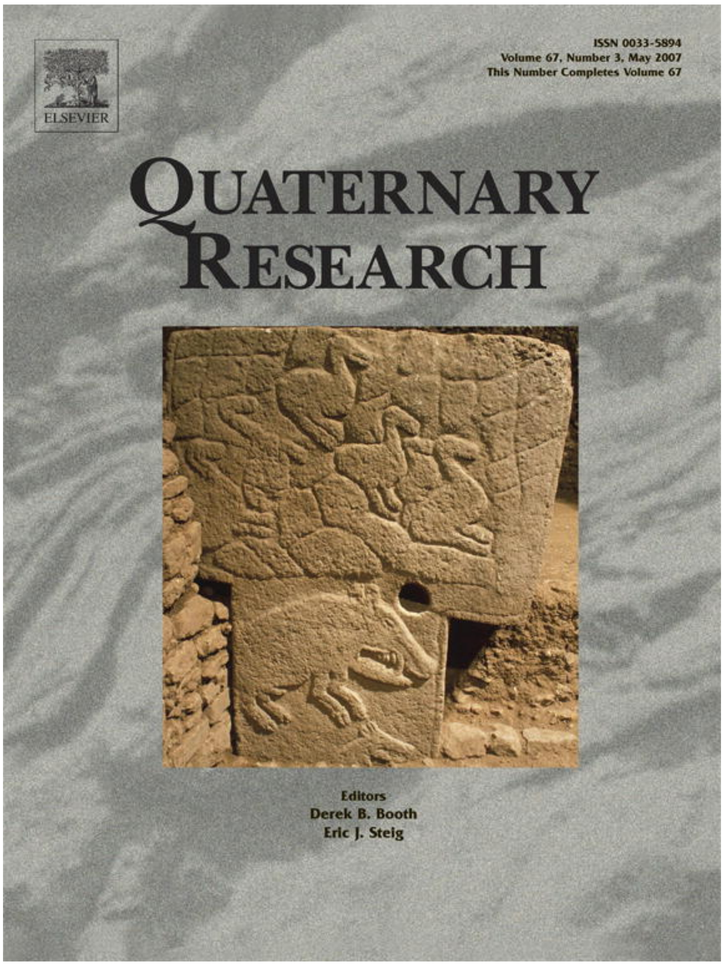
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Environmental changes in the northern Altai during the last millennium documented in Lake Teletskoye pollen record

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Abstract

A high-resolution pollen record from Lake Teletskoye documents the climate-related vegetation history of the northern Altai Mountain region during the last millennium. Siberian pine taiga with Scots pine, fir, spruce, and birch dominated the vegetation between ca. AD 1050 and 1100. The climate was similar to modern. In the beginning of the 12th century, birch and shrub alder increased. Lowered pollen concentrations and simultaneous peaks in herbs (especially *Artemisia* and Poaceae), ferns, and charcoal fragments point to colder and more arid climate conditions than before, with frequent fire events. Around AD 1200, regional climate became warmer and more humid than present, as revealed by an increase of Siberian pine and decreases of dry herb taxa and charcoal contents. Climatic conditions were rather stable until ca. AD 1410. An increase of *Artemisia* pollen may reflect slightly drier climate conditions between AD 1410 and 1560. Increases in *Alnus*, *Betula*, *Artemisia*, and Chenopodiaceae pollen and in charcoal particle contents may reflect further deterioration of climate conditions between AD 1560 and 1810, consistent with the Little Ice Age. After AD 1850 the vegetation gradually approached the modern one, in conjunction with ongoing climate warming.

Keywords: Pollen; Paleoclimate; Vegetation history; Northern Altai; Last millennium

Introduction

Lacustrine sediments of Lake Teletskoye represent important archives of regional climate and environmental changes in the northern Altai region of southern Siberia. Sedimentological microfacies analyses on a laminated-sediment sequence 90 cm thick revealed a high-resolution proxy record of changes in palaeotemperature, precipitation, and fluvial runoff during the last eight centuries (Kalugin, 2001; Kalugin et al., 2005), which is consistent with regional glaciation history (Butvilovsky, 1993), tree-ring records (Jacoby et al., 1996; Panyushkina et al., 2000), and instrumental meteorological data for the last 160 yr.

Kalugin et al. (2005) distinguished five distinct climatic stages that show affinities to climate developments in Europe, such as the recognition of a marked cool and dry episode during the Maunder sun-spot minimum period (AD 1645–1715). Although different types of high-resolution analyses on the Lake Teletskoye sediments have been done to infer climate fluctuations (e.g., Kalugin, 2001; Kalugin et al., 2005), biological proxies such as pollen analyses have not been previously used for paleoenvironmental reconstructions. This paper presents first pollen records from Lake Teletskoye, focusing on the regional vegetation history and inferred climate changes.

Study area

Situated in the autonomous Republic of Altai (the Russian Federation), Lake Teletskoye is located in the northeastern part of the Altai Mountains (from 48° to 53°N and from 82° to 90°E; Fig. 1). The lake area is surrounded by the West Siberian Lowland in the north and the Kazakhstan steppes westward, while the Altai highlands of China and Mongolia form the

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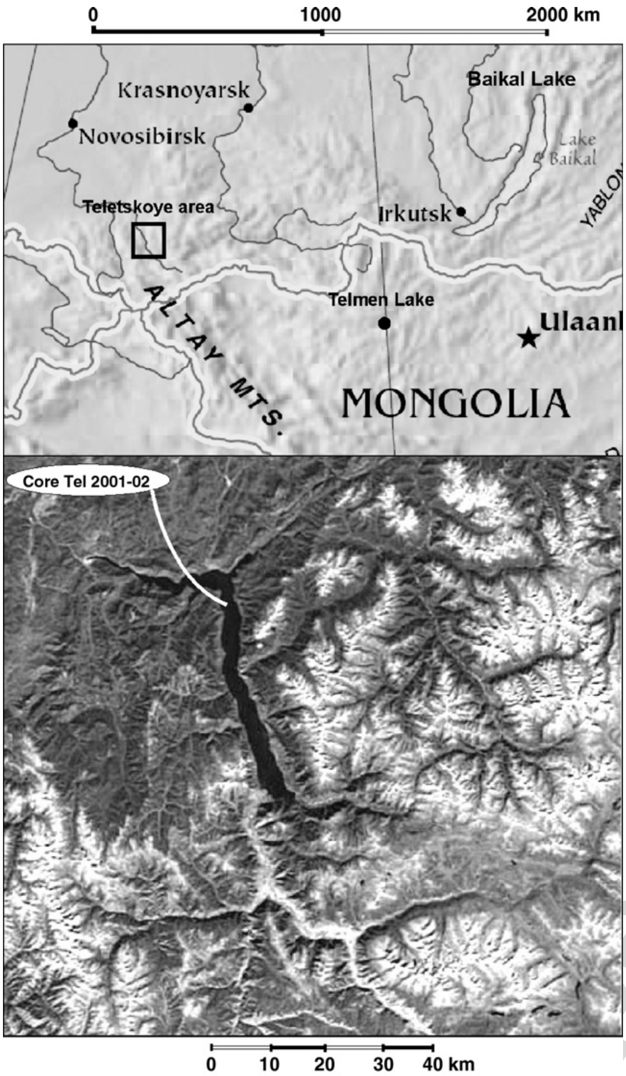

Figure 1. Map showing the location of Lake Teletskoye. Line marks the coring site. Light shading indicates treeless steppe areas, and dark grey shading indicates forested areas.

southern and eastern boundaries. The average altitude of the mountains surrounding the lake is ca. 1900 m a.s.l. The highest elevations rise to more than 4000 m a.s.l. in the central and southern parts of the region (Chlachula, 2001).

The lake basin has a long history. Intensive uplift occurred during the Permian and Triassic eras. Tectonic movements stopped between the Cretaceous and Paleogene, and large planation surfaces were formed. The subsequent collision of the Indian plate with Eurasia during the Eocene started a new tectonic phase, which intensified in the Late Pliocene and resulted in the opening of the Teletskoye basin (Chlachula, 2001). The modern Lake Teletskoye graben structure was formed during two tectonic phases: (1) the southern part of the lake opened in the middle Pleistocene and (2) an old fault structure (West-Sayan fault) reactivated during the late Pleistocene/Holocene transition and initiated the opening of the northern subbasin (Dehandschutter et al., 2002).

The modern 77-km-long lake occupies an intermontane basin. The lake basin is situated within north–south-trending graben 50 km long and the east–west-orientated lake segment with a length of 27 km. The maximum width of the lake is 5 km, with a maximum depth of 325 m. At the southern end the Chulyshman River flows into the lake, draining 84% of the catchment area. The outlet is the Biya River at the northwest end. A number of smaller rivers also flow into the lake.

The lake is subdivided into three parts. The southern basin extends from the mouth of the Chulyshman River to the inflow of the Kokschi River. This basin is completely filled with sediments supplied by the Chulyshman River (Dehandschutter et al., 2002). The water depth slowly increases northward and reaches a depth of 300 m not far from the Chelyush River mouth. The second basin starts from the Kokschi River and extends northwards, ending at the inflow of the Kamga River. This basin is the deepest part of the lake, with a maximum water depth of 330 m near the mouth of the Korbu River. The northern east–west basin extends from the village of Jailu to the outflow of the Biya River. It has a maximum water depth of 270 m.

Because of the pronounced relief and the central location of the Altai Mountains in Asia, the great distance to the ocean moisture sources, and the influence of winds coming from the northern Siberian lowland, the region experiences an extreme continental climate (Blyakharchuk et al., 2004). The Siberian high-pressure cell dominates the winter, bringing cold and dry weather. Mean January temperatures range from −23° to −20°C (Kuminova, 1960). In summer the area is situated in the low-pressure zone formed over West Siberia. Mean July temperatures near the lake range from 16 to 18°C (Selegei and Selegei, 1978). Rainfall occurs primarily during the summer in the western and northern parts of the Altai Mountains. Annual precipitation averages from 800 to 1000 mm in the northern part of the lake, reducing to nearly 300 mm in the southern part (Selegei and Selegei, 1978). The local climate conditions strongly depend on orography and altitude.

The vegetation in the Altai Mountains is generally dominated by a mixed taiga consisting of Siberian pine (*Pinus sibirica*), Scots pine (*P. sylvestris*), fir (*Abies sibirica*), spruce (*Picea obovata*), birch (*Betula pubescens* and *B. verucosa*), and larch (*Larix sibirica*) (Kuminova, 1960). Vegetation of the northern Altai is characterized by open steppe parkland, with birch and Scots pine as the dominating trees.

The local vegetation cover is linked with the annual precipitation and topographic setting. Pine, fir, spruce, and larch taiga with birch covers lower mountains around the lake. Steppe elements are almost missing in the north-eastern part of the lake. Elevations between 700 and 1200 m a.s.l. are dominated by Siberian pine and fir, while the level between 1200 and 1700 a.s.l. m is covered mostly by Siberian pine, followed by the subalpine vegetation. At higher elevations only alpine vegetation exists. Steppe and semi-desert communities dominate the southern part of the lake basin.

Materials and methods

The studied 110-cm-long sediment core (Tel 2001–02) was obtained by a 60-mm gravity corer in May 2001. It was taken at 330 m water depth from the central and deepest part of the lake

(Fig. 1, 51°43′N, 87°39′E). To gain undisturbed recovery from the highly unconsolidated top sediments, the upper 20 cm of the sediment section were collected by using a Wildco box corer. The sediments were subsampled in 5-mm interval in Novosibirsk. A total of 41 samples were used the analyses of pollen and palynomorphs at the Alfred Wegener Institut for Polar and Marine Research in Potsdam, Germany. Pollen and spores were identified using a Zeiss microscope with 400× magnification. For each sample at least 250 terrestrial pollen grains were counted, plus other pollen and spores. In addition to pollen grains, charcoal particles were identified and used as a proxy of paleo fire history, providing a linkage between climate and vegetation (Whitlock and Larsen, 2001). Pollen percentages were calculated based on the tree and herbs pollen sum. Pollen zonation was done by visual inspection. The TILIAGRAPH plotting program (Grimm, 1991) was used for graphing the pollen and charcoal data.

The age–depth model worked out by Kalugin et al. (2005) for the studied core has been also used for this study. The model, based on ^{137}Cs and ^{210}Pb dates, suggests an average sedimentation rate of 1 mm/yr for the deepest basin (for details see Kalugin et al., 2005). The small indeterminable plant remains from the 95 to 97 cm depth were dated to 897±43 ^{14}C yr BP (KIA26018). The Calpal program (http://www.calpal-online.de/) has been used to calibrate the date.

Results

Core lithology and chronology

The sediment core Tel 2001–02 consists of bluish-grey to dark-green finely laminated clays and silts. The core shows undisturbed, horizontal layers without any traces of bioturbation (Kalugin, 2001). The lower segment of the core (between 99 and 89 cm depth) includes a 10-cm-thick sand-rich layer, which possibly is a turbidite.

The applied age model of the studied sediment core refers to the age–depth relationship as worked out by Kalugin et al. (2005). The age model is based on ^{137}Cs and ^{210}Pb data that suggest an average sedimentation rate of 1.125 mm/yr at the core site. The extrapolated ^{137}Cs chronology for the 110-cm-long sediment core suggests a basal age of AD 1020. The inferred sedimentation rate is also consistent with the calibrated age (AD 1120±61) of the plant remain from 95 to 97 cm core depth. Therefore, we assume that the age–depth model worked out by Kalugin et al. (2005) is correct and can be used for data interpretation. Thus, the core has been palynologically analyzed at approximately 25-yr intervals. Each analyzed sample consists of the sediments accumulated during ca. 5 yr.

Pollen and charcoal stratigraphy

The pollen data are shown in Figure 2. The pollen diagram can be subdivided into five pollen assemblage zones. The lowest pollen zone (PZ-I, 106–101 cm) is characterized by a high content of *Pinus sibirica*, *P. sylvestris*, and *Abies* pollen. Pollen concentration is high in this zone. PZ-II (101–90 cm) is notable for a relatively high contents of *Betula*, *Alnus*, and *Artemisia* pollen; Polypodiaceae spores; and charcoal particles. Pollen concentration is rather low in this zone. PZ-III (90–50 cm) is characterized by the high content of *Pinus* and *Abies* pollen, while contents of *Betula*, *Alnus*, and *Artemisia* pollen, and Polypodiaceae spores and charcoal particles are very low. PZ-IV (50–20 cm) is notable for a relatively higher contents of *Betula*, *Alnus*, *Artemisia*, and Chenopodiaceae pollen, and charcoal particles. PZ-V (20–0 cm) is characterized by a high content of *Pinus* pollen and high overall pollen concentration.

Interpretation and discussion

Pinus sibirica pollen dominates the spectra from the core, reflecting the dominance of Siberian pine around the lake during the last millennium. The sediments accumulated ca. AD 1050–1100 (PZ-I, Fig. 2) and contain relatively large amounts of *Abies* and *Picea* pollen and low amounts of charcoals. This assemblage indicates rather humid climate and low fire frequency.

Pollen spectra from the overlying PZ-II (Fig. 2) contain larger amounts of charcoals; *Alnu*s, *Betula*, *Artemisia*, Poaceae, and Chenopodiaceae pollen; and Polypodiaceae spores. The pollen spectra reflect that environmental conditions at about AD 1100–1200 were cooler and perhaps drier than before, resulting in more frequent fires. Such fires led to the deforestation of surrounding mountain slopes and increase of soil erosion in the lake catchment, marked by the sand layer at 950 cm. Whether the sand layer represents a short event layer (turbidite) or continuous sedimentation over a longer time interval is hard to recognize. The graded structure of the layer favors an event layer, but the variability in pollen composition within the layer argues against a single event. The deforested slopes were gradually colonized by pioneer herbs (*Artemisia*, Poaceae, Chenopodiaceae) and trees (*Alnus*, *Betula*). Ferns (*Athyrium filix-femina*, *Dryopteris spinulosa*, *D. filix-mas*) are dominant around Lake Teletskoye, especially after fires (Kuminova, 1960).

Higher pollen concentration, decreased contents of charcoal fragments, *Alnu*s, *Betula*, *Artemisia*, Poaceae, Chenopodiaceae pollen and Polypodiaceae spores, together with increase of *Pinus sibirica* and *Abies sibirica* indicate that climate conditions were more humid with only rare fire events during a relatively long period, from ca. AD 1200 to ca. 1410. The dendrochronological (e.g., D'Arrigo et al., 2001; Yang et al., 2002), palynological, and lacustrine (Fowell et al., 2003) data from the adjacent areas show the similar climatic change during this time. This relatively warm interval data can be attributed to the late Medieval Warm Epoch. Kalugin et al. (2005) also inferred this warm and humid period between AD 1210 and 1410, consistent with the pollen data.

An increase of *Artemisia* pollen content in the upper part of P-III may reflect slightly drier climate conditions between AD 1410 and 1560. The trends of annual air temperatures (B on Fig. 2) also reflect this short episode, consistent with the pollen data.

The pollen spectra from the PZ-IV indicate further aridisation of climate between AD 1560 and 1820 that

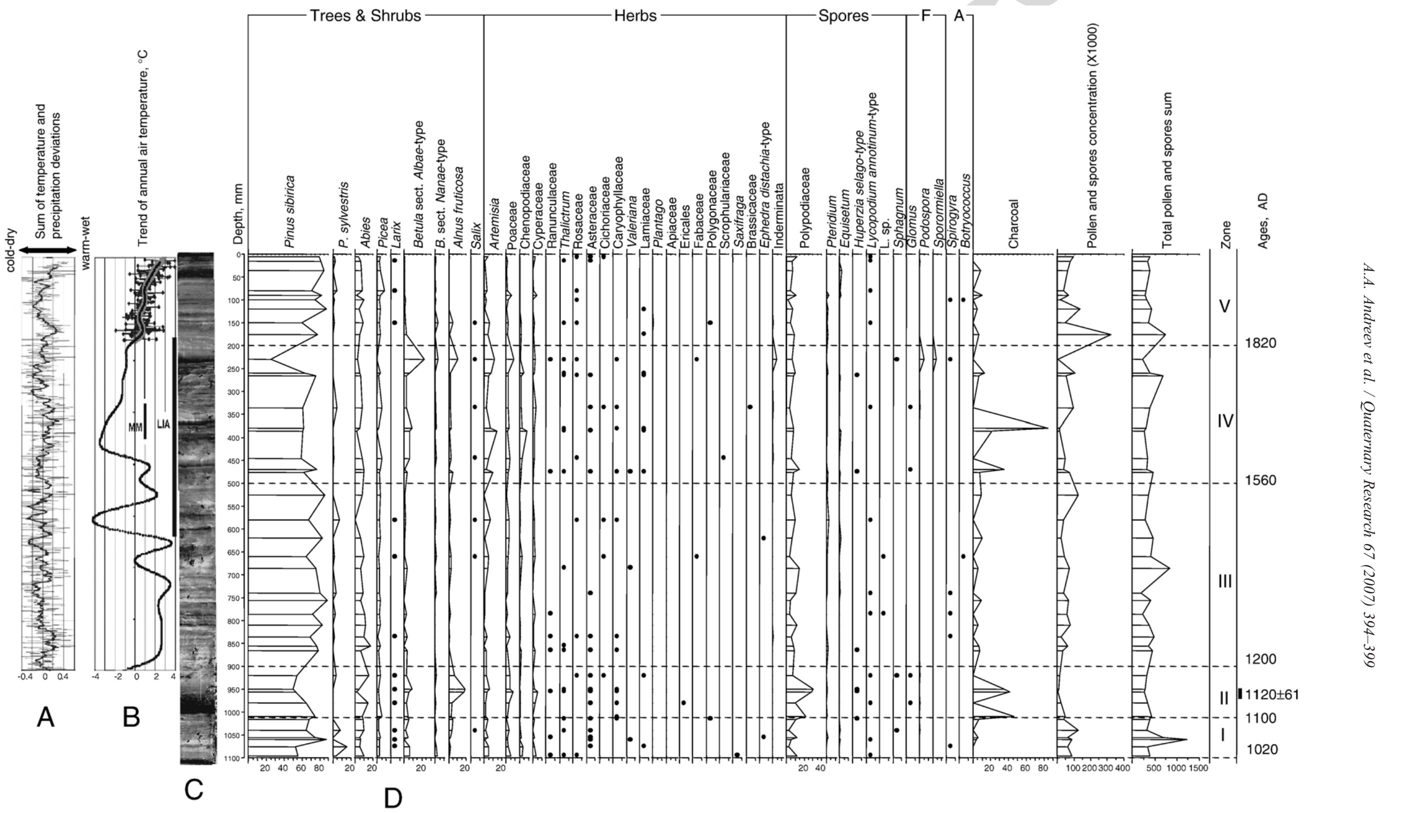

Figure 2. Pollen stratigraphy of Lake Teletskoye and reconstruction of climate oscillations during the last millennium. (A) Sum of temperature and precipitation deviations (devT+devP) reflecting alternative warm-wet and cold-dry climate conditions, from reconstructed annual T and P profiles (for details see Kalugin et al., this issue); (B) Reconstructed trend of annual temperature based on the Br, Sr/Rb, and XRD proxies (—◆— - instrumental temperature data from the Barnaul meteorological station, [symbol] - smoothed temperatures; ⎯ - reconstructed trend); (C) Photo image of laminated sediments (core Tel 2002-2001); (D) Pollen stratigraphy.

apparently was connected with the Little Ice Age (LIA). According to Kalugin et al. (2005), the LIA in the northern Altai region lasted approximately from AD 1580 to 1840, and the coldest reconstructed interval corresponded with Maunder Minimum between AD 1650 and 1715. Fowell et al. (2003) reconstruct a relatively cold and dry interval around AD 1500 and an increase in moisture ability after AD 1600 in Mongolia. Their reconstruction of "relatively moist conditions that prevailed at this time" is based on an increase in the abundance of Cyperaceae in Telmen Lake pollen record. It should be taken in the consideration that some representatives of Cyperaceae, such as *Kobresia*, are abundant in the dry mountain steppes of Mongolia (Hilbig, 1995). Macrofossils of *Kobresia* are abundant in sediments accumulated during cold and dry intervals during Late Pleistocene indicating very dry and cold climatic condition (e.g., Kienast at al., 2005, and references therein). Therefore, increases in the abundance of Cyperaceae in the pollen records from dry areas of Mongolia cannot be used directly as humidity indicator. However, we agree that they can be interpreted as an indicator "of cool temperatures and expansion of cold-adapted sedge/grass steppe-tundra vegetation" in this time. Moreover, we believe that the expansion sedge/grass steppe-tundra vegetation points to the increase of aridity as well.

Thus, we assume that existing pollen records correlate well with our pollen and charcoal record. Environmental conditions during this interval were similar to the ca. AD 1100–1200 dry interval. Very high content of charcoal in the sediments may reflect increased human activity in the area connected with colonization of the area by Russian settlers at the beginning of the 19th century.

The fire activity was significantly reduced after AD 1820, probably reflecting that climate became more humid. Vegetation cover became similar to the modern one. The climate interpretation from the uppermost pollen spectra is consistent with the instrumental data from the Barnaul weather station (ca. 200 km northwest of the study area; Fig. 1). These records show an increase in temperature between AD 1890 and 1925 (see instrumental temperature data in Fig. 2). Associated precipitation was clearly higher during this interval than in previous years. The increase of the sediment layer thicknesses may be another indicator of the increase in precipitation (Kalugin et al., 2005).

The climate changes inferred from the reconstructed vegetation history coincide with results of numerical climate simulation (A and B in Fig. 2; for details see Kalugin et al., 2005, this volume). Sum of temperature and precipitation deviations (devT+devP) reflects alternative warm–wet and cold–dry climate conditions based on reconstructed annual T and P profiles (B in Fig. 2; for details see Kalugin et al., this issue). The reconstruction of annual temperature is based on three selected proxies: Br, Sr/Rb, XRD (C in Fig. 2; for details see Daryin et al., 2004; Kalugin et al., 2005). The instrumental climate records for the AD 1840–1996 interval have been used to extrapolate smoothed annual temperature up to AD 1210 (C in Fig. 2).

Conclusions

The pollen record from Lake Teletskoye is the first detailed climate and vegetation reconstruction for the last millennium in the northern Altai Mountains. Dense Siberian pine forest dominated the area around the lake at least since ca. AD 1020. The climate conditions were similar to modern. Between AD 1100 and 1200, a short dry period with increased fire activity occurred. Around AD 1200, climate became more humid with the temperatures probably higher than today. This period of rather stable climate possibly reflecting Medieval Warm Epoch lasted until AD 1410. Slightly drier climate conditions occurred between AD 1410 and 1560. A subsequent period with colder and more arid climate conditions between AD 1560 and 1820 is well correlated with the Little Ice Age. A climate warming inferred from the uppermost pollen spectra, accumulated after AD 1840, is consistent with the instrumental data from the Barnaul meteorological station.

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