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HOLOCENE SEDIMENTS OF THE ADYCHA RIVER VALLEY, YAKUTIA

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Palynological analysis of radiocarbon-dated sediments from floodplain deposits and peat bogs preserved in the terraces along the Adycha River, a tributary of the Yana River, document the regional presence of larch forests over at least the last 10 500 ^{14}C BP (12 500 cal BP). The Adycha records indicate that the most favorable climatic conditions during this interval occurred during the Early Holocene, persisting up to 8 200 ^{14}C BP (9 200 cal BP), and during the Middle Holocene between c. 6 000–5 100 ^{14}C BP (6 900–5 800 cal BP). Climatic warming also happened between 400–190 calendar years ago, following the cooling of the Little Ice Age. The expansion of *Pinus pumila* into the Yana River basin occurred c. 7 000 ^{14}C BP (7 800 cal BP). A date of 8 200 ^{14}C BP falls within an interval of global cooling, referred to as the Bond 5 event, as defined from North Atlantic marine deposits.

***Keywords*: river terraces, Holocene, palynological analysis, radiocarbon dates, climatic optimum, climatic cooling.**

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INTRODUCTION

The Adycha River, a right tributary of the Yana River, has its headwaters on the Yana Plateau. The source of the river is located on the southern slope of the Borong Ridge at an elevation of 1815 m a.s.l. (above sea level). The length of the river is 715 km and the watershed spans an area of 89.8 thousand km^2. In the upper reaches, the river flows in a deep canyon bordered by 100–120 m high rocky cliffs. The Yana Plateau, with highest peaks of about 500–800 m a.s.l., is bordered to the west and south by the spurs of the Verkhoyansk Range and to the east by the spurs of the Chersky Mountains. The lower reaches of the Adycha River cross the Tuostakh depression, which has been infilled with Neogene and Quaternary sediments.

The surface elevations within the depression vary from 300–700 m a.s.l. and increase from north to south. The bed of the Adycha River at its confluence with the Yana River has an elevation of 104 m a.s.l. Sediments in the depression have been exposed along the right bank of the Adycha River c. 60 km from its mouth (67° 49′ N, 135° 40′ E; Fig. 1). This outcrop, called Ulakhan-Sular, is a key reference section used for addressing questions of regional Quaternary stratigraphy and paleogeography in the "cold pole" of the Northern Hemisphere (Kaplina et al., 1983; Minyuk, 2004). To the north, the Yana Plateau gives way to the vast Primorskaya Lowland, the border of which is delimited by the coasts of the Laptev and East Siberian Seas.

The Yana River basin belongs to the northern taiga subzone (Karavaev, 1958). Little variability occurs in these forests. *Larix cajanderi* Mayr is virtually the only tree species constituting these forests. *Populus suaveolens* Fisch. and *Chosenia arbutifolia* (Pall.) A. Skvorts. form stands on sandy and pebble-rich sediments in the river valleys. In relict *Chosenia*-*Populus* forests, there are individual trees or small stands of *Picea obovata* Ledeb. (Fig. 2). *Betula platyphylla* Sucacz. grows within the *Larix* forests, penetrating north along river valleys up to 68–70° N. The forest understory includes *Pinus pumila* (Pall.) Regel, *Betula middendorffii* Trautv. & C. A. Mey., *Betula exilis* Sucacz., *Duschekia fruticosa* (Rupr.) Pouzar, various species of shrub *Salix*, *Rhododendron adamsii* Rehd., *R. parvifolium* Adams, and *Ledum palustre* L., *L. decumbens* (Aiton) Lodd. ex Steud. The vegetation of the Yana River basin is determined by the sharply continental, very harsh regional climate, which is influenced by cyclones and climatic fronts coming from the north, since topographic barriers to the winds off the Arctic Ocean are absent.

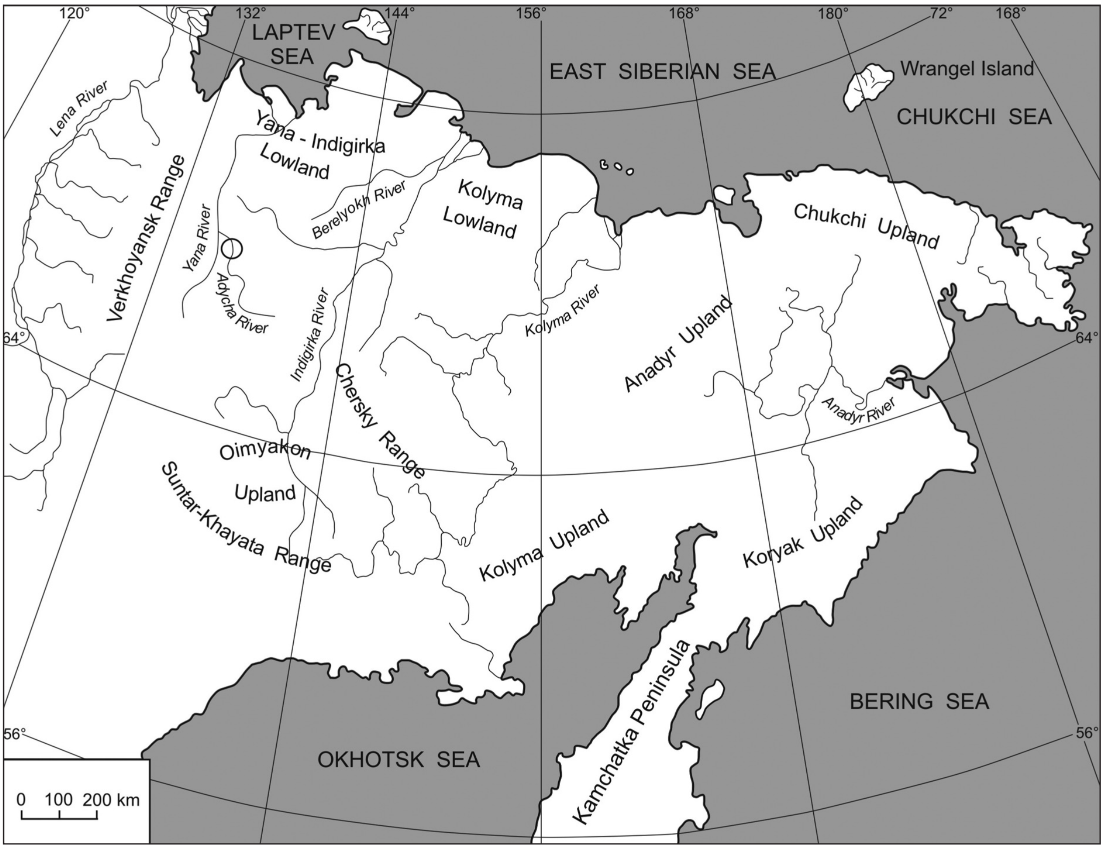

Рис. 1. Географическое положение района исследований в низовьях р. Адыча.

Fig. 1. Location of the research area in the lower reaches of the Adycha River.

Рис. 2. Лиственничный лес в бассейне р. Яна. Темнохвойные деревья в низовьях долины – *Picea obovata* (https://sun9-5.userapi.com/nt6n9VeUQGHxTVHJr08oaI1_0yB2dPXTdeQWvQ/t0WyOjrmERA.jpg).

Fig. 2. Larch forest in the Yana River basin. Dark coniferous trees in the lower reaches of the valley are *Picea obovata* (https://sun9-5.userapi.com/nt6n9VeUQGHxTVHJr08oaI1_0yB2dPXTdeQWvQ/t0WyOjrmERA.jpg).

TERRACES OF THE VALLEY OF THE ADYCHA RIVER

During the study of the Ulakhan-Sular exposure, sediments composing the terraces in the Adycha River valley were examined. The sediments of the 4.5-m-high terrace, located on the left bank of the Adycha River (67° 39′ N, 135° 35' E with an elevation of 142 m a.s.l.)*, are characterized by sands, which include plant remains and a distinct layering that is characteristic of floodplain alluvium. Although the deposits represent alluvial floodplain facies, the remains of small willow bushes found in them retain their in-growth position and are confined to contacts with the horizontal layers of sand. The lithology from the top to the bottom of the outcrop is: 0–15 cm – soil layer; 15–40 cm – fine-grained sand with a mixture of silt; 40–60 cm – buried soil; 60–250 cm – fine-grained sand with a mix of silt and layers of plant remains; 250–450 cm – silt with a mixture of fine-grained sand and layers of fine organic matter. At a depth of 125 cm, a radiocarbon date of 740 ± 100 (MAG-831) was obtained from grass macrofossils, and at 225 cm a date of 1 420 ± 90 (MAG-830) (Table) from wood of *Salix* sp. Interpolation of radiocarbon dates with an average sedimentation rate of 0.16 cm/year indicates that the sediments in the terrace exposure were deposited over a span of 2 850 ^{14}C years, that is, in the second half of the Late Holocene.

On the right bank of the Adycha River (67° 50′ N, 135° 35′ E), sediments comprising a 5-m-high terrace were studied. This outcrop, the surface of which has an elevation of 130 m a.s.l., consists of the following: 0–25 cm – soil layer; 25–120 cm – fine-grained sand with isometrical inclusions of peat; 120–230 cm – sedge peat; 230–350 cm – poorly sorted sand, layered, floodplain alluvium. The lower 1.5 m of the outcrop is covered by frozen slope deposits. Radiocarbon dates were obtained from bulk peat samples at depths: 130 cm – 5 840 ± 100 (MAG-829), 165 cm – 6 020 ± 100 (MAG-828), and 230 cm – 6 960 ± 120 (MAG-827) (Table 1).

In the area of 67° 50′ N, 135° 07′ E, also on the right bank of the Adycha River, deposits were exposed that formed an 8-m-high terrace: 0–30 cm – soil layer; 30–210 cm – lens-shaped deposits of sedge peat; 210–630 cm – alluvial sands with lenses of gravel and pebbles. The lower 170 cm of the outcrop is covered by frozen colluvium. A peat sample taken at the contact of the peat deposit and underlying sands (depth of 210 cm) was radiocarbon dated to 8 200 ± 160 (MAG-832) (Table).

RESEARCH METHODS

Palynological analysis and radiocarbon dating of sediments from the terraces of the Adycha River were done in the laboratories of the North East Interdisciplinary Research Institute in Magadan. The preparation of the palynological samples followed the methodology proposed for the study of arctic lakes and estuaries (PALE, 1994). Percentage calculations and the construction of the palynological diagrams were done using the programs "Tilia" and "Tilia-graph". Approximately 300 pollen grains were counted in each sample. Individual pollen taxa are shown as a percentage of the sum of all terrestrial pollen grains. The percentages of specific spore taxa are based on the pollen sum. In addition, the diagrams (Figs. 3, 5, 7) show the percentages of three vegetation groups: trees and shrubs, herbs, and spores. These percentages are based on a sum of all

Table. **Radiocarbon and calibrated dating**
Таблица. **Радиоуглеродные и калиброванные датировки**

Sample depth, cm	^{14}C age	Median cal age; 2 sigma range	Sample number	Material dated
Terrace 4.5 m high				
125	740 ± 100 BP	685 540–800	MAG-831	Herbaceous plant fragments
225	1 420 ± 90 BP	1330 1175–1525	MAG-830	*Salix* wood
Terrace 5 m high				
130	5 840 ± 100 BP	6650 6440–6890	MAG-829	peat
165	6 020 ± 100 BP	6870 6740–6990	MAG-828	peat
230	6 960 ± 120 BP	7790 7580–7980	MAG-827	peat
Terrace 8 m high				
210	8 200 ± 160 BP	9150 8720–9500	MAG-832	wood

* On this terrace is the village of Betenkes in the Verkhoyansk ulus (administrative district) of Yakutia, which was damaged during a flood caused by the July rains of 2008. Gradually, the village with a population of about 1000 people and known for its excellent dairy farming has recovered.

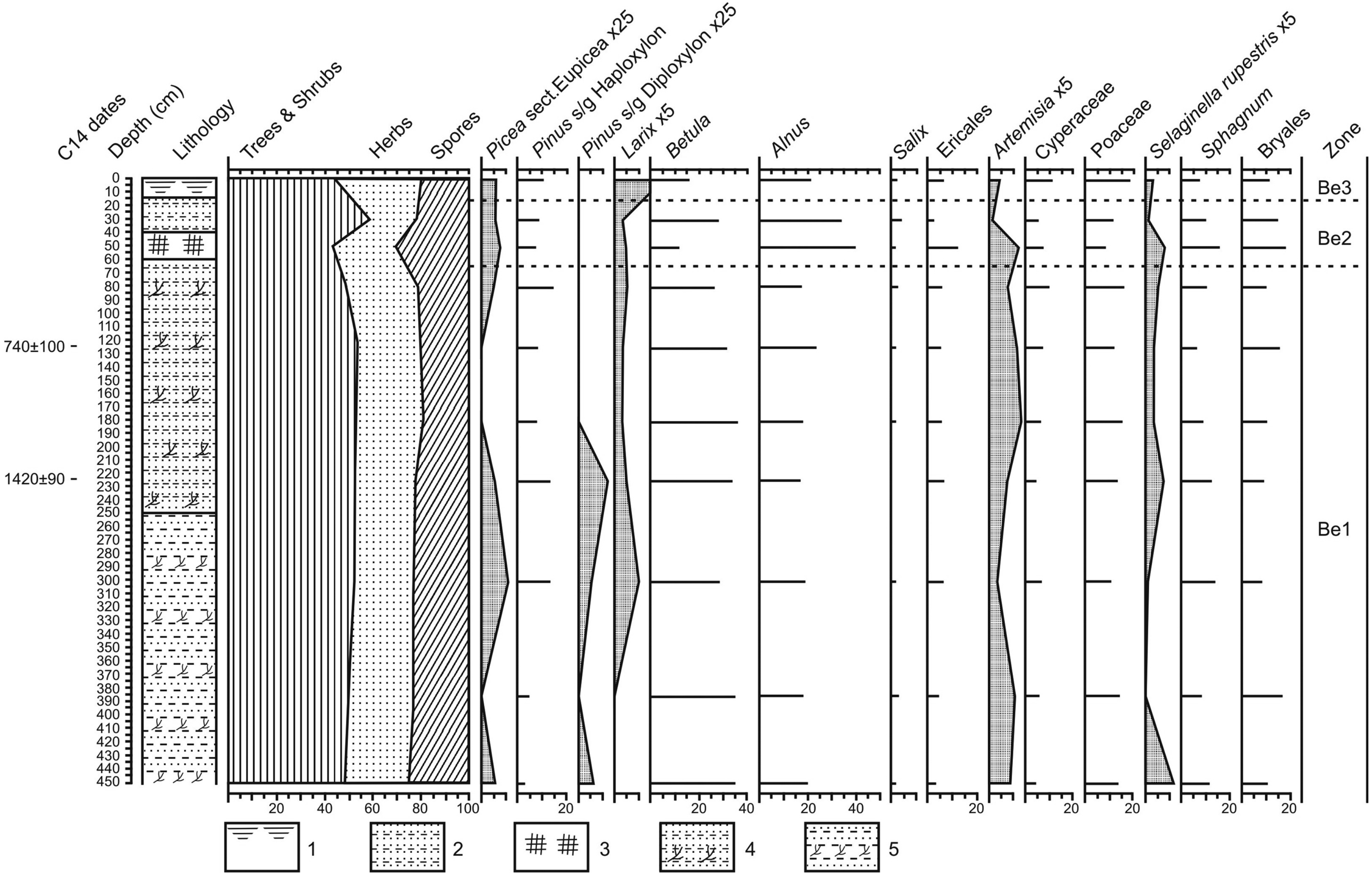

Рис. 3. Процентные соотношения групп растительности, основных пыльцевых и споровых таксонов в спектрах осадков 4.5-м террасы р. Адыча: 1 – почвенный слой; 2 – песок с примесью алеврита; 3 – погребенная почва; 4 – песок с алевритом и растительными остатками; 5 – алеврит с песком и тонкой органикой.

Fig. 3. Percentage ratios of vegetation groups and the main pollen and spore taxa in the palynological spectra of the sediments from the 4.5-m terrace of the Adycha River: 1 – soil layer; 2 – sand mixed with silt; 3 – buried soil; 4 – sand with silt and plant remains; 5 – silt with sand and fine organic matter.

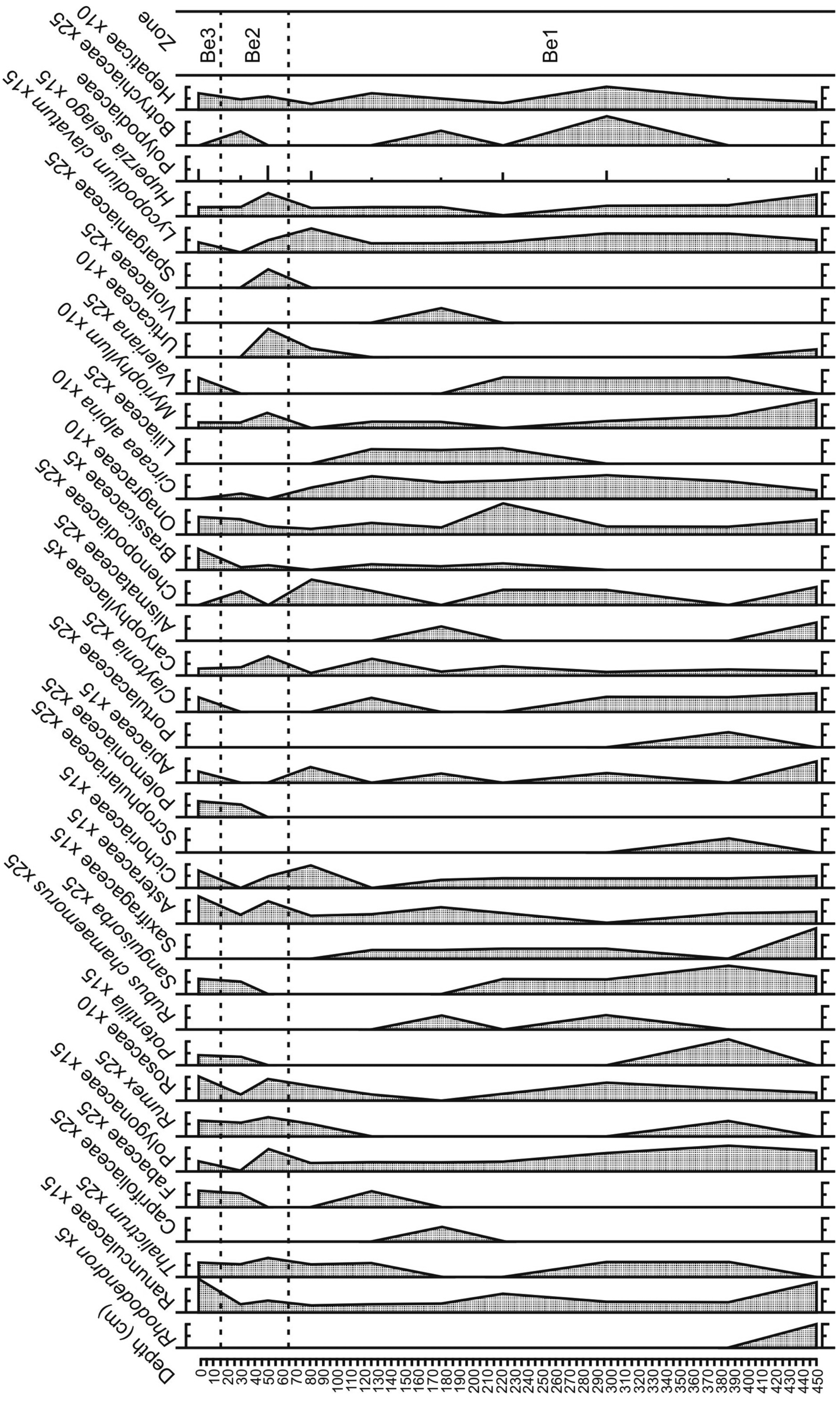

Рис. 4. Второстепенные пыльцевые и споровые таксоны в спектрах осадков 4.5-м террасы р. Адыча.

Fig. 4. Minor pollen and spore taxa in the palynological spectra of sediments from the 4.5-m terrace of the Adycha River.

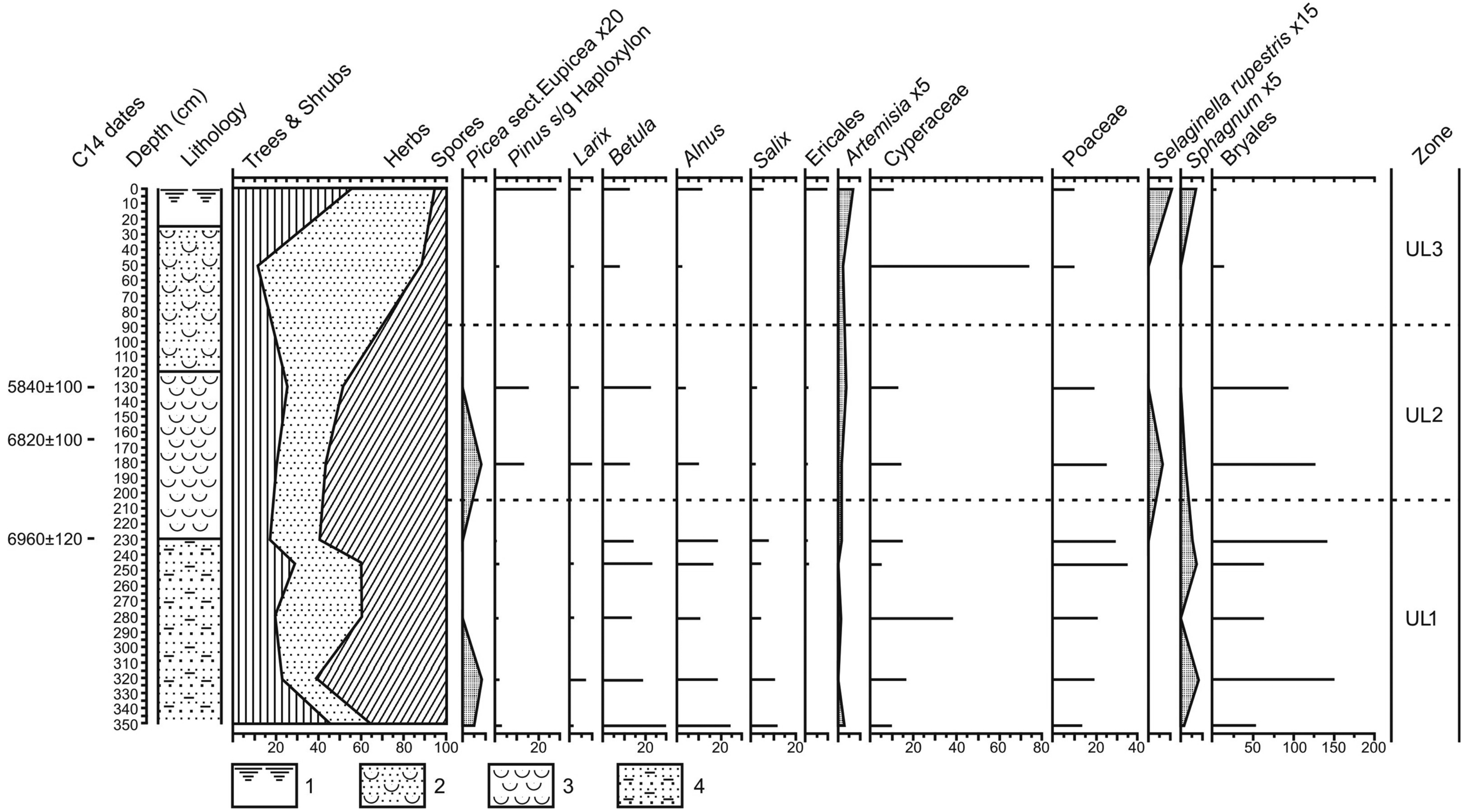

Рис. 5. Процентные соотношения групп растительности, основных пыльцевых и споровых таксонов в спектрах осадков 5-м террасы р. Адыча: 1 – почвенный слой; 2 – песок с включением торфа; 3 – торф; 4 – песок слоистый.

Fig. 5. Percentage ratios of vegetation groups, and the main pollen and spore taxa in the palynological spectra of sediments from the 5-m terrace of the Adycha River: 1 – soil layer; 2 – sand with inclusions of peat; 3 – peat; 4 – layered sand.

pollen and spores. The percentages of minor pollen and spore taxa are illustrated in Figs. 4, 6, and 8. When reconstructing the paleovegetation, the ecology and composition of the modern plant communities of the Yana River basin were considered. Plant taxonomy follows Czerepanov (1995).

Radiocarbon dating of bulk organic samples was performed by A. V. Lozhkin using a liquid scintillation method. Benzene was chosen as the carrier of natural radiocarbon activity. Radiocarbon dates (Table) were converted to calibrated ages using the IntCal13 calibration curve in CALIB 7.1 (Reimer et al., 2013; Stuiver et al., 2020).

FEATURES OF THE SPORE AND POLLEN SPECTRA

A common feature of the Holocene spore-pollen spectra from the terraces of the Adycha River is the consistent presence of *Larix* pollen. *Larix* pollen reaches 10 % in a sample from the sedge peat, which has a date of c. 6 000 ^{14}C BP (radiocarbon years BP); 6900 cal BP (calibrated years BP). The larch pollen represents *Larix cajanderi* Mayr, the only coniferous tree currently forming forests in North East Siberia. *Larix cajanderi* pollen is poorly preserved even in modern spore-pollen samples, and its occurrence in the terrace sediments likely indicates the development of forest or forest-tundra communities in the Adycha region (Vaskovsky, 1957).

Another characteristic of the spore-pollen spectra from the terraces is the high percentage of *Betula* pollen (up to 35 % in the interval 1 400–700 ^{14}C BP; 1 300–630 cal BP). Shrub species, such as *Betula exilis* Sucacz. and *B. middendorffii* Trautv. & C. A. Mey., not only were found in the understory of the larch forests, but they also formed thickets (ernik) on the valley slopes. The larch forest perhaps included *Betula platyphylla* Sucacz., which would have grown in isolated stands on the hill slopes.

The comparison of modern spore-pollen percentages with the fossil spectra indicates a widespread presence of shrub *Alnus* (*Duschekia fruticosa* (Rupr.) Pouzar), both in the understory of the larch forests and in thickets along the river banks. Shrub *Alnus* played a particularly noticeable role in the vegetation cover during the Early Holocene (up to 8 000 ^{14}C BP, 8 900 cal BP) and in the interval between 160 and 450 years ago (*Alnus* pollen with peaks of 35–43 %).

Salix is another consistently appearing taxon, which reaches a maximum of 12 % between 8 000 and 6 000 ^{14}C BP (8 900–6 900 cal BP). Considering the poor preservation of *Salix* pollen both in the modern and fossil sediments, it can be assumed that willow probably was the most common shrub, particularly in thickets within the river valleys. *Chosenia arbutifolia* (Pall.) A. Skvorts. formed gallery forests on sandy and pebble-rich substrates within the valley.

The presence of Ericales pollen and *Sphagnum* spores in the Adycha spectra reflects the occurrence of heather communities with *Ledum palustre* L., *L. decumbens* (Aiton) Lodd. ex Steud., *Vaccinium vitis-idaea* L., and *V. uliginosum* L. The widespread development of meadow communities is suggested by the high percentages of Poaceae pollen (up to 35 % in sediments dating to c. 7 000 ^{14}C BP, 7 800 cal BP), Cyperaceae (up to 40 %; peak of 75 % dating to c. 5 000 ^{14}C BP, 5 800 cal BP). Moist conditions and the occurrence of swampy terrain are indicated by numerous Bryales spores, especially in spectra associated with the Middle Holocene.

As indicated by the radiocarbon dates, the expansion of *Pinus pumila* (Pall.) Regel. from refugia along the northern coast of the Sea of Okhotsk to the Yana River basin occurred c. 7 000 ^{14}C BP (7 800 cal BP), that is 2 000 ^{14}C years later than the spread of *Pinus pumila* in the mountainous regions of the Kolyma and Indigirka Rivers (Lozhkin, 1997). The spore-pollen spectra of Early Holocene lake sediments from various phytogeographical regions of northeastern Siberia typically do not contain pollen (or only single grains) of *Pinus* subgen. Haploxylon (*Pinus pumila*). In the Yana River basin, pollen of *Pinus* subgen. Haploxylon is also absent in sediments deposited during the first half of the Middle Holocene. Based on palynological analyses, *Pinus pumila* was widely distributed in southern Chukotka by c. 6 500 ^{14}C BP (7 400 cal BP) and in the mountainous regions of the Kolyma drainage by c. 9 000–8 000 ^{14}C BP, 10 200–8 900 cal BP (Lozhkin, 1997).

POLLEN ZONES AND ASSOCIATED PLANT COMMUNITIES

Three pollen zones characterize the sediments from the 4.5-m terrace (Fig. 3). Pollen zone Be1 indicates the presence of a larch forest with an undergrowth of *Betula middendorffii*, *Duschekia fruticosa*, *Salix* sp., and *Pinus pumila*. These forests were present across the region. As is seen today in the Adycha valley, gallery forests were formed by *Chosenia arbutifolia* and *Populus suaveolens* Fisch. with small stands of *Picea obovata*. Pollen zone Be1 shows many similarities with pollen zone Be3, the latter zone reflecting the establishment of modern plant communities. The main difference between the spectra of these zones is the more than twofold increase in *Betula* pollen percentages in the spectra of zone Be1 (35 %) as compared to zone Be3 (15 %). Most likely, such spectra indicate a wide distribution of shrub birch thickets (ernik), as well as the presence of tree birch in the forest communities from c. 2 800–400 ^{14}C BP (2 900–490 cal BP). The sharp decrease in the role of birch in the zone Be3 vegetation probably can be explained by the influence of human activity. Nevertheless,

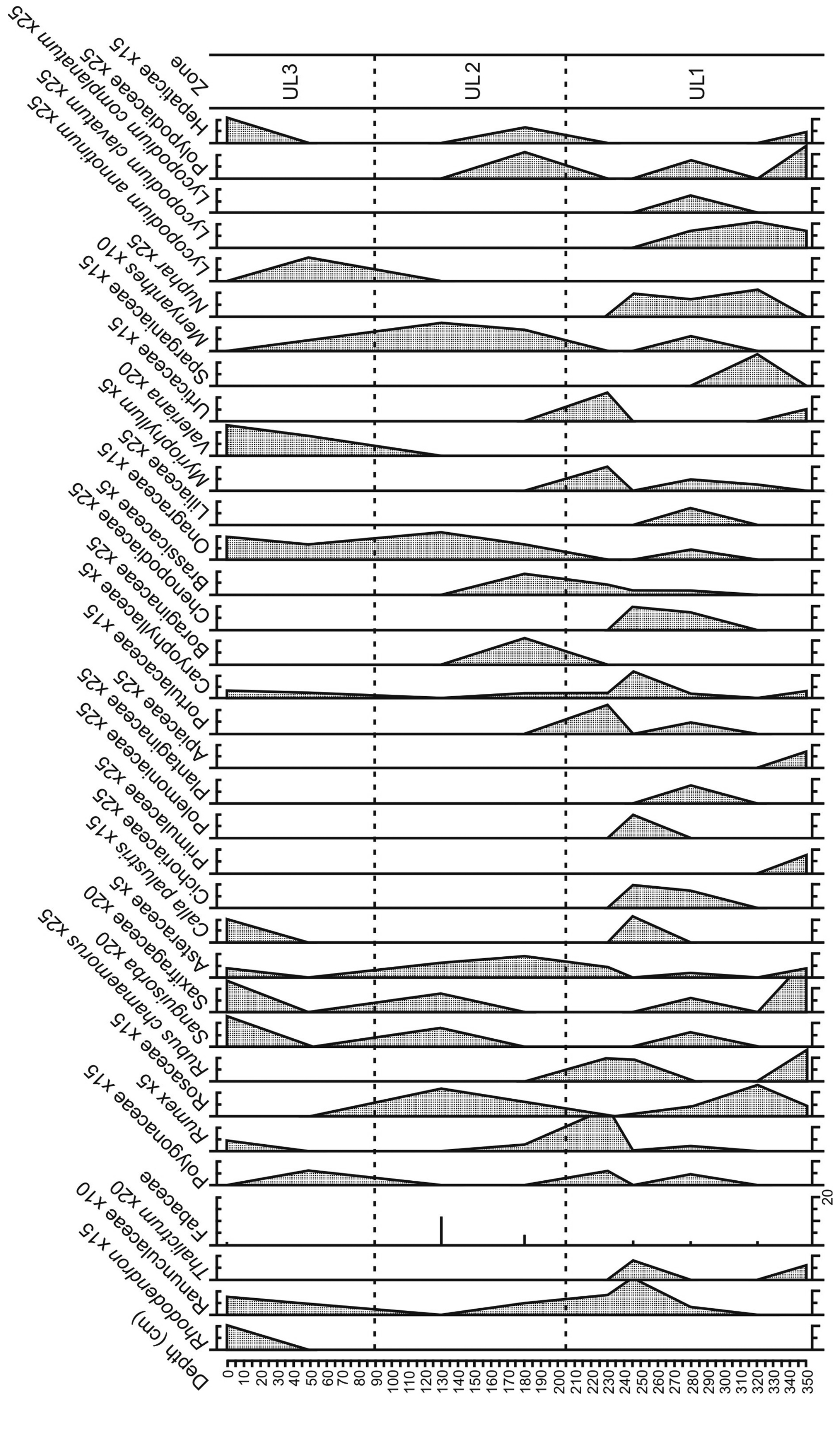

Рис. 6. Второстепенные пыльцевые и споровые таксоны в спектрах осадков 5-м террасы р. Адыча.
Fig. 6. Minor pollen and spore taxa in the spectra of sediments from the 5-m terrace of the Adycha River.

the diverse composition of the spectra and the increased pollen percentages (up to 55 %) of shrub and tree taxa in the zone Be1 assemblage (Figs. 3, 4) suggest that the growing season was longer, as compared to the modern one, between 2 800–400 ^{14}C BP.

The upper boundary of the Be1 pollen zone dates approximately to 1645 AD; that is, it corresponds to the first cold interval of the Little Ice Age (XVII–XIX centuries). The slight warming reflected by the spectra of zone Be1 may indicate a different direction of climate change occurred in the northeastern regions of Siberia, as compared to that documented for Europe.

Pollen zone Be2 is characterized by an increase in the pollen percentages of tree and shrub taxa (up to 60 %) and the dominance of *Alnus* pollen (35–42 %). The palynological data undoubtedly reflect the wide distribution of *Duschekia fruticosa*, which, together with *Pinus pumila* and *Betula middendorffii*, formed a shrub layer in the birch-larch forest. The shrubs also occurred in thickets along the banks of rivers and streams and grew in meadows on rocky slopes. The data suggest high pollen productivity, which is influenced by the length of the growing season. Flowering of *Duschekia fruticosa* in the northern regions occurs today in May–June, and in the tundra zone the growing season extends into July. In the lower reaches of the Lena River, this species reaches the latitude of 72° 23′ 15″ N. *Alnus hirsuta* Turcz. was probably found along the river banks, as is currently the case in the Verkhoyansk Range. The distribution of shrub and tree species of alder suggests that summer temperatures exceeded modern by 2–4 °C. The spore-pollen spectra of zone Be2 also indicate a noticeable role of heath communities in the vegetation and a slight reduction in sedge-grass-forb communities. The climate warming reflected by zone Be2 spans the interval of between 400–190 calendar years ago.

Based on the radiocarbon dates, the spore-pollen spectra characterizing the sediments of the 5-m terrace of the Adycha River reflect plant communities of the Middle Holocene. The pollen-spore diagrams include three pollen zones (Figs. 5, 6). Pollen zone UL1 shows a regional distribution of birch-larch forests with an understory of shrub *Betula*, *Duschekia fruticosa*, and *Salix* sp. Since *Pinus pumila* pollen is either absent or present as only single grains in the zone UL1 assemblage, we can conclude that dwarf pine was not characteristic of the vegetation of the Yana River basin until 7 000 ^{14}C BP (7 800 cal BP). The widespread development of meadow communities is indicated by the high pollen percentages of Poaceae (up to 35 % in sediments dating to c. 7 000 ^{14}C BP) and Cyperaceae (up to 40 %; a peak of 75 % dating to c. 5 000 ^{14}C BP, 5 700 cal BP). The presence of abundant soil moisture and the formation of swampy terrain are indicated by numerous Bryales spores, especially in spectra associated with the Middle Holocene.

Dates close to 6 000 ^{14}C BP (6 900 cal BP) fall within the climatic optimum of the Holocene, occupying the interval of 8 000–5 000 ^{14}C BP (8 900–5 800 cal BP) in the Holocene climatostratigraphy. During this interval, the greatest "blooming" of mixed oak forests are observed in northwestern and central Europe (Khotinsky, 1977). During the mid-Holocene thermal maximum in the Russian Far East, moderately thermophilic broadleaf forests, which are dominated by *Quercus* but also included *Ulmus*, *Juglans*, *Carpinus*, *Tilia*, *Acer*, and *Corylus*, spread in the lowlands. Pine-broadleaf forests established at mid-elevations and dark coniferous forests were present at higher elevations. In Northeast Siberia (Western Beringia), most palynological records from lake sediments do not provide sufficiently convincing evidence for a thermal maximum in the mid-Holocene (Lozhkin, 1997).

The strongest records indicating a mid-Holocene climatic optimum occur in the western part of Western Beringia. Quantitative paleoclimatic reconstructions indicate that within the Yana Lowland, a warm interval appeared between 6 000–5 100 ^{14}C BP (6 900–5 800 cal BP) (Andreev et al., 2001). New pollen records from lake sediments in the upper reaches of the Indigirka River (Oymyakon region of Yakutia) indicate warmer and wetter conditions than modern, starting from about 7 000 cal BP (indicated by the appearance and sharp increase in the amount of *Pinus pumila* pollen), possibly with optimal conditions between 6 000–4 900 cal BP (highest percentages of *Pinus pumila*). Increases in pollen percentages of dwarf pine occurred between 6 800–4 500 cal BP (Lozkin et al., 2018). This latter interval is consistent with the work of Kaufman et al. (2016), who showed that in Eastern Beringia the Holocene thermal maximum occurred at 6 100–4 500 ^{14}C BP (7 000–5 000 cal BP). Continuous pollen records of sediments from the lakes of Western Beringia show the maximum distribution of dwarf pine (*Pinus pumila*) was c. 6 000 ^{14}C BP, 6 900 cal BP (Lozhkin, 1997).

Such high-quality paleoclimatic reconstructions based on paleobotanical data are consistent with results of paleoclimate computer models. For example, a regional climate model for Beringia simulates the continuation of Early Holocene warm conditions into the mid-Holocene, but with greater fall and winter precipitation and a longer growing season in the latter interval (Bartlein et al., 2015).

These conditions reflect the effects of changing atmospheric circulation associated with both greater than present summer insolation and the melting of the Laurentian ice sheet. Radiocarbon-dated paleobotanical materials indicate that c. 6 000 ^{14}C BP (6 900 cal BP) in Western Beringia herb-shrub tundra

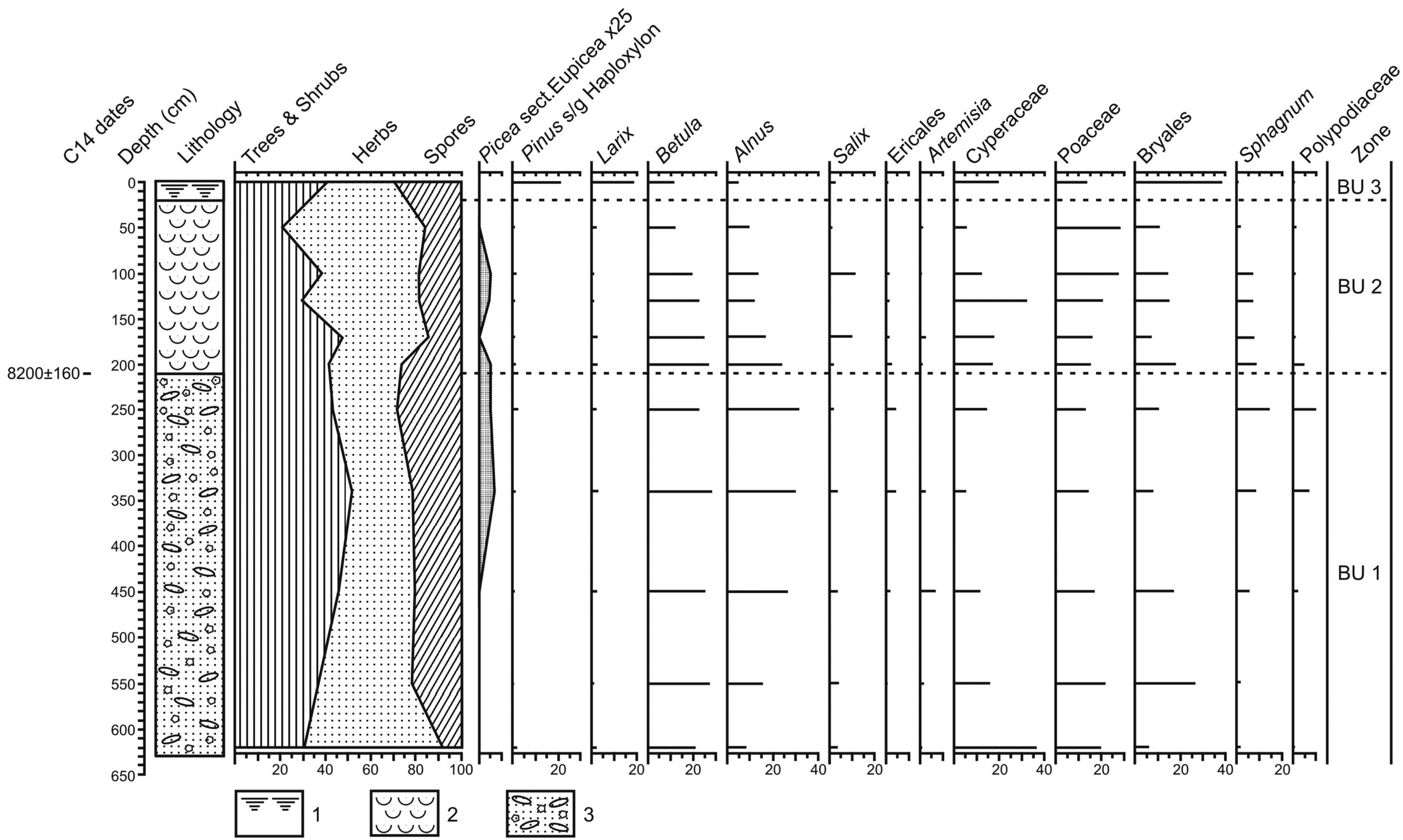

Рис. 7. Процентные соотношения групп растительности, основных пыльцевых и споровых таксонов в спектрах осадков 8-м террасы р. Адыча: 1 – почвенный слой; 2 – торф; 3 – песок с гравием и галькой.

Fig. 7. Percentage ratios of vegetation groups and the main pollen and spore taxa in the spectra of sediments on the 8-m terrace of the Adycha River: 1 – soil layer; 2 – peat; 3 – sand with gravel and pebbles.

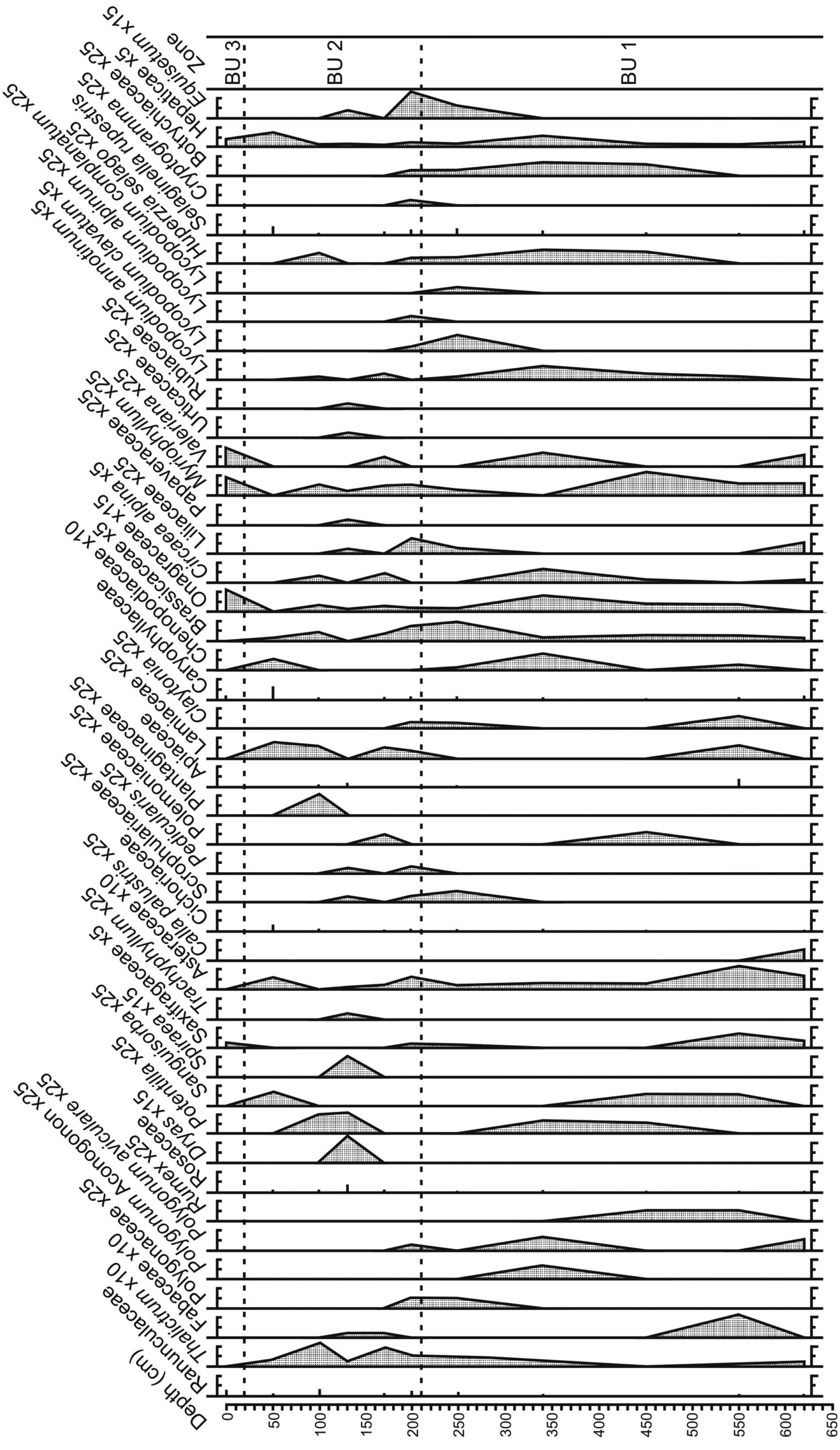

Рис. 8. Второстепенные пыльцевые и споровые таксоны в спектрах осадков 8-м террасы р. Адыча.

Fig. 8. Minor pollen and spore taxa in the spectra of sediments from the 8-m terrace of the Adycha River.

was replaced by high shrub tundra and birch forest-tundra, which had previously dominated during the Early Holocene (Lozhkin, Vazhenina, 1987). Such changes in the vegetation in areas of the modern coast of the East Siberian Sea were caused by a rise in sea level, which at c. 7 000–6 000 ^{14}C BP (7 800–6 900 cal BP) approximates the modern coastline (Kliege, 1982). The rising sea levels led to a decrease in the contrast of summer and winter temperatures and, thus, a decrease in the continentality of the regional climate and a significant reduction in the growing season. Consequently, the development of graminoid-forb tundra near the modern coast of the Arctic seas of Western Beringia during the mid-Holocene optimum can be explained by the "cooling" influence of the rising sea levels.

Palynological analysis of sediments composing the 8-m terrace indicate three pollen zones. Zone BU3 is represented by only one modern soil sample. The spore-pollen spectrum of the soil reflects the modern pollen rain and is characterized by relatively high pollen percentages of such coniferous taxa as *Pinus* subgen. Haploxylon and *Larix*.

The extremely low pollen percentages (or absence) of *Pinus* subgen. Haploxylon (*Pinus pumila*) in the zone BU1 and BU2 assemblages indicate that the formation of an alluvial channel and the accumulation of peaty floodplain sediments on the river terrace perhaps occurred as early as 7 000 ^{14}C BP (7 800 cal BP).

The spore-pollen spectra of zone BU1 reflect the regional establishment of larch forests. The dominance of *Betula* and *Alnus* pollen undoubtedly indicates not only a dense forest understory of shrub birch and alder, but also the presence of alder thickets in river valleys and of shrub birch on the slopes (ernik). Tree birch species such as *Betula platyphylla* Sucacz. and *B. lanata* (Regel.) V. N. Vassil. perhaps formed isolated stands. The floodplain forests were dominated by *Populus suaveolens* and *Chosenia arbutifolia*, with *Alnus hirsuta* Turcz. and *Picea obovata* Ledeb. occurring as single trees or in small stands.

A radiocarbon date of 8 200 ± 160 ^{14}C BP (MAG-832) shows that the vegetation reflected by the spore-pollen spectra of zone BU1 characterized the Early Holocene. In an alas peat bog located in the modern shrub-herb tundra of the Kolyma Lowland, trunks and roots of tree birch (*Betula platyphylla*), radiocarbon dated to 8 560 ± 60 ^{14}C BP (MAG-253; 9 500 cal BP), were discovered (Lozhkin, Vazhenina, 1987). These finds indicate that the vegetation was birch forest-tundra. Perhaps such forest-tundra communities resembled the modern birch (*Betula tortuosa*) forest-tundra of the Kola Peninsula. The expansion of tree birch into the modern tundra zone resulted in the identification of the first climatic optimum of the Holocene (Lozhkin, Vazhenina, 1987).

The spore-pollen spectra of zone BU1, in comparison with the spectra of modern plant communities (zone BU3) and pollen zone BU2, characterize vegetation that developed in more favorable climatic conditions with a longer growing season.

The radiocarbon date of 8 200 ± 160 ^{14}C BP (9 200 cal BP) corresponds to a time of global cooling and the only Bond event (Bond 5) in the Holocene that left clear temperature markers in the Greenland ice sheet (Bond et al., 1997).

Indeed, the spore-pollen spectra of zone BU2, like the spectra of zone BU1, indicate the regional establishment of larch forests, yet still show a noticeable climatic cooling. Attention is drawn to the reduction in the amount of pollen of shrub taxa, especially *Alnus* pollen (by 2–3 times). At the same time, Poaceae (up to 25 %) and Cyperaceae (up to 30 %) pollen increase significantly. Such a change may reflect the wide distribution of sedge-grass meadow communities. The variety of forb pollen indicates the presence of a variety of microhabitats (Figs. 7 and 8). This climatic cooling occurred at the boundary of the Early and Middle Holocene.

CONCLUSION

The Adycha River basin lies in an area of extreme fluctuations in seasonal temperatures. As such, it is a region of particular interest for examining the nature of climatic changes during the Holocene. The basin of the Adycha River is in the Verkhoyansk ulus of Yakutia, which is characterized by extremely low winter temperatures. The officially registered absolute minimum temperature in Verkhoyansk is −67.6 °C. However, in 1885 and in February 1933 a temperature of −67.8 °C was noted in the official records. Additionally, S. V. Obruchev in 1926 noted a temperature of −71.2 °C in the upper reaches of the Indigirka River. Temperatures of −71.2 °C in 1924 and −77.8 °C in 1938 were noted from the Oymyakon region of Yakutia, although these are not official measurements. Thus, the official status as the Northern Cold Pole still belongs to Verkhoyansk. The absolute maximum temperature in the Arctic of +38 °C was also recorded in Verkhoyansk. Mean annual precipitation in this region is 150–200 mm, which is comparable to that in desert areas. Frosts can occur all year round, including summer.

Palynological analysis of radiocarbon-dated floodplain deposits and peat bogs in the terraces of the Adycha River valley highlights the response of vegetation to Holocene climatic change. The palynological records span an interval of at least the last 10 500 ^{14}C BP (12 500 cal BP). The most favorable climatic conditions, which included a longer than present growing season, occurred in the Early (up to 8 200 ^{14}C BP, 9 200 cal BP) and Middle (c. 6 000–5 100 ^{14}C BP, 6 900–5 800 cal BP) Holocene. Climatic warming also occurred 190–400 years ago, following the cooling of the Little Ice Age. Interestingly, a radiocarbon date of 8 200 ± 160 ^{14}C BP falls within an interval of global cooling, associated with the Bond 5 event defined from the North Atlantic.

A common feature of the spore-pollen spectra of the Holocene sediments from the Adycha River terraces is the persistent appearance of *Larix* pollen, reflecting the regional establishment of larch forests. Gallery forests formed by *Chosenia arbutifolia*, *Populus suaveolens*, and *Larix cajanderi* with a minor presence of *Alnus hirsuta* and *Picea obovata* characterized the river valleys.

Dwarf stone pine was not characteristic of the vegetation of the Yana River basin until 7 000 ^{14}C BP (7 800 cal BP). The expansion of *Pinus pumila* from refugia along the northern coast of the Sea of Okhotsk into the Yana River basin occurred c. 7 000 ^{14}C BP or c. 2 000 ^{14}C years later than the spread *of Pinus pumila* in the mountainous regions of the Kolyma and Indigirka Rivers.

During the climatic cooling, which occurred at the boundary of the Early and Middle Holocene, the presence of Poaceae-Cyperaceae forb communities indicates that a variety of microhabitats were present near the Adycha site. The warming detected in the Late Holocene portion of the Adycha record may indicate that a different direction of climate change occurred in the northeastern regions of Siberia, as compared to more western regions of northern Asia and in Europe.

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ГОЛОЦЕНОВЫЕ ОТЛОЖЕНИЯ В ДОЛИНЕ РЕКИ АДЫЧА, ЯКУТИЯ

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Палинологический анализ датированных по радиоуглероду пойменных отложений и торфяников террас долины р. Адыча, притока р. Яна, подчеркивает региональное распространение лиственничных лесов в интервале не менее 10 500 лет. Наиболее благоприятные климатические условия отмечаются в раннем голоцене до 8 200 л. н. (9 200 калиброванных л. н.) и в среднем голоцене около 6 000–5 100 л. н. (6 900–5 800 калиброванных л. н.). Потепление климата проявилось также 400–190 л. н., сменив похолодание малого ледникового периода. Экспансия *Pinus pumila* в бассейн р. Яна происходит около 7 000 л. н. (7 800 калиброванных л. н.). Радиоуглеродная датировка 8 200 л. н. соответствует времени проявления глобального похолодания, температурные маркеры которого установлены в морских отложениях Северной Атлантики как событие Бонда 5.

***Ключевые слова*: речные террасы, голоцен, палинологический анализ, радиоуглеродные датировки, климатический оптимум, похолодание климата.**

ЛИТЕРАТУРА

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