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РЕКОНСТРУКЦИИ НА ОСНОВЕ ПАЛЕОБИОЛОГИЧЕСКИХ МЕТОДОВ

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ИЗМЕНЕНИЯ ОКРУЖАЮЩЕЙ СРЕДЫ ТЕРСКОГО БЕРЕГА БЕЛОГО МОРЯ (КОЛЬСКИЙ ПОЛУОСТРОВ) В ГОЛОЦЕНЕ ПО ДАННЫМ КОМПЛЕКСНОГО ИЗУЧЕНИЯ БОЛОТА КУЗОМЕНСКИЙ МОХ

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Реконструированы процесс заболачивания и история развития растительности за последние 8000 лет в западной части Терского берега (юг Кольского полуострова), в устье реки Варзуга по данным комплексного изучения торфяника Кузоменский Мох. Исследования включали спорово-пыльцевой и ботанический анализы торфа, измерения потерь при прокаливании, AMS радиоуглеродное датирование и морфоскопию песчаных кварцевых зерен. Установлено, что после дегляциации на территории исследований действовали эоловые процессы, позже сменившиеся заболачиванием. Согласно данным анализа морфоскопии песчаных кварцевых зерен, отложения, подстилающие торфяную толщу, имеют ледниковый и водно-ледниковый генезис, но впоследствии песчаные зерна частично были переработаны эоловыми процессами, на что указывают характерные текстуры на их поверхности, связанные с переносом частиц в воздушной среде. Накопление торфяной залежи началось не позднее 7865 ± 45 кал. (календарных) л. н., что может служить признаком затухания эоловых процессов на окружающей территории. На основе ботанического анализа торфа выявлены этапы эволюции болота от эвтрофной до олиготрофной стадии и показано, что развитие локальной растительности болота, очевидно, находилось под влиянием пожаров в период между 7800 и 2700 кал. л. н. Результаты спорово-пыльцевого анализа показали, что история растительности западной части Терского берега Белого моря в течение последних 8000 лет включала серию чередующихся фаз распространения березовых, сосново-березовых и сосновых лесов. Долгопериодная динамика растительности, возможно, была обусловлена изменениями климата и пожарной активности. Ель появилась в лесных сообществах изучаемой территории около 7000 кал. л. н., в течение последних 200 лет ее обилие в древостоях сократилось в результате антропогенного воздействия на растительный покров и пожаров.

Ключевые слова: Кольский полуостров, заболачивание, палеоклиматические реконструкции, спорово-пыльцевой анализ, ботанический состав торфа, морфоскопия песчаных кварцевых зерен

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1. INTRODUCTION

The Kola Peninsula is one of the key areas for the study of the postglacial development of the natural environment in Northern Europe. Pleistocene glaciations have shaped the topograpy, Quaternary deposits, and modern landscapes of the peninsula. Numerous (geological, geomorphological, paleogeographical, botanical, etc.) studies have been carried out on Tersky Coast of the White Sea since the 19th century. They have produced important data on the ice sheet extensions, marine transgressions, the soil cover, etc. (Lavrova, 1947, 1960; Belov, Baranovskaya, 1969; Koshechkin, 1979; Evzerov et al., 1981; Zhirov et al., 2006; Korsakova et al., 2011; Kolka et al., 2013; Repkina et al., 2020, 2021). Nevertheless, a lot of issues of the environmental history and evolution of landscapes during postglacial time and the Holocene remain unclear. The presented study was focused on Kuzomen Sands – one of the most extensive and poorly investigated aeolian massifs in the north of European Russia, situated on a large (ca. 10 km long, ca. 3 km wide) spit in the Varzuga River mouth. Apart from aeolian deposits, lake sediments and peat sequences are quite

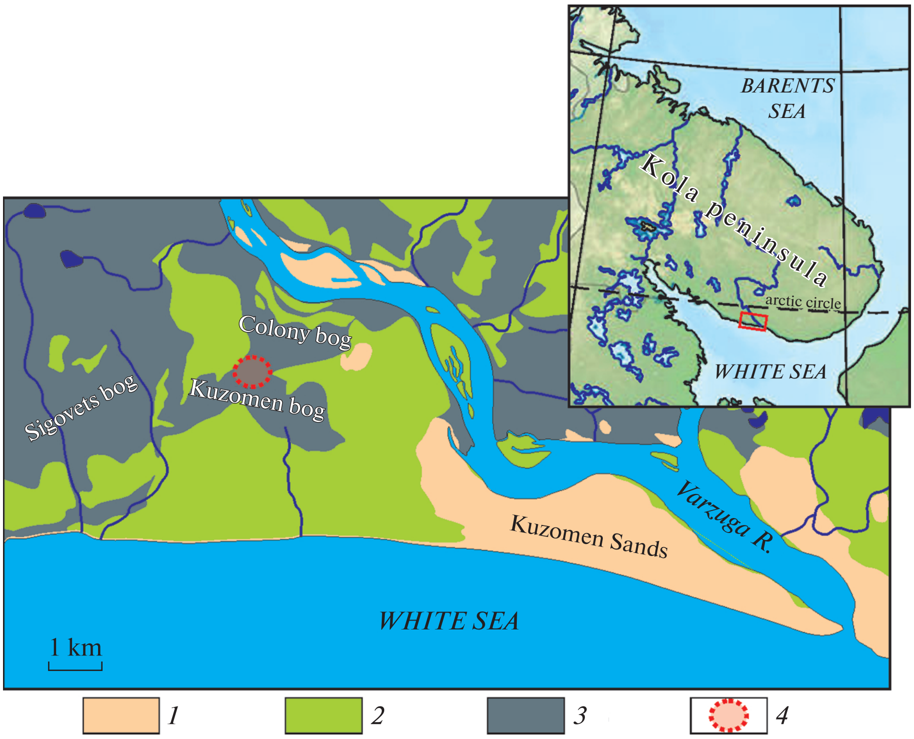

Fig. 1. Study area. *1* – turf-free sites; *2* – vegetated sand sites; *3* – peatlands; *4* – sampling site.
Рис. 1. Район исследований. *1* – незадернованные участки; *2* – песчаные участки с растительностью; *3* – торфяники; *4* – места отбора проб.

common here. Peatlands are important natural archive, containing rich and reliable information about past environment and climate changes. However, most of the paleobotanical data was obtained from peatlands located in the north-western and in the central parts of the Kola Peninsula (Elina et al., 2000; Matishov et al., 2005). The peatlands of the Tersky Coast remain poorly studied. Our study provides the first paleoecological evidence for the last 8000 years based pollen and plant macroremains analyses, loss on ignition measurements, AMS radiocarbon dating of the peat, and quartz grain morphoscopy analysis for sandy deposits underlying the peat sequences in the Kuzomen Mokh peatland located between aeolian dunes.

2. STUDY AREA

The study area is situated within Tersky District of the Murmansk Region, which stretches along the White Sea southern coast, roughly from Porja Guba Bay in the west to Cape Svyatoy Nos in the east. The area is quite uniform orographically – rolling hilly plain in the north and north-west and gently rolling plain in the east abundant in mires and paludified sites (fig. 1). In the relief of the sea coast the marine abrasion terrace with a height of 50–65 m is clear determined. The flat surface of this terrace is occupied by wide (above 16 km in length) Sigovetsky Moch peat bog. The marine abrasion terrace gently declines eastward gradually turning to the accumulative marine terrace, with a height of 20–30 m. Aeolian forms of relief as dunes and ridges with a relative height of up to 10–12 m are widespread on this terrace. From the north, the marine abrasion terrace is cut off by the Varzuga River Valley with river accumulative terraces with a height of 7–15 m and 1–4 m. The alluvial deposit of river terraces are affected by intensive aeolian processes. The Kuzomen Mokh peatland is located in the depression between dunes on the marine abrasion terrace at elevation of 20–26 m. This mire could be defined as western part of large peatland massive Sigovetsky Moch, located at the higher elevation.

The climate in Tersky District is of subarctic type, but notably warmer and milder than at the same latitudes in eastern Eurasia. Mean annual temperature is around 0°C. Mean annual precipitation is 500–600 mm (Atlas..., 1971). The coldest month of the year for the entire area is February and the warmest month is July (Zhirov et al., 2006).

The study area is situated in the northern taiga subzone and is part of the Umbozero geobotanic sector (Geobotanicheskoe..., 1989), where different types of pine forests cover 39.6% or the area, spruce forests – 29.4%, and mires – 31.0% (Payanskaya-Gvozdeva, 1990). The soils in the study area are psammozem, over aeolian deposits and coastal sand with a sparse

Table 1. Results of ^{14}C dating
Таблица 1. Результаты ^{14}C-датирования

Lab. No.	Sample depth, cm	Conventional ^{14}C age, years BP	Calibrated age, years BP
8533	25	1440 ± 20	1330 ± 15
8534	40	3125 ± 20	3340 ± 40
8535	60	4015 ± 25	4475 ± 35
8536	85	4525 ± 25	5170 ± 80
8537	92	4920 ± 20	5635 ± 25
8538	110	5560 ± 25	6350 ± 30
8539	130	6000 ± 25	6835 ± 40
8541	185	7025 ± 25	7865 ± 45

natural plant cover. The soils under forest vegetation are podzol illuvial-glandular (Kazakov et al., 2009).

3. FIELDWORK

Several boreholes were drilled and two sample plots were located in Kuzomen Mokh peatland (eastern margin of the Sigovets Mokh mire area) situated on the right-hand bank of River Varzuga (fig. 1). The 2.0–2.5 m thick peat sequences is underlain by sand deposits. Drilling was carried out by the Edelman peat drill of the EIJKELKAMP company, with a sampler length of 50 cm and a diameter of 5 cm.

Borehole KUZ-1 (66°18′43.9″ N 036°41′58.4″ E) was sampled for plant macrofossil and palynological analyses and for radiocarbon dating, and KUZ-3 excavation (66°18′43.9″ N 036°41′54.4″ E) – for carpological analysis and for radiocarbon dating. Samples for quartz sand grain morphoscopy were collected from the sand deposits underlying the peat.

4. LABORATORY METHODS

Radiocarbon dating of samples from the borehole and the excavation was performed at the Centre of Collective Usage “Laboratory of radiocarbon dating and electronic microscopy” of the Institute of Geography of RAS (Moscow, Russia) and at the Center for Applied Isotope Studies at the University of Georgia, USA. 8 AMS-radiocarbon dates were obtained. The calibrated age of the dated samples were calculated in OxCal software (https://c14.arch.ox.ac.uk/oxcal.html) using the IntCal20 calibration curve (Reimer et al., 2020). Results of radiocarbon dating are given in the table 1. Age-depth models were developed using the Clam 2.2 package (“classical” age-depth modeling (Blaauw., 2010)) in the R language environment.

Loss on ignition (LOI). LOI 550°C is a measure of organic matter content (Bengtsson, Enell, 1986; Heiri, 2001). Samples from the peat core (sample volume was 10 cm^3, sampling interval was 5 cm) were dried for 12 hours at 105°C to remove moisture (incl. hygroscopic moisture) and then burnt at 550°C for 4 hours. Weight losses were measured by re-weighing with electronic balance with up to 0.01 gram precision. The LOI values were calculated as follows:

$$LOI550 = \frac{DW105 - DW550}{DW105} \times 100,$$

where DW is dry weight.

Analysis of *quartz sand grain morphoscopy* (surface texture and roundness) was performed for 0.5–1.0 mm grains using an integrated technique developed at the Institute of Geography RAS (Velichko, Timireva, 1995). This approach has been widely used up to the present (Timireva, Velichko, 2006; Velichko et al., 2009, Sizikova, Zykina, 2015; Kalinska-Nartisa et al., 2017; Velichko et al., 2017; Panin et al., 2019; Sheinkman et al., 2021). The roundness of quartz grains was estimated using the five-grade scale of A.V. Khabakov (1946) and patterns of L.B. Rukhin (1969). The roundness coefficient was then calculated following R.D. Russel and R.E. Taylor (1937). The grain surface type and degree of surface dullness (glossy to matted) was estimated using the modified method of T.A. Salova (Kuzmina et al., 1969).

Plant macroremains analysis. 39 samples we collected from the borehole KUZ-1; samples were taken with 5 cm interval. The laboratory treatment of samples, calculation of the percentages of peat-forming plant remains and determination of the degree of peat decomposition (R) were carried out using M. Korotkina (1939) and C. Minkina and P. Varlygin (1939) techniques. Plant macroremains were identified following Kats et al. (1977) and reference collections of the Mire Ecosystems Laboratory of the Institute of Biology KarRC RAS. Samples for carpological analysis (identification of subfossil seeds and fruits) were collected to obtain additional paleobotanical data. As such studies require greater volume of samples, peat samples were collected from the KUZ-3 excavation, 10 meters west of the KUZ-1 borehole, from 15–150 cm depth as a continuous series every 5 cm. At depths from 150 cm to 200 cm (the bottom of the peat and transi-

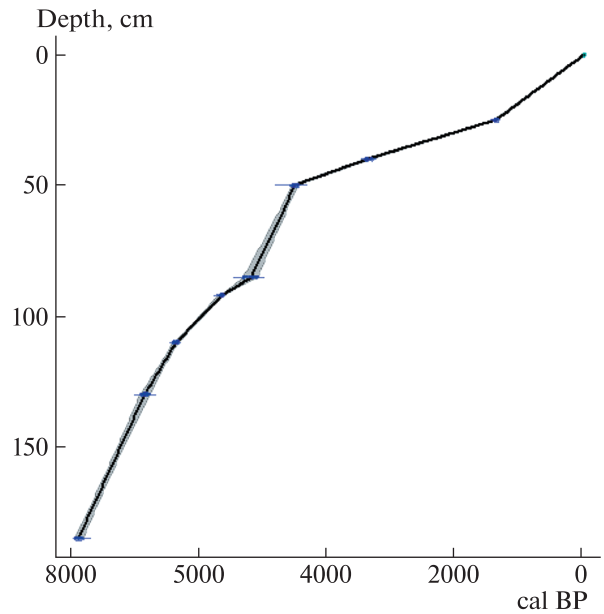

Fig. 2. Age-depth model for the KUZ-1 peat core, based on the calibrated ^{14}C dates shown in table 1.

Рис. 2. Модель роста торфяных отложений болота Кузоменский Мох (по керну KUZ-1), основанная на калиброванных радиоуглеродных датах, показанных в табл. 1.

tion to sand), samples were taken from the core every 10 cm. In total 32 samples were collected and analyzed. Plant remains were extracted by the procedure suggested by V.P. Nikitin (1969). Carpological remains were picked out using stereomicroscope Altami CM-T and identified following atlases (Dombrovskaya et al., 1959; Kats et al., 1965; Digital Plant Atlas, 2006).

Samples for *pollen analysis* were taken from the core (KUZ-1 borehole) with 4 cm sampling interval. Sample series included 47 peat samples and 3 samples of sand with plant detritus admixture. The sampling preparation included treatment with 10% HCl, boiling in 10% KOH solution, separation with heavy liquid using a modified method of Grichuk (1948), and acetolysis with propionic anhydride (Mazei, Novenko, 2021). Reference keys were used for pollen and spore identification (Moore et al., 1991 etc.). Pollen and plant macroremains diagrams were plotted using TILIA, TILIA GRAPH, and TGView software (Grimm, 2004, 2011). Pollen zones were distinguished using the CONIS procedure in the TILIA program (Grimm, 2011). Pollen percentages were calculated based on total terrestrial pollen, which included arboreal pollen (AP) and non-arboreal pollen (NAP), but excluded spores.

5. RESULTS

Morphoscopic analysis of 0.5–1.0 mm quartz sand grains from the sandy deposits underlying the peat showed the grains had diverse surface textures and roundness. There stands out a large group of grains of glacial and fluvioglacial genesis with glossy surface and with traces of active mechanical weathering in the form of chipping, dents, cracks, conchoidal surfaces. The second group of grains is associated with aeolian transport. Quartz grains in this group are rounded, their surface is covered in small pits formed by collision of particles in the air. The surface is matted or half-matted. Importantly, traces of aeolian impact are seen on many grains but only on their protuberant parts indicating that this was not a lasting process. The sand grains were apparently transported over relatively short distances. Grain roundness was 57.5% and dullness was 35%. Morphoscopic analysis of quartz sand grains from the deposits underlying the peat body points to glacial and fluvioglacial genesis of the sand grains, which were then engaged in air transport, the result being aeolian textures on grain surface.

Chronology and peat accumulation rates. The results of radiocarbon dating (table 1, fig. 2) show that peat accumulation started around 7800 cal yr. BP. The lower part of peat core (depth 185–100 cm; 7800–5600 cal yr. BP) features by relatively high peat accumulation rates around 0.4–0.5 mm/yr Between 5600 and 5200 cal yr. BP the peat vertical growth decreased to 0.2 mm/yr in and increased again to 0.5 mm/yr during the period 5200–4400 cal yr. BP. The peat accumulation rate was relatively low (0.07–0.09 mm/yr) between 4400 and 1300 cal yr. BP and increased to 0.2 mm/yr during the last 1300 years.

Plant macroremains analysis and LOI. The following types of peat were revealed in the borehole KUZ-1:

Depth 195–185 cm: transition from underlying sand to highly decomposed (over 50%) eutrophic peat. Samples contain scanty plant macroremains, which are mostly represented by epidermis of *Eriophorum vaginatum* and sedges (*Carex lasiocarpa*, C. *rostrata*). Peat is mixed with sand. At the depth of 195–190 cm, LOI values were the lowest entire the peat core, indicating a high content of mineral matter in the deposits. At the depth 185 cm, LOI values increase sharply, signifying the onset of peat accumulation (fig. 3).

Depth 185–160 cm: mesotrophic peat. The lower (15 cm) part of this layer is formed by the shrub- *Eriophorum* – *Carex* peat. *Salix* contributes 10–20% of macroremains, *Betula* – 5–10%, Ericales – 5%. Further up, the content of shrub and *Carex* macroremains decreases sharply while the percentages of dwarf shrubs and Sphagna increase. The upper layer of the *Eriophorum -Sphagnum* peat contains 40% of *Sphagnum* and 10% of Ericales remains. The degree of peat decomposition decline to 30–40%. LOI rises to 99%, indicating very low content of mineral matter in the peat.

Carpological remains from the lower part of the peat (190–170 cm depth) in the KUZ-3 section were represented by numerous sedges achenes (*Carex ros-*

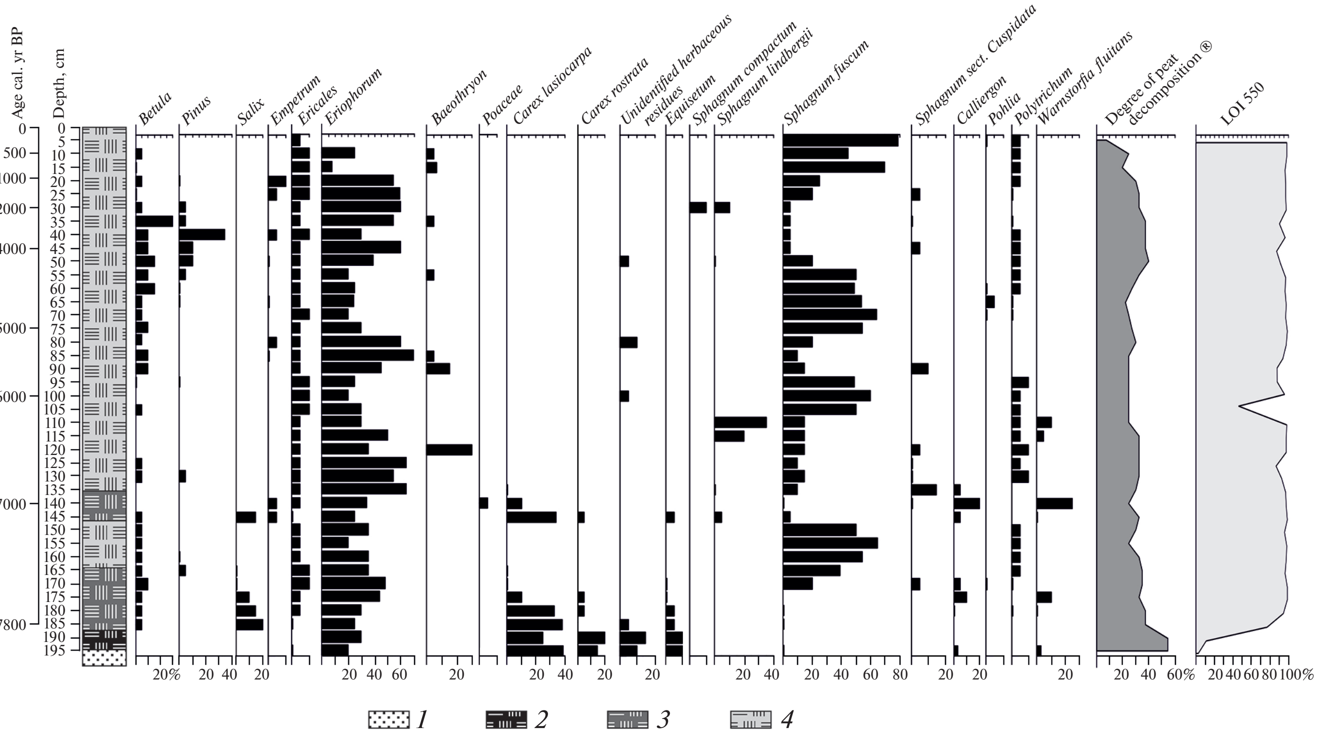

Fig. 3. Diagram of peat forming plant macroremains from the Kuzomen Mokh peatland (Kuz-1 borehole). *1* – Sand; *2* – eutrophic fen peat; *3* – mesotrophic peat; *4* – oligotrophic raised-bog peat.

Рис. 3. Диаграмма ботанического состава торфа Кузоменский Мох (скважина Kuz-1). *1* – песок; *торф: 2* – низинный, *3* – переходный, *4* – верховой.

trata, C. cf. *elata*, C. *cespitosa*) and *Andromeda polyfolia* seeds (fig. 4).

Depth: 160–145 cm: oligotrophic *Eriophorum-Sphagnum* peat dominated by *Sphagnum fuscum* remains. The degree of decomposition decreases to 25–35%, LOI values are high (96–98%).

Depth: 145–135 cm: an interlayer of mesotrophic peat (*Salix-Eriophorum-Carex* and *Eriophorum*-brown moss peat). The degree of decomposition and LOI remain almost the same as in the underlying deposits.

Depth: 135–5 cm: oligotrophic raised-bog peat; the composition of peat-forming plant remains changes somewhat with depth. Layers of *Eriophorum* and *Eriophorum-Sphagnum* peat alternate in the 135–60 cm interval. The 60–35 cm interval features a growing contribution of tree macroremains (woody-*Eriophorum* and woody-*Sphagnum* peat). At the depth of 35 cm, there is a high content of *Betula* macroremains (35%). At the depth of 55–25 cm, the peat contains *Pinus* macroremains. They reach their maximum amount (35%) in the interval of 40–35 cm. Upper peat layers contain a high amount of *Eriophorum* and *Sphagnum* (*S. fuscum* – up to 80%). Percentages of Ericales macroremains varies from 5 to 10% throughout the oligotrophic peat unit. Their seeds were iden-

Fig. 4. Carpological remains from KUZ-3 section. *1* – *Carex* cf. *elata* (achene), *2* – *C. rostrata* (achene), *3* – *C. cespitosa* (achene), *4* – *Andromeda polyfolia* (seed), *5* – *Empetrum* sp. (seed). All scale bars are 1 mm.

Рис. 4. Карпологические остатки из расчистки KUZ-3. *1* – *Carex* cf. *elata* (семянка), *2* – *C. rostrata* (семянка), *3* – *C. cespitosa* (семянка), *4* – *Andromeda polyfolia* (семя), *5* – *Empetrum* sp. (семя). Масштабная линейка – 1 мм.

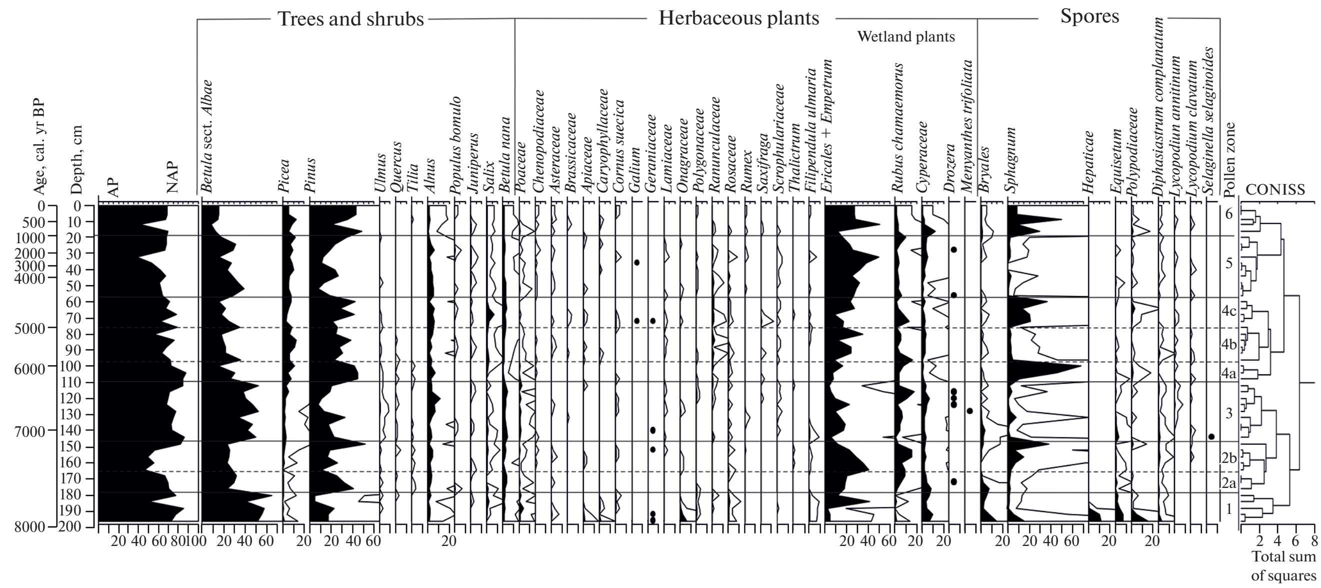

Fig. 5. Pollen diagram of the Kuzomen Mokh peatland (Kuz-1 borehole). Arboreal and selected non-arboreal taxa; additional curves represent ×10 exaggeration of base curves.

Рис. 5. Пыльцевая диаграмма торфяника Кузоменский Мох (скважина Kuz-1). Дополнительные кривые показывают увеличение содержания базового таксона в 10 раз (AP + NAP = 100%).

tified as *Andromeda polyfolia* and *Chamaedaphne calyculata* those are the typical raised bog dwarf shrubs. These seeds were found in almost all studied samples from oligotrophic peat unit in the KUZ-3 section. Few seeds of *Empetrum* sp. were noted (fig. 4) in the samples from the uppermost layers of peat. It should be noted, that oligotrophic peat is usually poor in carpological remains (Nikitin, 1969).

The degree of peat decomposition varies from 25% to 40%. The relatively low value of peat decomposition (25%) is revealed in *Eriophorum* and *Eriophorum-Sphagnum* peat layers between 110 and 85 cm. In the uppermost layer of peat sequences (10 cm) the peat decomposition degree drops to 5–10%.

Peat at the depth of 45–40 cm and 135 cm is mixed with fine sand that is succeed by the decrease of LOI values to 86–90%. An abrupt drop of LOI value up to 48% was determined in the sample from 100–105 cm depth. Plant macroremains percentages and degree of peat decomposition at this level exhibited no significant changes.

Pollen analysis. The pollen diagram (fig. 5) was divided into 6 local pollen assemblage zones (LPAZ). Calculating using the age-depth model (fig. 2) allowed us to determine the age (cal yr. BP) of local pollen zones in the diagram and to attribute them with the chronological subdivisions of the Holocene period in Northern Eurasia suggested by N.A. Khotinsky (1977, 1987).

LPAZ-1 (196–178 cm, ca. 8000–7700 cal yr. BP) was dominated by arboreal pollen (70–85%) mainly by *Betula* (50–60%) and *Pinus* (10–20%) with a small proportion of *Alnus* and shrubs (*Salix, Juniperus, Betula nana*). Rare pollen grains of *Ulmus* and *Quercus* (0.4%) were registered in the upper part of the zone. The share of NAP varies between 20 and 40%, pollen curve of dwarf shrubs (Ericales and *Empetrum*) forms a distinctive peak up to 35% at the depth 180 cm. Herbaceous plants were represented by Cyperaceae, Poaceae, as well as Apiaceae, Asteraceae, Polygonaceae, Ranunculaceae, Rosaceae, *Rubus chamaemorus*, Scrophulariaceae and other herbs. Caryophyllaceae, Geraniaceae, Onagraceae pollen was frequent in the lowermost samples taken from the transition from sand to peat. Spores (*Sphagnum*, Bryales, Hepaticae, *Equisetum*, *Diphasiastrum complanatum*, Polypodiaceae) are abundant in the lower part of the zone (50–60% compared to sum of AP+NAP) and gradually decline toward its upper boundary. Concentration of pollen and spores in samples from sand layer is low and it sharply increased in the peat. We suggest that the LPAZ-1 formed during the early-middle Atlantic phase of the Holocene.

LPAZ-2 (178–144 cm, 7700–7100 cal yr. BP) is characterized by the increase of *Pinus* pollen (25–45%) and the reduction of *Betula* sect. *Albae* percentages (20–30%). AP values remained high (80–85%) in subzone 2a (178–164 cm) and decreased to 55–60% in subzone 2b (164–144 cm). Pollen of broadleaved trees (*Ulmus*, *Quercus*, and *Tilia*) occurred sporadically, while their amount does not exceed 0.8%. Ericales and *Rubus chamaemorus* were the most abundant among NAP and formed noticeable peaks in the subzone 2b up to 35–40% and 18–20% respectively. In the group of spores Hepaticae and *Equisetum* disappeared, while

Sphagnum achieved the maximum in the subzone 2b up to 40%. *Sphagnum* spores were obviously belonged to *S. fuscum*, whose macroremains reached 40–65% among peat forming plants in this layer. According to the age-depth model the LPAZ-2 was formed in the middle Atlantic phase of the Holocene.

LPAZ-3 (144–108 cm, 7100–6300 cal yr. BP) is marked by increase of tree pollen values (85–90%) mainly due to *Betula* sect. *Albae* (40–50%). The proportion of *Pinus* varied between 10 and 25%, *Picea* and *Alnus* pollen values grew to 3–5% and 10–12% respectively. The share of broadleaved tree pollen does not exceed 1% in total, with *Ulmus* contributing 0.4–0.7%, while *Quercus* and *Tilia* pollen occurring sporadically. The NAP group was formed mainly by wetland plants: Ericales (10–20%), *Rubus chamaemorus* (5–15%) and Cyperaceae (7–10%). Pollen of *Drosera* and *Menyanthes trifoliata* were registered. The proportion of spores was relatively low compared to the previous zone. Spores of *Lycopodium clavatum* and *L. annotinum* appeared in this zone and further formed the continuous curves throughout the peat core. Single spore of *Selaginella selaginoides* was found. The LPAZ-3 is attributed to the late Atlantic phase of the Holocene.

LPAZ-4 (108–56 cm, 6300–4600 cal yr. BP). Pollen values of *Pinus* and *Picea* increased to 40–50% and 10–15% respectively. Since the lower boundary of the LPAZ-4 *Picea* formed the remarkable curve in the pollen diagram. The proportion of *Betula* sect. *Albae* reduced to 20–30%. Percentages of broadleaved trees declined and at the upper boundary of the PAZ-4 their pollen disappeared from assemblages. The share of *Alnus* varied between 3 and 10%, these of *Salix* and *Betula nana* slightly increased. Herbaceous pollen was diverse (Poaceae, Asteraceae, Polygonaceae, Ranunculaceae, Rosaceae, *Saxifraga*), however wetland plants dominated (Ericales (10–40%), *Rubus chamaemorus* (5–15%) and Cyperaceae (7–10%)). The composition of spores allowed us to divide the LPAZ-4 into 3 parts. The subzones 4a (108–96 cm) and 4c (76–56 cm) were marked by conspicuous peaks of *Sphagnum* spores up to 60% from the sum of AP+NAP in subzone 4a and 40% in subzone 4c together with growth of *Pinus* pollen and Polypodiaceae spore values. In the subzone 4b (96–76 cm) values of *Sphagnum* fell to 10–12%. According to the age-depth model the LPAZ-4 was formed in the late Atlantic and early-middle Subboreal phases of the Holocene.

LPAZ-5 (56–20 cm, 4600–1100 cal yr. BP) was distinguished by the increase in *Betula* sect. *Albae* and Ericales pollen values (30–60%) while the share of *Pinus* and *Sphagnum* reduced. *Pinus* pollen values varied between 13 and 40%, the share of *Sphagnum* was not above 10%. The proportion of other components of pollen assemblages was close to the previous zone. We suggest that the LPAZ-5 was formed during the late Subboreal and the early-middle Subatlantic phases of the Holocene.

LPAZ-6 (20–0 cm, 1100 cal yr. BP – present time) is characterized by the abrupt decline in *Betula* sect. *Albae* pollen values from 40 to 10–15% and the rise of *Pinus* and Ericales percentages. *Picea* pollen values reduced in the uppermost 5 cm (ca. 200 cal yr. BP). AP value remained high (80–82%) with exception of the sample at the depth 12 cm where the AP value fell to 55%. The peak of Ericales pollen (up to 50%) was registered at the same depth. NAP group was represented by pollen of Poaceae, Apiaceae, Chenopodiaceae, Asteraceae, Polygonaceae, Ranunculaceae, Rosa-ceae, *Rumex* as well as *Rubus chamaemorus* and Cyperaceae. *Sphagnum* spores were abundant (40–60%), the share of Polypodiaceae slightly increased. We suggest that LPAZ-6 was formed in the middle-late Subatlatic phase of the Holocene.

6. DISCUSSION

The Scandinavian ice sheet reached its maximum during 20000–23000 cal yr. BP, when it covered the entire Kola Peninsula. Deglaciation of the study area started after the Neva stage (~13800–14600 cal yr. BP), which has left behind fluvioglacial deposits (Ekman, Iljin, 1991; Yevserov, Nikolayeva, 2000; Velichko et al., 2000, 2017; Yevserov, 2018 etc.). During the Late Glacial and Early Holocene time aeolian processes caused the formation of numerous dunes, deflation basins and hummocky sand areas in the study area. Active aeolian processes occurred over the wide areas in Europe and Siberia and were the essential factor in the relief transformation in the transitional period from the Late Pleistocene glacial epoch to the Holocene in regions where sandy grounds dominate (Timireva, Velichko, 2006; Velichko et al., 2017). According to our data glacial and fluvioglacial sands underlying peat sequences in Kuzomen Mokh peatland were partly affected by aeolian processes that are indicated by specific textures on the surface of quartz sand grains typical for air transport.

The beginning of peat accumulation in local depressions between dunes marked a decline of aeolian processes in the study area. A few radiocarbon dates from the basal layers of peat sequences in the Tersky coast are known. The most ancient date ca. 9500 cal yr. BP (8560 ± 100 ^{14}C yr. BP) was obtained from the central part of the Morskie Mkhi peat bog, located to the west of the study site (Elina et al., 2005). Paludification in the Kuzomen Mokh peatland started at about 7800 cal yr. BP. A high abundance of Onagraceae pollen in the basal layer of peat sequences suggests active paludification processes of this depression after a fire.

At the early stage of peatland development (7800–7500 cal yr. BP) the local vegetation of the poor fen was formed by *Eriophorum vaginatum*, sedges (*Carex lasiocarpa*, *C. rostrata*), *Equisetum* with participation of *Salix* and *Betula*. Since the 7500 cal yr. BP *Eriophorum vaginatum* and *Sphagnum fuscum* were the main peat forming species. However, a series of consecutive phases with high abundance of *Sphagnum fuscum* together with increasing values of Ericales and phases of higher abundance of *Eriophorum vaginatum* with growing content of *Polyrtichum* were clear determined between 7500 and 4500 cal yr. BP. A high amount of *Rubus chamaemorus* pollen in assemblages mainly from the layer with dominance of *Eriophorum vaginatum* indicated its significant role in the plant cover. We suggest that these changes in plant communities could be post-fire successions of mire vegetation. An occurrence of fine sand grains in peat at the depth 135 cm (ca. 6900 cal yr. BP) and sharp decrease of LOI up to 48% at the depth 100–105 cm (5900–6000 cal yr. BP) implied a soil cover disturbance and impact of aeolian dust transport on mire ecosystem.

During the period 4600–2700 cal yr. BP a high proportion of wood macroremains in peat (*Betula* and *Pinus*) signified afforestation of the peatland and, probably, lower surface wetness in the mire and drier conditions compared to the previous time interval (Elina et al., 1995). An admixture of fine sand in the peat and decrease of organic matter content to 86–90% (depth 40–45 cm) indicated an activity of aeolian processes in the area adjacent to the peatland between 3900 and 3300 cal yr. BP.

Since the 2700 cal yr. BP Kuzomen Mokh peatland existed as ombrothrothic bog with predominance of *Sphagnum fuscum* in moss cover and dwarf shrubs and *Eriophorum vaginatum* in the higher plant canopy. *Andromeda polyfolia*, *Chamaedaphne calyculata* and *Empetrum* sp. whose seeds were identified were common in vegetation. The transition from the forested poor fen to bog in the peatland under study occurred at about 2700 cal yr. BP. The time of fen/bog transition is determined by autogenous process of peatland development and peat accumulation rate. However peatland development was affected by climatic changes and mainly by cooling and increase of climate moistening in Arctic regions since 2700–2500 cal yr. BP (Klimanov, Elina, 1984; Novenko, 2020).

The results of pollen analysis revealed vegetation history in the area adjacent to the peatland as a series of successive phases of birch, birch-pine and pine forests during the last 8000 cal yr. BP caused probably by climatic changes and fire activity. Although birch pollen was identified as *Betula* sect. *Albae*, we can assume that *B. pubescens* and *B. czerepanovii* occurred in forests. The presence of these species in the plant cover from the Preboreal to the present time has been recorded both for the territory of the Kola Peninsula (Elina, Filimonova, 2000; Elina et al., 2000, 2002, 2005, 2010), and for the Karelian White Sea region (Elina et al., 2000, 2010; Lavrova et al., 2011). *B. pubescens* grew in relatively moist conditions and *B. czerepanovii* preferred dry habitats.

The warmer and moister climate of the Holocene Thermal Maximum (Klimanov, Elina, 1984; Novenko, 2020) favored the spread of *Picea obovata* in the study area. The increase in *Picea* pollen value above 3% since 7000 cal yr. BP and subsequent permanent establishment could be considered a sign of the appearance of spruce in forest stands (Giesecke, Bennett, 2004). According to published pollen records from the region, spruce appeared on the Tersky coast of the White Sea approximately 7200 cal yr. BP. In the southeast of the Kola Peninsula, this happened 7000 cal yr. BP (Kremenetsky et al., 1988), around Lovozero Lake – 5300–5500 cal yr. BP (Elina et al., 1995).

Broadleaved trees most likely did not grow in the study area. Pollen of *Ulmus, Quercus,* and *Tilia* occurred sporadically in the peat core in minor amounts, and it was obviously transported by wind from southerner areas. However, the presence of thermophilous trees in pollen record from Kuzomensky Mokh peatland suggests that the geographical ranges of these species came closer to the study area during the Holocene climate optimum. Similar data were obtained both for the Kola (Kremenetsky et al., 1988; Nikolaeva et al., 2015) and for the Karelian White Sea region (Elina, 1981; Elina, Lebedeva, 1992; Elina, Kuznetsov, 1996; Lavrova et al., 2011 and etc.). Since the 5000 cal yr. BP broadleaved tree pollen disappeared from pollen assemblages from the study site with exception of rare occurrence of single pollen grains of *Ulmus*, indicating the retreat of the northern limit of their ranges (Elina, 1981; Elina et al., 2000, 2010) as a result of climate cooling (Klimanov, Elina, 1984; Novenko, 2020).

Human induced changes in vegetation were traced during the last 200–300 years. The reduction in *Picea* pollen value was detected in pollen assemblages from the uppermost peat layer and growth of proportion of *Pinus* indicates a disturbance of forest stands eventually by logging and fires.

7. CONCLUSIONS

The first results of detail radiocarbon dating, pollen, plant macroremains, loss on ignition measurements and quartz sand grain morphoscopy analysis of the Kuzomen Mokh peatland situated in the Tersky coast of the White Sea gave us a unique possibility to examine the mid- to late Holocene palaeoenvironmental changes in the study area, which is very important for better understanding the landscape processes, vegetation changes and peatland development in Northern Europe. Our main conclusions are as follows:

1. Analysis of quartz sand grain morphoscopy revealed that glacial and fluvioglacial sands underlying peat sequences in Kuzomen Mokh peatland were partly affected by aeolian processes that are indicated by specific textures on the surface of quartz sand grains typical for air transport. Our data demonstrate that the

paludification stage in the study area was preceded by aeolian processes, which commenced after deglaciation.

2. Peat accumulation at Kuzomen Mokh started around 8000 cal yr. BP suggesting a decline of aeolian processes in the study area. Analysis of plant macroremains showed that the peatland was affected by fires particularly in the period between 7800 and 2700 cal yr. BP.

3. Pollen analysis defined vegetation history in the Tersky coast of the White Sea in the area adjacent to the peatland as a series of successive phases of birch, birch-pine and pine forests during the last 8000 cal yr. BP caused probably by climatic changes and fire activity. Picea appeared in forests around 7000 cal yr. BP and decrease in abundance during the last 200–300 years probably due to human impact.

Environmental Changes in the Tersky Coast of White Sea (Kola Peninsula) During the Holocene Inferred From Multy-Proxy Study of the Kuzomen Moch Peatland

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This paper presents the first reconstruction of the paludification process and vegetation history during the last 8000 cal years BP in the western part of the Tersky Coast (south Kola Peninsula), in the River Varzuga mouth, based on multi-proxy studies of the Kuzomen Mokh peatland including high resolution pollen and plant macroremains analyses, loss on ignition measurements, AMS radiocarbon dating of the peat, and quartz grain morphoscopy analysis for sandy deposits underlying the peat sequences. The obtained data revealed that the paludification stage was preceded by aeolian processes occurred in the study area during the Late Glacial and Early Holocene. Analysis of quartz sand grain morphoscopy revealed that glacial and fluvioglacial sands underlying peat deposits in Kuzomen Mokh peatland were partly affected by aeolian processes that are indicated by specific textures on the surface of quartz sand grains typical for air transport. Peat accumulation started not later than 7865 ± 45 cal yr. BP assuming a decline of aeolian processes in the study area. Analysis of plant macroremains showed an evolution of mire from the poor fen to ombrotrophic rised bog. Local vegetation successions were obviously influenced by fire in the period between 7800 and 2700 cal yr. BP. According to pollen data vegetation history in the Tersky coast of the White Sea during the last 8000 cal yr. BP included a series of successive phases of birch, birch-pine and pine forests caused probably by climatic changes and fire activity. *Picea* appeared in the study area around 7000 cal yr. BP and reduced in abundance during the last 200 years due to human impact and fires.

Keywords: Kola Peninsula, paludification, paleoclimatic reconstructions, pollen analysis, plant macroremains, quartz grain morphoscopy

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