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Vegetation and climate history of the Yana River lowland, Russia, during the last 6400 yr

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Abstract

New pollen records and radiocarbon dates from two sites in the Yana River lowlands, Arctic Yakutia, Russia provide reconstructions of vegetation and climate history of this region during the last 6400 yr. The fluctuations in pollen and spores reflect the local hydrological events and regional climate changes. The data show that larch (*Larix dahurica*) forests with shrub alder (*Alnus fruticosa*) and dwarf birch (*Betula exilis*) dominated the area during the last 6400 yr BP. There is no evidence for tree-line fluctuations at the sites during the latter half of the Holocene. Climate reconstructions made by transfer function from one site show that the warmest time was between 6000 and 4500 yr BP. All climate fluctuations reconstructed at this site correspond well with regional climate changes.

1. Introduction

The Yana River coastal lowlands are situated in Arctic Yakutia, Russia. This region constitutes the western most part of Western Beringia according to most investigators (Hopkins, 1972; Lozhkin, 1976; Yurtsev, 1981). The region is classified as arctic tundra, shrub tundra and forest tundra within continuous permafrost. Peatlands are important components of the local landscape.

Although peatlands cover a significant part of the lowlands, little is known about their long-term history or the local vegetation and climate changes through the Holocene. A number of scientists have worked in the region (Khotinsky et al., 1971; Plakht et al., 1976; Kaplina and Lozhkin, 1982), but the chronology of the local vegetation and climate dynamics are not well known because of lack of high-resolution radiocarbon-dated records (Kaplina and Lozhkin, 1982). Our two new paleoenvironmental records from the Yana River valley provide a reconstruction of vegetation and climate history in this Arctic region over the last 6400 yr.

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2. Setting

The study area is a part of the Yana-Kolyma coastal lowland region with extensive peatlands and numerous thermokarst lakes. Most of the lakes are shallow, probably because short summers do not allow much thermokarst melting and infilling by reworked material. Numerous peat banks are exposed along the lakes and Yana River shores and continue to expand due to the river and thermokarst activity.

The Kazach'e (Samandon) exposure is located on the lowest terrace of the Yana River (70°46′N, 136°15′E, 15 m elevation), 3 km north of the Kazach'e settlement, in the forest-tundra zone (Fig. 1). The Khocho exposure is located on the floodplain of the Yana River (71°08′N, 136°14′E, 10 m elevation), 15 km north of the Ust'-Yansk settlement near the former settlement of Khocho (Fig. 1).

Both sites are located in the forest-tundra zone within continuous permafrost. The depth of the permafrost active layer is about 30 cm in the summer. *Larix dahurica* is the only tree forming open parkland forests. *Betula exilis*, *Alnus fruticosa* and *Salix* species are the most abundant shrubs today. Numerous larch trees grow on the Kazach'e peatland as well as alder shrubs and dwarf birch. *Sphagnum* mosses dominate on the modern peatland surface with some *Carex, Ledum palustre, Vaccinium uliginosum* and *Rubus chamaemorus*. Some larch trees and alder shrubs grow on the surface of the Khocho peatland

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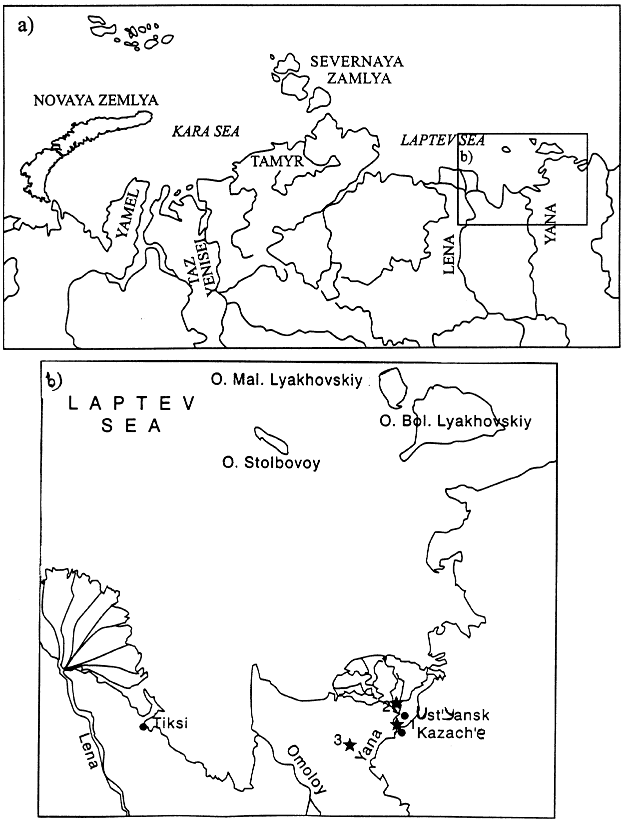

Fig. 1. Map showing the location of the studied sites: (1) Kazach'e site; (2) Khocho site; (3) Yano-Omoloi site (Khotinsky et al., 1971).

as well as numerous dwarf birch and willow. *Hypnum* mosses dominate on the modern peatland surface with some *Carex* and *Vaccinium uliginosum*.

3. Climate

The mean July temperature is about 11°C, mean January temperature is about -37°C, and mean annual temperature is about -15 to -16°C. Total annual precipitation is about 200 mm. The frost-free period is about 40–60 days, from July 1–11 until August 21–30 (Klimatichesky atlas SSSR, 1960).

4. Field and laboratory methods

The peat exposures were measured up to 3.0 m near the Kazach'e site and up to 3.5 m near the Khocho site. We selected the thickest parts for detailed sampling. Monoliths were collected by cleaning with a shovel to expose frozen peat, then cutting 50 cm^3 blocks of contiguous samples at 10 cm intervals and transferring these to the sample bags. A total of 30 samples from Kazach'e site and 35 samples from Khocho site was collected for pollen analyses.

Pollen and spores were concentrated from 1 cm^3 sediment subsamples, and processed by KOH deflocculation, HCl and heavy liquid separation (Berglund and Ralska-Jasiveczowa, 1986) followed by acetolysis and glycerin mounts. A minimum of 300 pollen grains were counted for each sample, and spores were also tallied. Determination of the relative frequency of pollen was calculated based upon the total pollen number, and percentage of spores was based upon a sum of pollen and spores.

The samples for ^{14}C dating were collected separately from the same sections. The radiocarbon measurements for the Kazach'e samples were conducted at the Laboratory for the Isotope Geochemistry and Geochronology of the Geological Institute (GIN), Russian Academy of Sciences. Radiocarbon assay of the Khocho samples was done at the Radiocarbon Laboratory of Department of Geography, Moscow State University (MGU) by V. Parunin. The decay count liquid scintillation method was used for radiocarbon dating of all samples.

5. Radiocarbon dates chronologies

Of the 15 radiocarbon dates from the Kazach'e site four are rejected because of dating reversals that occurred in the chronology (Table 1). We have obtained two or three radiocarbon dates for some peat samples by dating different peat fractions: unidentified peat, plant remains, humic acids extracts, and wood. Normally, humic acids extracts show older ages, because they contain older carbon from underlying peat layers. The older radiocarbon dates obtained from humic acids show that these acids can permeate peat sediments even in permafrost

Table 1
Radiocarbon dates from Kazach'e and Khocho peatlands

Laboratory no.	Depth (cm)	Material	Age (yr BP)
Kazach'e site			
GIN-5383a	20–30	Peat	480 ± 15
GIN-5383b	20–30	Humic acids	550 ± 100
GIN-5383a	60–70	Peat	4230 ± 300*
GIN-5383b	60–70	Humic acids	6310 ± 90*
GIN-5385a	100–110	Peat	1530 ± 70
GIN-5385b	100–110	Humic acids	1760 ± 50
GIN-5386	120–130	Peat	3990 ± 100
GIN-5387a	160–170	*Betula nana* twig	4030 ± 180
GIN-5387b	160–170	Peat	4260 ± 300
GIN-5388	190–200	Peat	4950 ± 70
GIN-5389	220–230	Peat	5310 ± 50
GIN-5390a	260–270	Decomposed peat	2920 ± 240*
GIN-5390b	260–270	Plant remains	5980 ± 100
GIN-5390c	260–270	Humic acid	3580 ± 350*
GIN-5391	290–300	*Larix* wood	6970 ± 40
Khocho site			
MGU-1125	50–60	Peat	2170 ± 130

* rejected dates

areas and can result in older age of the sediments. In permafrost peatlands it probably is not a very important factor as we can see from our studies, but in more southern areas it may result in erroneously older ages for some peat layers. AMS dates from identified plant remains would avoid this problem.

Most of Kazach'e exposure dates are in sequence, but the dates from the 60–70 cm depth (both from humic acid extracts and peat) show anomalous older ages compared with ^{14}C dates below and above. This is difficult to explain by natural causes. The possible explanation could be a contamination, but no visible contamination of the peat exposure was recorded during the field work. Another possible explanation can be an error during the laboratory treatments. We reject these dates as obviously wrong. Three dates from the 260–270 cm depth (decomposed peat, plant remains and humic acid extracts) show different ages (Table 1), probably because we had not enough material to date the decomposed peat and humic acid extracts. The age obtained for plant macrofossils fraction is in sequence with the dates below and above.

The wood from the woody layer (160–170 cm depth) is about 200 yr older than the peat, which suggests that the dwarf birch twigs were overlain in situ by growing peat. The bottom age from a *Larix* trunk is probably correct, but we do not use in our reconstruction as it is difficult to say when the trunk was deposited before the peat accumulation begun. It is also unclear whether this tree grew here or was moved by Yana River during a flood.

Six samples for radiocarbon dating were collected from the Khocho section, but only one ^{14}C date was obtained for the section (Table 1). Other samples contained insufficient organic material according to V. Parunin (pers. comm.). The obtained date shows a rather old age for peat from the 60–70 cm depth. It is difficult to imagine such slow accumulation over the last two millennia for the peatland situated on the modern floodplain surface. All radiocarbon dates from Yana River valley show ages not older than 6000 yr BP for floodplain sediments and indicate a high accumulation rate for these sediments (V.N. Korotaev, pers. comm.). We believe that this date is erroneous and did not use it for the section chronology. The bottom of the Khocho peatland located on the Yana floodplain should be theoretically younger than the Kazach'e one located on the lowest terrace of the Yana River because of their relative geomorphologic positions.

6. Pollen diagrams

6.1. Kazach'e site

The section lithology (Fig. 2) indicates that underlying clay sediments are overlain by a sequence of predominantly *Sphagnum* peat layers (up to 260 cm). Predominantly sedge peat layers then dominate up to about 170 cm depth. A small woody layer is present in the sedge peat from 170 to 160 cm composed of *Betula exilis* twigs. Overlying sediments from 160 to 50 cm exhibit a return to sedge peat. A more decomposed, *Sphagnum*–sedge zone is present between 50 and 30 cm. The upper 30 cm is *Sphagnum* peat.

Pollen zone 1 (*Alnus–Betula–Sphagnum,* 6400–6000 yr BP, 300–260 cm). This zone is notable for its large amounts of *Alnus* pollen (up to 60%) and *Sphagnum* spores (up to 40%).

Pollen zone 2 (*Betula–Alnus–Cyperaceae,* 6000–1100 yr BP, 260–50 cm). This zone is distinctive for its increasing percentages of *Betula* pollen and maximum amounts of Cyperaceae pollen (up to 50%). It is possible to subdivide this zone into two subzones. Relatively high *Sphagnum* spore percentages are characteristic of subzone 2b (6000–5000 yr BP, 260–200 cm). A peak in *Salix* also occurs in this subzone. Ericales pollen is notable in subzone 2a (5000–1100 yr BP, 200–50 cm). A peak in Poaceae also occurs in the uppermost part of subzone 2a.

Pollen zone 3 (*Alnus–Betula–Larix,* 1100 yr BP to modern, 50–0 cm). An increase in *Alnus* pollen occurs with a decline in *Betula* pollen. A slight increase in *Larix* is also notable in this zone as well as a single peak in *Sphagnum* spores.

6.2. Khocho site

The section lithology (Fig. 3) indicates that underlying gray sandy sediments are overlain by a sequence of predominantly bryophyte peat.

Pollen zone 1 (*Alnus–Betula–Cyperaceae,* 350–130 cm). It is possible to subdivide this zone into two subzones. One (1a, 350–290 cm) is notable for its large amounts of Cyperaceae and the other subzone (1b, 290–130 cm) for its smaller amounts of Cyperaceae and some major peaks in Rosaceae.

Pollen zone 2 (*Alnus–Betula–Pinus,* 130–0 cm). This zone is distinctive for its large amounts of long-transported *Pinus* sect. *Haploxylon* (*P. pumila,* most likely) pollen.

7. Peatland and vegetation history

The Khocho record cannot be used to verify the Kazach'e chronology, but its pollen stratigraphy is similar to that of Kazach'e record suggesting that the paleovegetational interpretations from Kazach'e site are representative of the Yana River lowland region. Unfortunately, a pollen record published by Khotinsky (1977) and Khotinsky et al. (1971) from an alas (drained thermokarst lake) exposure located in 35 km west of the Kazach'e settlement on the Yana-Omoloy interfluvial

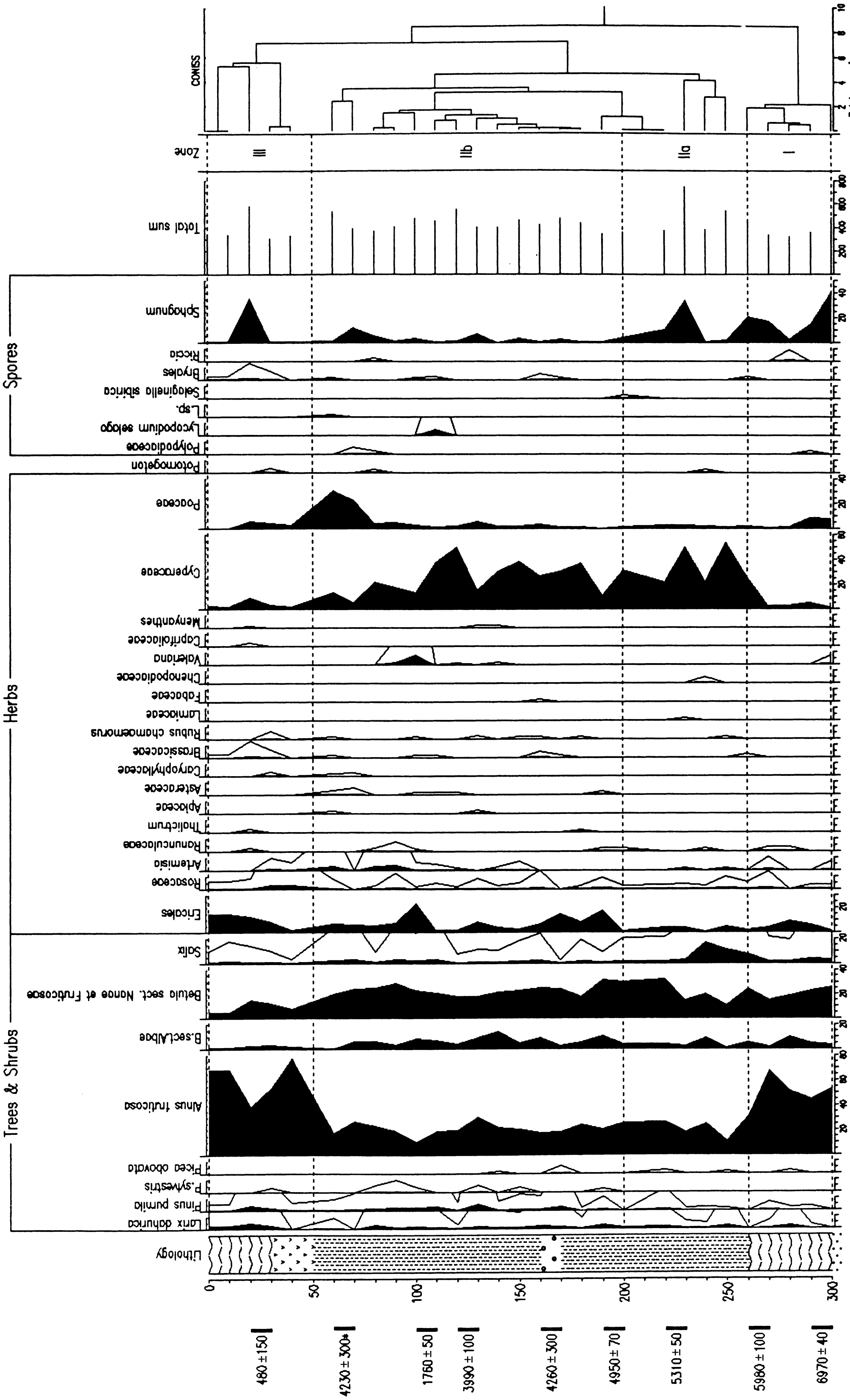

Fig. 2. Pollen diagram of Kazach'e site.

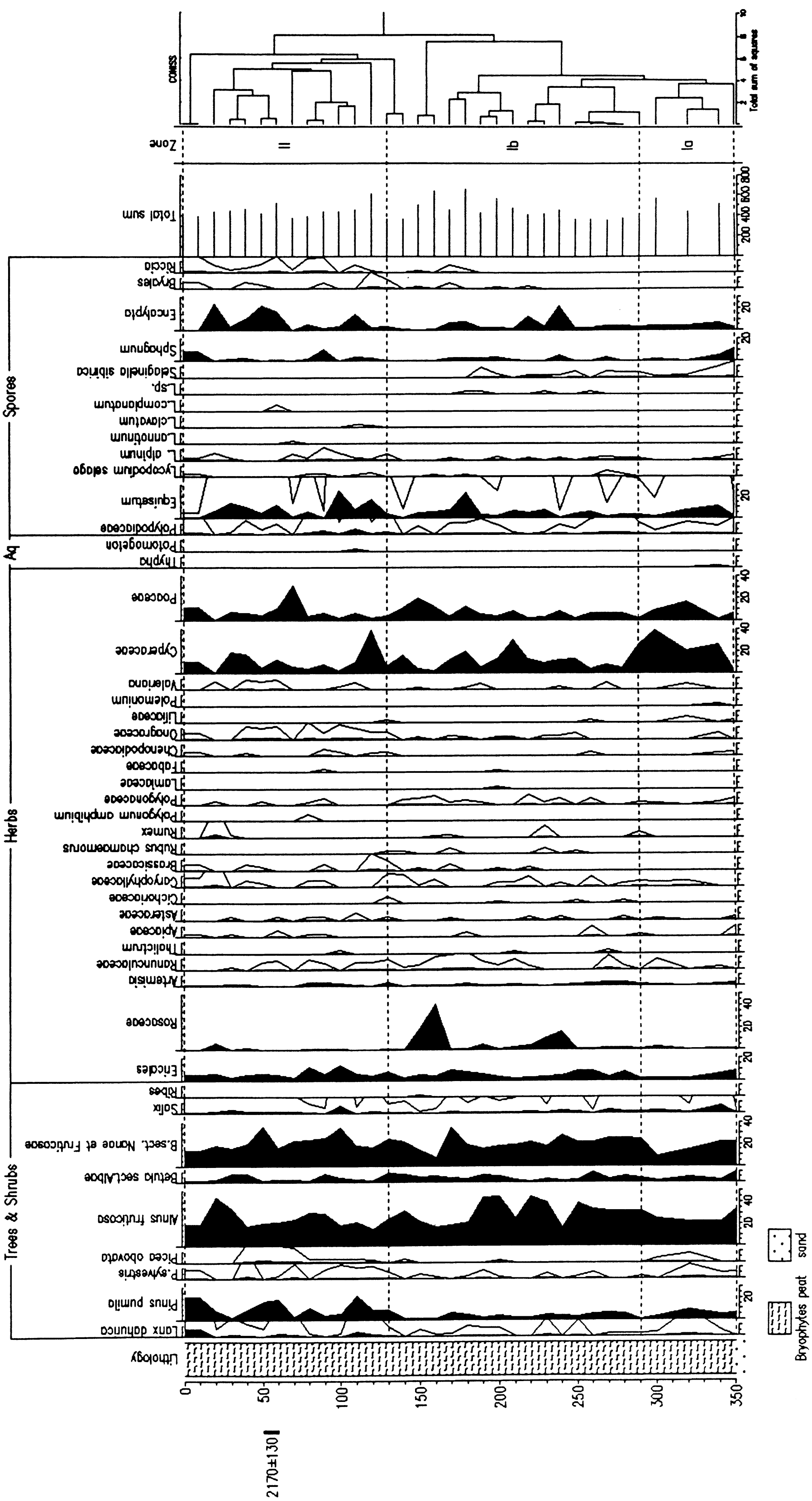

Fig. 3. Pollen diagram of Khocho site.

plain (site 3 in Fig. 1) also cannot be used to verify the Kazach'e chronology because of lack of ^{14}C dates. A radiocarbon date of 4730 ± 120 yr BP (Vs-36) obtained for a peat from the 75–80 cm depth may be erroneous because sediment mixing may have occurred throughout much of the site history (N.A. Khotinsky, pers. comm.). The sediment contamination was possibly sufficient to affect not only the radiocarbon, but also pollen spectra.

7.1. 6400–6000 yr BP

At 6400 yr BP, the initial *Sphagnum*-dominated wetland was largely surrounded by *Larix dahurica* trees and *Alnus fruticosa* shrubs with some shrubby *Betula exilis*. Although *Larix* is an important species in the Siberian forests, its history is not well known because of its poor representation in pollen diagrams. *Larix* pollen is relatively rare even in surface samples from larch forests and its low frequency in pollen spectra does not reflect its true regional abundance, as evidenced by surface samples from larch forests in many areas of East Siberia (Vas'kovsky, 1957; Popova, 1961; Giterman, 1963; Savvinova, 1975; Andreev and Klimanov, 1989; Klimanov and Andreev, 1992). Thus, even scant larch pollen in pollen records is interpreted as reflecting widespread *Larix* distribution. Several locations in the adjacent coastal lowland areas (Kaplina and Lozhkin, 1982) demonstrate similar pollen stratigraphy at this time as well as the upper part of Yana-Omoloy site.

Larix was already present in this region, prior to the early Holocene time (Kaplina and Lozhkin, 1982). In general, the expansion of *Larix* beyond modern treeline in the Northern Eurasia occurred between 9000 and 8000 yr BP and the density of *Larix* tree cover north of the modern treeline was at a maximum between 8000 and 4000 yr BP (MacDonald et al., 2000).

Alnus fruticosa is now a common shrub in the northern larch forests (northern taiga) and was a very common species in the forest about 6400–6000 yr BP. The presence of tree birch, spruce (*Picea obovata*), Scotch pine *(Pinus sylvestris*) and dwarf pine (*Pinus pumila*) pollen probably does not reflect the growth of these species around the sites. Their northern tree limit is far to the south. Their pollen probably reflects the long-distance transport to the study region by wind (Kazach'e site) and by combination of water and wind (Khocho site). These pollen grains could also be reworked from some interstadial (Kargian) or even from interglacial sediments. The single pollen grains of *Tilia* and *Juglans* in the Khocho site also support this interpretation.

Sphagnum mosses with some sedge, grasses, heaths and Rosaceae species dominated the peatland surface and surrounding forest. The herb species were more variable on the Khocho site (river floodplain) and Yano-Omoloy site (drained lake), where open treeless communities were more abundant.

7.2. 6000–1100 yr BP

Larch forest with some alder and dwarf birch dominated the area at that time. A sedge fen characterized the Kazach'e site between 6000 and 1100 yr BP as evidenced by the change from *Sphagnum* peat to the sedge matrix. *Alnus* pollen percentages dropped with increasing percentages of Cyperaceae, but abundant *Sphagnum* macrofossils with some peaks in spores in the lower part of the Kazach'e site diagram indicate its subdominance at the site until about 5000 yr BP. The peak in *Salix* pollen probably reflects wetter conditions on the wetland transition. The higher amount of Ericales pollen may reflect drier conditions on the peatland after 5000 yr BP.

The slight (windblown) increase of *Pinus pumila* pollen after 4500 yr BP is noticeable in the Kazach'e pollen spectra. It may be indicative of the movement of dwarf pine into the southern mountain part of the region. Its greater abundance in the upper part of Khocho diagram, was probably caused by water transportation of pollen. Published pollen data also show significant increase in *Pinus pumila* pollen after 4700 yr BP (4700 ± 110 (MAG-131), 3955 ± 80 (MAG-161), 3660 ± 50 (MAG-172)) in different parts of the Kolyma-Indigirka lowlands (Kaplina and Lozhkin, 1982).

The radiocarbon dates of 3990 ± 100 (GIN-5386) and 1760 ± 50 (GIN-5385b) yr BP from 120–130 and 100–110 cm depths, respectively, indicate extremely slow peat accumulation or/and oxidation of the peat layers at that time. The hiatus may be explained by very dry conditions on the peatland or by destruction of the upper layers by a fire, but there are no evidence of these events in the pollen spectra. Even if the age for the peat from 120 to 130 cm depth is erroneously old, the peat accumulation was very slow between 4000 and 1800 yr BP.

We note a peak in Poaceae pollen and *Sphagnum* spores about 1200 yr BP followed by Cyperaceae decrease, which may be connected with local hydrological changes. A more decomposed, *Sphagnum*–sedge peat layer deposited above this zone after 1100 yr BP supports this hypothesis.

7.3. 1100 to modern

A return to *Sphagnum* wetland with some ericacous species at the Kazach'e site is evident from the numerous macrofossils, an increase in *Sphagnum* spores, and an increase in Ericales pollen. The alder pollen peaks and slight larch increase reflect the presence of alder shrubs on the peatland surface from 500 yr BP until present. Generally, all pollen spectra reflect the modern regional vegetation type.

8. Climate reconstructions

Vegetation changes reflected in the fossil pollen spectra are one of the primary sources of information about climatic fluctuation in the past. Various mathematical (transfer function) methods have been used to reconstruct Holocene climatic changes from pollen by different investigators (Webb and Bryan, 1972; Bryson and Kutzbach, 1974; Klimanov, 1976, 1984; Sachs et al., 1977 and others). We used a transfer function, based on the correlation of recent pollen spectra with modern climate conditions (Klimanov, 1976, 1984). The method was worked out on the basis of more than 800 surface pollen spectra from different parts of the former USSR. Modern climate variables were taken from a climatic atlas (Klimatichesky atlas SSSR, 1960). The climatic parameters used for the reconstructions are the mean annual, mean January, and mean July temperatures and total annual precipitation. The mean statistical error is $\pm 0.6°C$ for mean annual and mean July temperatures, $\pm 1°C$ for mean January temperatures and ± 25 mm for annual precipitation. The method is being used throughout the former Soviet Union region.

The paleoclimate curves are presented in Fig. 4. According to the reconstructions, several warm and rather moist intervals occurred during the last 6400 yr. The warmest time was between 6000 and 4500 yr BP with fluctuations in temperatures and precipitation in that time. Mean seasonal and annual temperatures were up to 2°C warmer than modern and annual precipitation was about 75 mm greater than today. The possible hiatus or/and very slow peat accumulation between 3990 ± 100 and 1530 ± 70 makes our reconstruction (shown by dished lines in Fig. 4) problematic for that interval. Generally, these climate reconstructions agree well with climate reconstructions from the Central and Southern Yakutia using the same transfer function method (Andreev and Klimanov, 1989; Andreev et al., 1989, 1993) and from Northern Eurasia (Khotinsky, 1977).

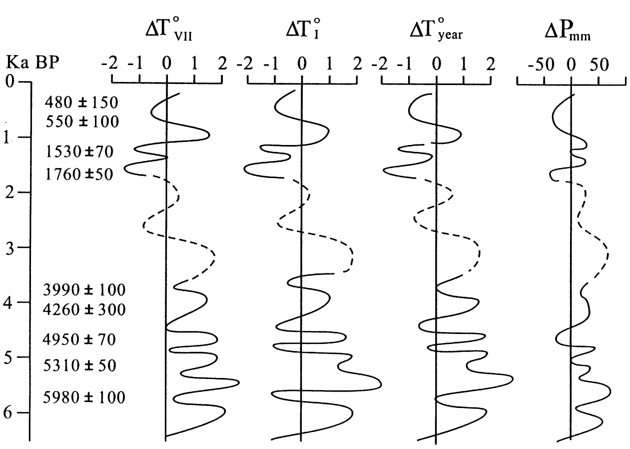

Fig. 4. Paleoclimate curves from Kazach'e section pollen.

9. Conclusions

Two new pollen records and radiocarbon dates from the Yana River lowlands indicate that larch forest with shrubs alder and dwarf birch dominated the study area during the last 6400 yr. The pollen and spore fluctuations in shrubs, herbs and mosses reflect both local hydrological events and regional climate changes. There is no evidence for tree-line movement in the investigated area during the latter half of the Holocene. Several climatic fluctuations were reconstructed from Kazach'e record by transfer function. These results agree well with regional climate changes inferred from palynological studies in the Northern Eurasia.

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