communities can be grouped into three major periods over the past 9 thousand years which in turn suggest changes in the regional climate
Fig. 3. A simplified spore and pollen diagram of the Ozernyi-5 trench.

1 – upper soil layer; 2 – light gray loam; 3 – grayish-yellow loam; 4 – black loam; 5 – location of dated samples.
and natural environment. The lower part of the 9–7.7 ka BP sequence consists of a grayish-yellow loam which accumulated slightly earlier than 8 ka BP. The composition of the spectra here seems to correspond with the expansion of shrub herbaceous tundra communities with Siberian dwarf pine and dwarf birch. The study of modern plant communities of this type suggest that they lived in an ecological and geographic setting which was a cold and rather humid climate with an accumulation of permafrost. The climate then was likely characterized by cold winters with little snow, which made possible the freezing of the soil to a great depth. The summers were likely relatively warm but short. They nevertheless afforded plants with enough available water in the soil during the time that the active layer of the permafrost thawed. The high hypsometric position of the site and constant strong winds could have also contributed to the weak growth of arboreal plants. The SPS display in separate layers a considerable number of pollen grains from spruce and both Siberian and common pine. These taxa have marked differences in their ability to travel (Peterson, 1983; Bezrukova et al., 2005). Their presence may indicate that an open spruce forest once stood near the trench. The pine pollen should be regarded as an element carried from afar. According to previous reconstructions of landscape and climate, subglacial warming in the Baikal basin occurred 11–10 ka BP (Tarasov et al., 2007; Tarasov, Bezrukova, Krivonogov, 2009; Bezrukova et al., 2010), although the most humid and warm conditions are thought to have occurred between 10–7 ka BP. During that time period, forest plants became dominant and the share of Pinus and spruce reached its maximum for the whole Holocene. Pine was an insignificant component of the forest vegetation in the Baikal area and contiguous regions (Bezrukova et al., 2005; Prokopenko et al., 2010; Bazarova et al., 2011).

The later accumulation of a thin layer of black loam (31–32 cm from the top of the trench) was dated to 7.8 ka BP. The deposition of the upper portion of the grayish-yellow loam layer continued up to ca 6.5 ka BP. However, based on significant changes in the SPS, we drew the upper boundary of zone OZY-3 lower at ~7–6.8 ka BP. The most noticeable change here was the constant increase in the amount of *Pinus sylvestris* pollen that corresponds to similar increases recorded in pollen...
records from other regions of Siberia (MacDonald et al., 2000; Bezrukova et al., 2005; Demske et al., 2005). It is important to note that another similar and statistically significant regional Holocene event was recorded in the neighboring Baikal region in an environmentally similar alpine setting (Bezrukova et al., 2008). Generally speaking, the results of our study suggest that between 7.8–6.8 ka BP (OZY-3a) the Ozernyi-5 area was dominated by trees and shrubs. Among the trees, the dark conifers such as spruce and Siberian pine predominated. Given the poor transportability of fir pollen (Bezrukova, 1999), its predominance in this zone suggests that fir was quite common in this locale at this time. This also correlates with the fact that its general distribution was greatest within the Baikal region during the period 10–7 ka BP. The greater number of charcoal fragments could possibly be explained by an increase in the volume of combustible material due to either the widening of distribution of trees and shrubs or their increased density. Key records of climate changes across the Northern Hemisphere suggest the gradual decline in the atmospheric temperature in the North Atlantic region (Svensson et al., 2008) and a weaker and cooler Pacific monsoon (Yuan et al., 2004). Variations in the counts of pollen grains from dark and light conifers speak to the dominance of dark coniferous plant communities around the Ozernyi-5 trench during this period.

The persistent presence of pollen representing arctic and alpine bushes (primarily, dwarf birch and, less commonly, shrub alder and Siberian dwarf pine) suggests that over the period ~6.8–4.3 ka BP (OZY-2), this locale was occupied by plant communities typical of shrub tundra. The high counts of spruce pollen might indicate that this tree was most common around Ozernyi-5 during this time period. Even the low counts of larch pollen (0.1–0.2 %) testifies that larch grew in the environs of the trench, if we take into account studies of how the pollen of this tree settles in SPS from other sites in this region (Peterson, 1983; Bezrukova, 1999). These reconstructed dark and light coniferous complexes suggest that at this time the dark conifers enjoyed their widest distribution over the past 9 thousand years and, correspondingly, the presence at that time of a less-continental and moderately-cold climate. The maximum amount of charcoal fragments can be used as an indirect indicator of a dense tree and shrub layer.

The gradual decrease in arboreal pollen and the increase in herbaceous pollen in the SPS of OZY-1 from ~4.3 ka BP to the recent times might be indicative of a retreat or thinning of the forest plant communities. It is quite possible that the slight reduction in the counts of coal fragments also reflect this. The increase in Pinus sylvestris pollen and the marked decrease of spruce pollen might indicate the further spread of pine over the region and a significant decline in spruce population at the local site. Similar changes in arboreal taxa are also typical to other parts of the Baikal region (Bezrukova et al., 2006, 2008; Belov et al., 2006). A quantitative reconstruction of climate indicators demonstrated that in the 4th and 3rd millennia BC the mean annual precipitation might have been 20–30 mm below, and mean summer and winter temperatures 1.5–2 °C greater than those during the Holocene optimum. The moisture index dropped significantly during this time (Tarasov et al., 2007). This reconstruction of the changes to the plant communities around the Ozernyi-5 trench corresponds to changes to the regional climate. Further, they point to a continuous reduction of dark conifer community. Such environmental and climatic conditions could have led to a greater thawing of the permafrost in turn leading to a greater amount of available water in the locale. This would have encouraged the expansion of the sedge communities and appearance of spike moss (Selaginella selaginoides selaginella) on stream banks, among the dwarf birch, and on wet rocks. Larch remained the most important element of the local forest community. High soil humidity may have reduced the frequency of forest fires, as indicated by a lower content of charcoal particles in the OZY-1 sequence.

The expansion of sedge remains and the permanent presence of willows in the region during the last millennia may have two explanations. One may be an anthropogenic effect. This suggestion can be supported by the following arguments. In the modern observable vegetation community, sedges (especially Carex caespitosa) are dominant in the eutrophic swamps. Their high frequency in the spectra could be the result of the overpasturing of ungulates and the consequent trampling of damp soils with their hooves. The contemporary territory around Bolshoe Inyaptukskoe reveals one other important feature: willow shrubs grow mainly in depressions and on hilltops which had been trampled by people (normally these places are covered by fruticous birch shrubs). Therefore it is possible that human activities in the past resulted in the replacement of fruticous birch on hilltops by much faster growing varieties of willows. However, the same palynological indicators can be interpreted as natural succession. Our comparison of the data with documented changes in vegetation that occurred in other parts of the Baikal region suggests a natural rather than anthropogenic explanation for the changes in the plant communities near Ozernyi-5. A significant cooling of the landscape and climate around 3–2 ka BP have been recorded in almost all medium and high latitude settings in the Northern Hemisphere: in Canada (Tillman et al., 2010), Europe (Wanner et al., 2008; Sëppa et al., 2009), and Central Mongolia (Wang et al., 2009). In the Baikal region, this climatic event is reflected in pollen records from the lower reaches of the Verkhnaya Angara River.
The reasons behind the environmental changes around Ozernyi-5

To gain a better understanding of factors causing local and regional environmental changes, we correlated the sequence of reconstructed events with other key sequences reflecting climatic changes in the Northern Hemisphere. Figure 4 shows the dynamics of the proportion of dark and light coniferous taxa (DC/LC, index of relative variability of the climatic continentality). It compares this data with variations of mean air temperatures in the North Atlantic, with the variability of intensity of the Pacific summer monsoons, and with periods of cooling known as Bond events. It is clearly seen in the figure that the interval ~9.2–7.7 ka BP is characterized by unstable temperature in the North Atlantic region and by the active summer (warm) monsoon. Values of the continentality index (DC/LC) in the region are also unsteady. A relatively stable warm period in the North Atlantic and Pacific regions occurred ~7.7–4.3 ka BP. The continentality index also points to a rather stable moderately cool and humid climate existing in the Ozernyi-5 region at that time. In the Northern Hemisphere, the climate deterioration ended around 4.5–4 ka BP (Fig. 4, Bond event 3). It is possible that the appreciable decrease in the dark coniferous taxa in the region under study ca 4.5 ka BP occurred at the same time as the deterioration of the global climate. The increasing cooling trend observable in both stratotopic sections after 4.3 ka BP correlates well with intensification of continentality in the Ozernyi-5 region. The relationship between the later (4.3 ka BP – present) reduction of dark coniferous vegetation at Ozernyi-5 and global climate variations (Fig. 4) is less distinct. The reasons behind the decline of the dark coniferous forests in the region during the Late Holocene need to be examined in more detail.

Conclusions

A detailed sampling of the trench at Ozernyi-5 has made it possible for the first time to produce a high-resolution record of environmental changes for this territory which corresponds with the standard time periods used when studying the environmental history of the Holocene around the world. Despite the low content of pollen and spores in the lower part of the trench, new palynological and radiocarbon data suggest significant changes in pollen spectra and consequently in the vegetation in the Bolshoe Inyaptukskoe Lake basin. Using pollen analysis and a count of charcoal particles, a qualitative and semi-quantitative reconstruction of the fluctuations of the continentality index, has resulted in a reliable picture of environmental change over the last 9 thousand years. The boundaries marking major changes in the plant communities around Ozernyi-5 can be correlated with regional and global climatic trends. There is also a local signature to the environmental changes in the region which can be associated with its geographic and orographic location. Specifically, the maximum expansion of dark coniferous forests took place during the period ~8–4.3 ka BP, while in the Baikal basin this occurred earlier ~10–7(6) ka BP. In the Baikal region, contemporary plant communities began to form after 7(6) ka BP, while around Ozernyi-5 this process started somewhat later. The main reason for this offset of the time horizons for the local appearance of global and regional paleogeographic events could be the high elevation and high latitude of the site.

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