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РЕКОНСТРУКЦИИ НА ОСНОВЕ ПАЛЕОБИОЛОГИЧЕСКИХ МЕТОДОВ

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ИЗМЕНЕНИЯ РАСТИТЕЛЬНОСТИ ПРИЕНИСЕЙСКОЙ СИБИРИ В ПОСЛЕДНИЕ 4700 ЛЕТ: НОВЫЕ ПАЛЕОЭКОЛОГИЧЕСКИЕ ДАННЫЕ ИЗ РАЙОНА ИГАРКИ (КРАСНОЯРСКИЙ КРАЙ)

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Проведены палеоэкологические реконструкции изменений растительности и климата Приенисейской Сибири за последние 4700 лет, выполненные по результатам подробного радиоуглеродного AMS датирования, спорово-пыльцевого и ботанического анализов торфа и изучения концентрации макроскопических частиц угля в болотных отложениях в окрестностях г. Игарка. Полученные данные свидетельствуют о том, что потепление климата в период 4700–3600 кал. л. н. (календарных лет назад) послужило причиной продвижения среднетаежных лесов к северу. В этот период изучаемую территорию занимали лиственничные леса с участием *Abies sibirica, Picea obovata* и *Pinus sibirica*. Северная граница ареала *Abies sibirica* проходила на 200 км севернее, чем в настоящее время. Начиная с 3600 кал. л. н. происходило изреживание лесного полога, формирование характерного для подзоны северной тайги мозаичного растительного покрова, состоящего из редкостойных лиственничных и березово-лиственничных лесов с примесью ели и сосны сибирской и безлесных местообитаний. Около 2600 кал. л. н. растительный покров стал близок к современному. Изучение макроскопических частиц угля в торфе показало, что пожарная активность на окружающей болото территории была низкой на протяжении всего изученного периода вплоть до последних 500 лет, за исключением крупного пожара около 3500–3600 кал. л. н. Увеличение поступления макрочастиц угля в конце XIV – начале XV вв. н. э., очевидно, связано с пожарами, обусловленными антропогенным фактором.

Ключевые слова: спорово-пыльцевой анализ, ботанический состав торфа, анализ макроскопических частиц угля, радиоуглеродное датирование, палеоклимат

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1. INTRODUCTION

The Holocene vegetation and climate history in polar regions increasingly attract attention of researchers because of their importance for better understanding of modern environmental processes and their anticipated changes (IPCC, 2019). Among the best possible lines of evidence for the impacts of paleoclimate changes on ecosystems in circumpolar regions as a model for better understanding their modern dynamics are the results of multiproxy studies of lakes and peatlands. Our paleoecological study is focused on the forest-tundra ecotone at the eastern edge of the West Siberian Lowlands.

Our study presents a new pollen, plant macrofossil and charcoal evidence for the last 4700 years from a peat sequence, located in vicinity of the town of Igarka (Turukhansky district, Kranoyarsk Region). Studies of peatlands in the Igarka region began in the middle of the last century (Orlov, 1962; Khomichevskaya, 1962; Konstantinova, 1963). Vegetation of different types of the mires located near Igarka was described by Katz (1948). Pollen and plant macrofossil data from peatlands with radiocarbon age of about 8000 years BP were obtained by Piavchenko (1955) and Levkovskaya (1973). A review of available data on the regional vegetation, peat stratigraphy and the Holocene dynamics of mires was presented by Vasilchuk et al. (2008).

The records obtained provided the first high-resolution reconstruction of the Late Holocene vegetation and fire history in the study area, confirmed by detailed radiocarbon dating. The main goal of the study was to identify the dynamics of the paleoenvironment on the eastern margin of the West Siberian Lowland and to compare new data with already available information on the main stages of climate change in the Arctic region of Russia.

2. STUDY AREA

The mire under study (unnamed, hereafter peatland Igarka-3) is located about 10 km northeast of the town of Igarka (N 67°31′53.77″E 86°38′05.65″). The peatland occupies the gently undulating moraine plain of the Ermakov (Late Pleistocene) glaciation close to the border between the moraine plain and the Late Pleistocene fluvio-glacial and alluvial valley, which is nowadays inherited by the valley of the Graviyka River, the right tributary of the Yenisei River (fig. 1).

The climate of the study area is sub-Arctic with long, severe winter and short summer (Beck et al., 2018). The mean annual air temperature is –7.8°C, the mean annual precipitation is 647 mm. The study area is located within the zone of continuous permafrost. Vegetation cover is represented by northern taiga open larch and spruce-larch woodlands with participation of Siberian pine and tree birch (*Betula pendula* Roth.). The soil cover is formed by turbic and histic cryosols. Peatlands with perennial frost mounds, known as palsas (Fewster et al., 2020), and peat plateaus are widespread.

The Igarka-3 peatland is a mosaic of permafrost mounds with a height of more than 4.5 m and a width of 50–100 m and flat, mostly unfrozen hollows, 200–300 m wide. The seasonally thawed layer of permafrost at mounds reached 50–52 cm. Lichens (70%) and feather mosses (20%) in combination with *Betula nana* L., *Ledum palustre* L., *Rubus chamaemorus* L. and bare peat as well, occupy the mounds, while various species of *Carex*, feather mosses and thickets of *Betula nana* are common within the hollows.

3. MATERIAL AND METHODS

Field work and peat coring were carried out at the end of August 2020. The core was extracted from an unfrozen hollow located between perennial frost mounds using a Russian peat corer with 50-cm inner chamber length and 5-cm diameter. Unfortunately, technical problems did not allow reaching the base of the peat deposits, so we only took the top 120 cm of the peat section. The peat core samples were wrapped in plastic and aluminum foil, then placed in boxes and stored at 4°C before further analyses. In the laboratory, the core was sub-sampled with 1-cm thick slices every 3 cm for plant macrofossil and pollen analyses, while continuous sampling in 1-cm thick slices was applied for macro-charcoal analysis.

Four bulk peat samples were dated by AMS radiocarbon analysis in the Laboratory of Radiocarbon Dating and Electronic microscopy of the Institute of Geography of the Russian Academy of Science (Moscow) and the Center for Applied Isotope Studies of the University of Georgia (USA). The ^{14}C dates were calibrated using the Calib 8.2 software and the calibration dataset Intcal 20 (Reimer et al., 2020). The age-depth model for peat core (fig. 2) was developed using the “Bacon” package (Blaauw, Christen, 2011) in the R language environment (R Core Team, 2014).

Samples for plant macrofossil analysis were disaggregated with water and washed through a 250 μm mesh sieve. The plant remains were identified using a binocular microscope at 200× magnification following Katz et al. (1977).

The samples for macroscopic charcoal analysis were prepared according to Mooney and Tinner (2011) using a sieve with a cell size of 125 μm. Charcoal concentration or charcoal counts (pieces cm^{-3}) were transfered into charcoal accumulation rates or influx (pieces cm^{-2} year^{-1}) by multiplying charcoal concentration by sediment accumulation rates (cm yr^{-1}) using the CharAnalysis software (Higuera et al., 2009) adapted for the R language environment (R Core Team, 2021). Through the application the CharAnalysis software we have determined the interpolated Charcoal Accumulation Rate (C_{int}) and a background signal (C_{back}). The charcoal peaks (i.e., local fire episodes) were defined as a residual ($C_{peak} = C_{int} - C_{back}$).

Peat samples for pollen analysis (1 cm^3) were treated following Moore et al. (1991). Heating for 10 minutes in 10% KOH solution was applied to remove humic material. Afterwards, the residue was sieved over 200 μm mesh and then acetolyzed with propionic anhydride (Mazei, Novenko, 2021). Pollen was identified using a Zeiss Axio Lab A1 microscope at 400× magnification following Reille (1992) and Beug (2004). Calculation of relative pollen frequency is based on the total terrestrial pollen sum, arboreal pollen (AP) plus non-arboreal pollen (NAP). Spores and non-pollen palynomorphs (NPP) were excluded. A minimum of 500 pollen grains (AP+NAP) per sample was counted.

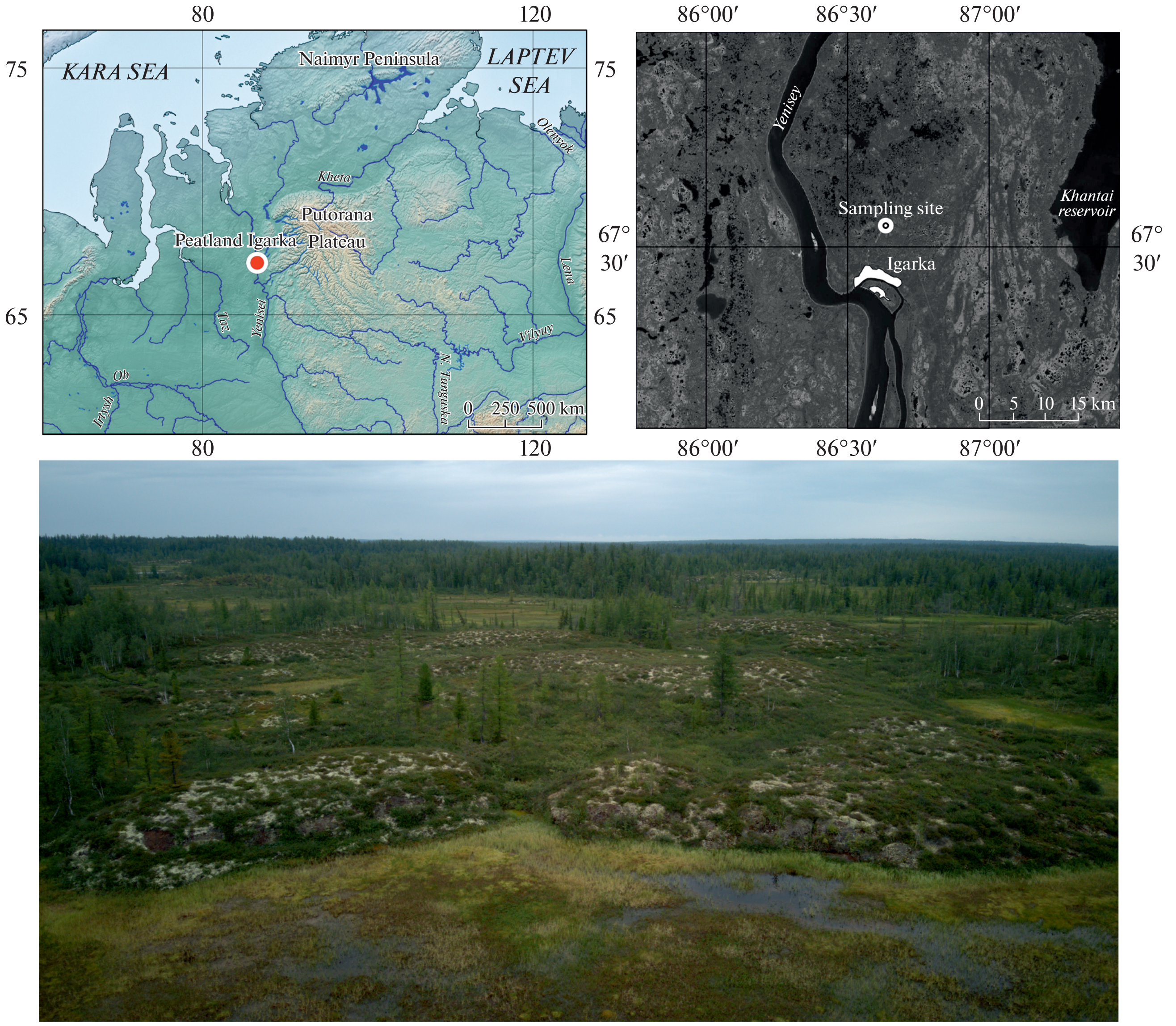

Fig. 1. Location of the study area and the sampling site: (a) – location of the study region; (b) – location of the study area and the sampling site; (c) – general view of the peatland.

Рис. 1. Положение района исследований и точки отбора образцов: (a) – положение изучаемого региона, (b) – положение изучаемого района и точки отбора образцов (космоснимок), (c) – вид на болото.

Pollen and plant macrofossil diagrams were constructed using Tilia and TGView software (Grimm, 1990). Zonation for pollen and plant macrofossil diagrams was performed by cluster analyses using CONISS tool in Tilia software (Grimm, 1987).

4. RESULTS AND INTERPRETATION

4.1. Peat accumulation rate. The age depth model (fig. 2) demonstrates rather fluent peat accumulation during the last ca. 4700 cal. years BP. The age of the peat sample from a depth of 120 cm is 4690 ± 50 cal. years BP (table 1), which corresponds to an average peat accumulation rate of 0.25 mm/year thus being quite consistent with Bleuten and Lapshina's (2001) reconstructions on the rates of vertical growth of peat in the peat bogs of the north of Western Siberia in the Late Holocene, varying from 0.09–0.10 mm/year in frozen mounds to 0.13–0.21 mm/year in thawed hollows and up to 0.48 mm/year in young sphagnum hummocks.

4.2. Plant macrofossil and peatland palaeoecology. The results of plant macrofossil analysis allows distinguishing 4 MAZs (macrofossil assemblage zones) (fig. 3), which characterize the main phases of mire evolution during the last ca. 4700 cal. years BP.

The first phase (MAZ 1; 120–112 cm/4700–4450 cal. years BP) is characterized by humified peat composed of the remains of feather mosses (*Paludella squarrosa* (Hedw.) Brid.) along with *Sphagnum girgen-*

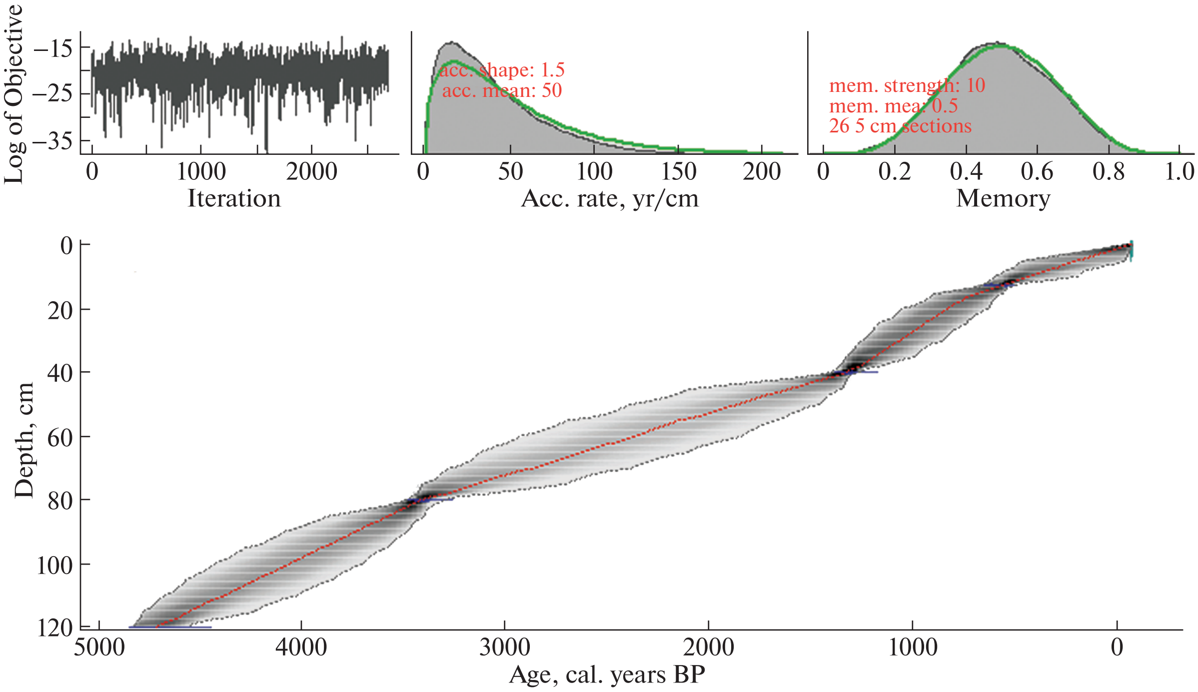

Fig. 2. Age-depth model for the peat core Igarka-3.
Рис. 2. Модель роста отложений скважины Игарка-3.

sohnii Russow and sedges. In the next phase (MAZ 2, 112–85 cm / 4450–3600 cal. years BP), the proportion of feather mosses (*Drepanocladus aduncus* (Hedw.) Warnst., *Meesia triquetra* (Jolycl.) Angstr.) and sedges (*Carex lasiocarpa*) increased, and the species, more sensitive to excessive moisture and minerotrophic conditions (Flora..., Chapter 1–2, 1979), such as *Paludella squarrosa,* became less abundant.

The beginning of the phase 3 (subphase 3a, 85–60 cm / 3600–2400 cal. years BP) is marked by an increase in the abundance of *Carex* species (*C. chordorrhiza* Ehrh., *C. lasiocarpa* Ehrh., *C. wuliica* Meinsh.) typical for wet thawed hollows (Flora..., Chapter 1–2, 1979). In addition to the high abundance of *Carex* species, plant macrofossil assemblages are characterized by alternating peaks of brown and feather mosses (*Drepanocladus* sp., *Scorpidium scorpioides* (Hedw.) Limpr., *Mnium cinclidioides* Huebener, *Meesia triquetra*) and *Calliergonella cuspidata* (Hedw.) Loeske. The abrupt rise of *Carex limosa* at a depth of 60–30 cm (subphase 3b; 2400–1070 cal. years BP) suggests very high surface wetness of the mire. At a depth of 30–12 cm (subphase 3c; 1070–540 cal. years BP), peat consists mainly of *Carex* (*Carex chordorrhiza*, *Carex lasiocarpa*) and *Eriophorum*.

Table 1. Results of radiocarbon dating of samples from Igarka-3 peat core
Таблица 1. Результаты радиоуглеродного датирования образцов из скважины Игарка-3

Laboratory code IGAN$_{AMS}$	Depth. cm	Material	^{14}C, BP (1σ)	Age, cal. years BP, 2 sigma (probability)
9151	12–13	plant rs.	550 ± 20	507–570 (0.528) 583–647 (0.472)
8351	40–41	TOC	1405 ± 20	1291–1317 (0.625) 1320–1346 (0.375)
8352	80–81	TOC	3190 ± 20	3373–3450 (1.000)
8353	120–121	TOC	4150 ± 20	4579–4603 (0.066) 4610–4733 (0.609) 4745–4823 (0.325)

TOC – total organic carbon; plant rs. – plant residuals.

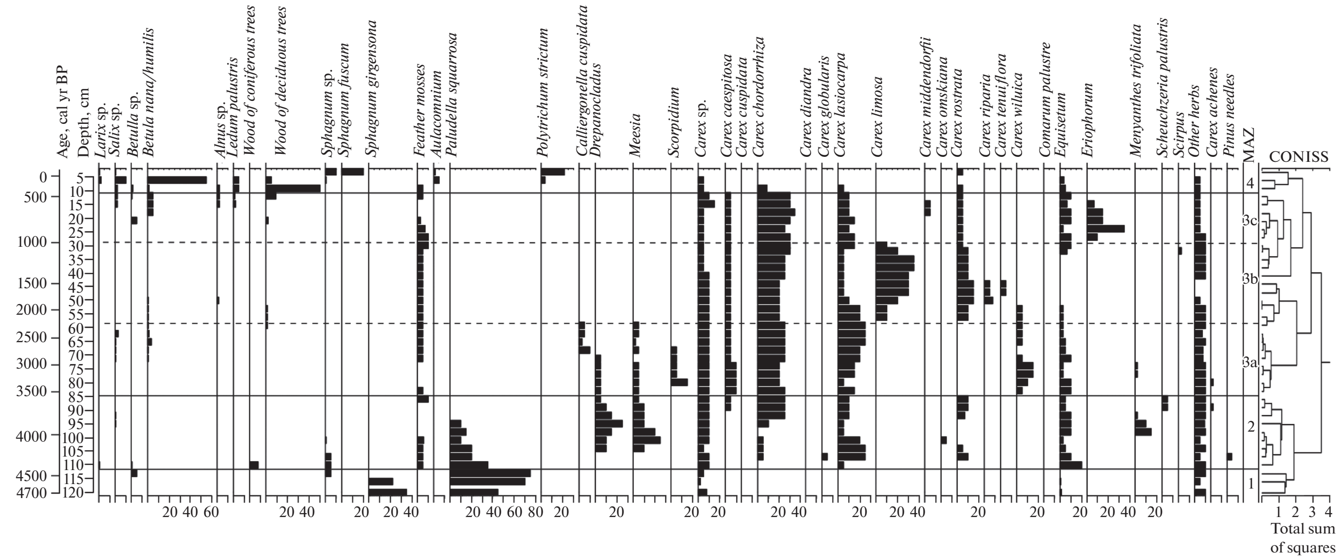

Fig. 3. Plant macrofossil diagram for the peat core Igarka-3.

Рис. 3. Диаграмма ботанического состава торфа скважины Игарка-3.

The beginning of phase 4 (MAZ 4, 12–0 cm / 540 cal yr BP – present) is marked by a dramatic changes in moisture conditions in peatland as evidenced by the appearance of *Polytrichum strictum* Brid. and *Sphagnum fuscum* (Schimp.) H. Klinggr. and abundance of wood remains of deciduous species, mainly *Betula nana* and *Salix*. The proportion of *Carex* remains reduced to a few percents. We suppose that a decrease in peatland surface wetness was caused by an uplift of the adjacent perennial frost mound. According to modern observations, the active growth of *Betula nana* shrubs together with *Rubus chamaemorus* and *Sphagnum* mosses, is characteristic of the marginal areas of the palsas, where such thickets of shrubs form ridges that border frost mounds (Preis, 2004).

4.3. Pollen analysis. Pollen assemblages are characterized by a high proportion of arboreal pollen (50–60%), composed mainly of *Pinus* and *Betula alba*-type with relatively high proportion of *Picea* in the lower part of the peat section. The overrepresentation of *Betula* and *Pinus* in pollen assemblages from larch sparse forests compared to their real share in the vegetation is a typical feature of the northern taiga of Siberia (Niemeyer et al., 2015). *Larix* pollen was not recorded in the Igarka-3 section in the interval of 85–120 cm, and in the rest of the section it ranges from 0.2 to 3%, which is in good agreement with the data on the percentage of *Larix* in surface samples from treeless regions and larch forests of northern Siberia (Klemm et al., 2013; Novenko et al., 2022). Pollen of broadleaved trees *Tilia* and *Ulmus* was found in the lower part of the peat core, however, we suppose that it was transferred by wind from remote regions.

The pollen diagram of the peat core was subdivided into 5 local pollen assemblage zones (LPAZ), each corresponding to the main phases of vegetation history (fig. 4).

Pollen assemblages of the LPAZ 1 (120–85 cm/4700–3600 cal. years BP) is characterized by a relatively high proportion of *Abies* (up to 12%), *Picea* (35–40%) and *Betula* alba-type (30–40%). Pollen values of *Pinus sibirica* vary from 10 to 20%, the occurrence of needle fragments from pine at the depth 110 cm suggests a local presence of *Pinus sibirica* in mire vegetation. Pollen of shrubs *Betula nana* and *Duschekia fruticosa* culminates at 5–10%. NAP group is dominated by Cyperaceae, while *Equisetum* is the most abundant among spores.

In the LPAZ 2 (85–60 cm/3600–2400 cal. years BP), the share of *Abies* and *Picea* decreased significantly at the expense of *Pinus sibirica* rising percentages up to 35–45%. In this zone, spores of Polypodiaceae, *Sphagnum* and *Lycopodium clavatum* were most frequently encountered.

The share of *Betula nana* and *Duschekia fruticosa* increases in the LPAZ 3 (subzone 3a, 60–45 cm, 2600–1600 cal. years BP). The beginning of the subzone 3a (45–12 cm/1600–540 cal. years BP) is marked by an increase in the content of pollen of *Betula alba*-type (up to 40–65%) and *Duschekia fruticosa*. The NAP-group becomes more diverse and its share in the pollen spectra is more significant. The Cyperaceae record on the diagram peaks at 20–30%, while the *Artemisia*, Poaceae and Rosaceae records do not exceed 1–5%. An increase in micro-charcoal along with single findings of Onagraceae pollen points to a burned area in the vicinity of the peatland.

Pollen assemblages of the LPAZ 4 (12–0 cm/540 cal. years BP – present) are characterized by a fur-

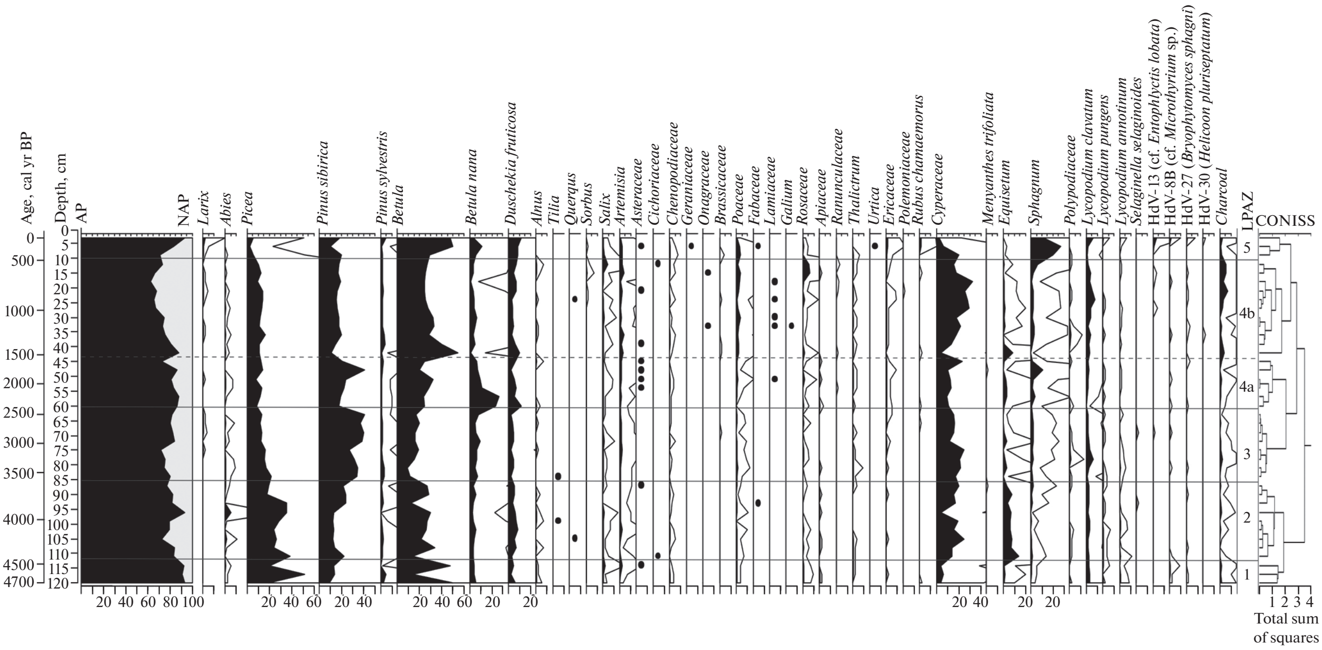

Fig. 4. Pollen diagram for the peat core Igarka-3. AP+NAP=100%. Additional curves represent ×10 exaggeration of base curves; black dots represent the presence of taxa <1%.

Рис. 4. Спорово-пыльцевая диаграмма отложений скважины Игарка-3. AP+NAP=100%. Дополнительный контур показывает увеличение базового таксона в 10 раз, точками показаны таксоны, содержание которых <1%.

ther increase in the pollen of both tree and shrub birches and *Duschekia fruticosa* as well. *Larix* pollen values increased up to 3%. *Rubus chamaemorus* and *Sphagnum* also peak. At the same time, the proportion of microscopic charcoal declined.

4.4. Macroscopic charcoal analysis. The reconstruction of the fire history from macro-charcoal data is based on the assumption that most charcoal particles with a size >125 μm were deposited at a distance inbetween several meters and 1–3 km from the fire place (Higuera et al., 2007; Conedera et al., 2009). Long-distance transport (from more than 3 km away) of macroscopic charcoal is an unlikely a pathway for particles to reach the sample plots.

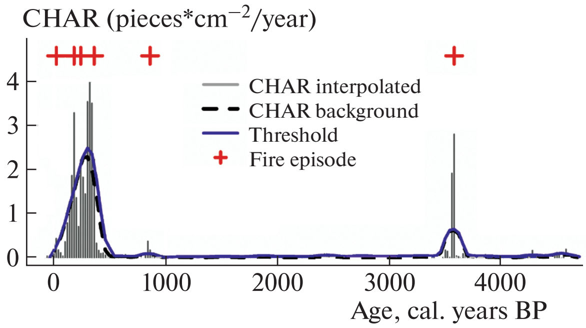

Fig. 5. Macroscopic charcoal accumulation rate in the peat core Igarka-3.

Рис. 5. Скорость аккумуляции макроскопических частиц угля в отложениях скважины Игарка-3.

The data obtained show that charcoal accumulation was low between 4700 and 500 cal. years BP, and background charcoal accumulation rate (C_{back}) did not exceed the value of 0.1 pieces cm^{-2} yr^{-1} with the exception of a distinct peak up to 0.7 pieces cm^{-2} yr^{-1} at 3600–3500 cal. years BP (fig. 5). Interpolated charcoal accumulation rate (C_{int}) shows several peaks in this time span with the highest one culminating at 2.9 pieces cm^{-2} yr^{-1}. It can be assumed that the fire record reflected not a single local fire episode, but, most likely, a whole series of forest fires in the vicinity of the Igarka-3 peatland, with a total duration of at least 100 years. Charcoal accumulation increased around 850 cal. years BP, and C_{back} and C_{int} raised to 0.2 and 0.4–0.5 pieces cm^{-2} yr^{-1} respectively. At 500 cal. years BP, background charcoal accumulation rate grew explosively to 2.5 pieces cm^{-2} yr^{-1}, and C_{int} reached 4 pieces cm^{-2} yr^{-1}. Since 150 cal. years BP, charcoal input gradually declined to a minimum. Over the past 500 years, four local fire episodes have been established with a frequency of once every 125 years.

5. DISCUSSION

Pollen, plant macrofossil and macro-charcoal archives obtained in the Igarka-3 peatland allowed establishing main phases of vegetation transformation and fluctuations in fire activity over the last ca. 4700 years.

Specifically, middle taiga larch forests with fairly significant share of *Abies sibirica*, *Picea obovata* and *Pinus sibirica* were widespread in the study area over the time span from 4700 to 3600 cal. years BP. Relatively high pollen values of *Abies* and *Picea* suggest the climate warming and northward shift of the boundary of the forest zone. Similar reconstructions in the framework of a case-study of the land-shelf interaction and the associated environmental changes were made on the basis of pollen data obtained from the inner shelf of the Laptev Sea adjacent to the Lena Delta (Rudenko et al., 2020). Most likely, forests were able to penetrate close to the sea coast along the river valleys due to milder and, perhaps, wetter local environments protected from harsh winds (MacDonald et al., 2000).

At present, northern taiga in the vicinities of Igarka is represented by sparse larch woodlands with the participation of tree *Betula*, *Picea* and *Pinus sibirica*, whereas the northern limit of *Abies sibirica* geographical range is about 200 km southward (Areals..., 1977). Therefore, a greater proportion of *Abies* pollen in fossil spectra, obviously, indicates more favorable climatic conditions. At the same time, part of the pollen of *Pinus* and *Abies* could have been wind-transported from the taiga region of Western Siberia; therefore, an increase in their share in pollen assemblages can be considered indirect evidence of an increase in the western transport of air masses.

Our reconstructions are in good agreement with chironomid-based reconstructions of the July temperature of lakes in the western part of the Putorana Plateau, which suggest a warmer and more maritime climate between 3900 and 3400 cal. years BP than at present (Self et al., 2015). Temperature reconstructions based on pollen records from Lama Lake in the northwest of the Putorana Plateau (Andreev et al., 2004) and Levinson-Lessing Lake in northern Taimyr (Andreev et al., 2003) also show several positive temperature anomalies for July inbetween 4700 and 3600 cal. years BP.

From 3600 cal. years ago, the forest canopy was gradually reduced to such an extent that the middle taiga was replaced by larch woodlands with spruce, pine and some herbs typical of the northern taiga. *Pinus sibirica* dominates pollen assemblages between 3600 and 2600 cal. years BP and pollen of *Pinus silvestris* is also found in small quantities (up to 5–10%), although it currently grows about 300 km south of the study area (Areals..., 1977). According to ecological conclusions based on the study of subrecent pollen assemblages in Northern Siberia (Klemm et al., 2013; Niemeyer et al., 2015; Novenko et al., 2022), in sparse or open plant communities, i.e., where the proportion of wind-transported pollen is higher, both pine species reach maximum values. Besides, the spread of *Pinus sibirica* in plant communities could have been facilitated by higher fire activity between 3600 and 3500 cal. years BP.

Climate deterioration in *ca.* 2700–2500 cal. years BP time span, as evidenced by a number of proxy data from the polar regions (Mayewski et al., 2004; PAGES 2k Consortium, 2013; Toschev, 2013), in Igarka vicinities could have led to the degradation of the dark coniferous taiga due to its displacement by sparse larch-birch woodlands and shrub communities with a predominance of *Betula nana* and *Duschekia fruticosa*. After this, the changes in vegetation pattern were already insignificant, it approached the modern one. The time-coeval pollen data from the more northern coastal regions of Taymyr Peninsula (Andreev et al., 2004) and even further to the northeast, including the coastal regions of the East Arctic seas (Razina et al., 2007; Rudenko et al., 2020 and references therein) also testify to the stabilization of the boundaries of vegetation zones precisely at this time. Further vegetation changes were, obviously, caused by local processes of peatland development such as palsa uplift and subsequent degradation.

According to charcoal data, fire activity in the study area was low between 4700 and 500 cal. years BP, with the exception of one strong fire episode that occured 3600–3500 cal. years ago. As both macro- and microscopic charcoal records indicate, biomass burning increased to the end of 14th – the beginning of 15th centuries AD. Historical chronicles of the Russian colonization of this part of Siberia reported an appearance of Russian settlers in the 17th century (PAGES 2k Consortium, 2013), but a local hunter population around Igarka were already found by the first travelers. Agreeing with (Novenko et al., 2022), we assume, that increase of biomass burning during 14th – 15th centuries was caused by human-induced fires, as the settlement is situated on the banks of the Yenisei River, which historically was one of the main trading routes in Siberia.

The development of the timber industry complex and the construction of a river harbor in Igarka in the 20th century were, undoubtedly, accompanied by active deforestation. A rise of *Betula* pollen values in the uppermost pollen assemblage zone suggests the extension of secondary birch forests and vegetation successions after fires and clear cutting. Charcoal input declined noticeably indicating the low fire activity. However, we detected several burned areas adjacent to the town of Igarka during the field work in August 2020.

6. CONCLUSIONS

The results of radiocarbon dating, as well as data on spores, pollen, plant macrofossil and charcoal macroscopic remains from the Igarka-3 peat bog allowed reconstruction of late Holocene vegetation changes in a remote and extremely poorly studied region of Yenisei Siberia. Our main conclusions are as follows:

1. During the period from 4700 to 3600 cal. years BP the eastern margin of the West Siberian Lowland was occupied by middle taiga larch forests with a high proportion of *Abies sibirica*, *Picea obovata,* and *Pinus sibirica*. Climate warming caused the northward shift of the boundaries of the vegetation zones in the Yenisei Siberia and the expansion of *Abies sibirica* range by 200 km to the north compared to the modern one.

2. Since ca. 3600 cal. years BP, the forest cover decreased gradually, and the middle taiga vegetation was replaced by sparse larch and birch-larch forests with the participation of spruce and Siberian pine and treeless vegetation characteristic of the northern taiga zone. Climate cooling, which was especially pronounced starting from 2600 cal. years ago, led to a degradation of dark coniferous forests in the study area due to the expansion of larch-birch woodlands and shrub communities dominated by *Betula nana* and *Duschekia fruticosa*.The vegetation pattern of the region became close to the modern one at around 2600 cal. years BP.

3. Fire activity in the area around Igarka was low between 4700 and 500 cal years BP, with the exception of one strong fire episode that occured 3600–3500 cal. years ago. Biomass burning increased in the late 14th – the beginning of 15th centuries AD, obviously, due to the increased scale of anthropogenic impact.

Vegetation Changes in Yenisei Siberia Over the Last 4700 Years: New Palaeoecological Data From Igarka Area, Krasnoyarsk Region

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The paper deals with new palaeoecological reconstructions for the last *ca.* 4700 years based on detailed AMS-radiocarbon dating, pollen, plant macrofossils and macroscopic charcoal records from peat sequence, obtained from the mire near Igarka (Yenisei Siberia). The data obtained testify to the widespread of middle taiga larch forests with a high proportion of *Abies sibirica, Picea obovata* and *Pinus sibirica* over the study area between 4700 and 3600 cal. years BP. Climate warming caused the northward shift of the boundaries of the vegetation zones in the Yenisei Siberia and the expansion of *Abies sibirica* range by 200 km to the north compared to the modern one. Starting from *ca.* 3600 cal. years BP the forest cover began to gradually decrease, and the middle taiga vegetation gave way to sparse larch and birch-larch forests with the participation of spruce and Siberian pine and treeless vegetation characteristic of the northern taiga. The vegetation pattern of the region became close to the modern one around 2600 cal. years BP. Macroscopic charcoal analysis revealed that biomass burning was low until the last 500 cal. years, with the exception of an episode of a strong fire 3600–3500 cal. years BP. Fire activity intensified in the late 14th and early 15th centuries AD, obviously due to anthropogenic impact.

Keywords: pollen analysis, plant macroremains, macroscopic charcoal analysis, radiocarbon dating, paleoclimate

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