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РЕКОНСТРУКЦИИ НА ОСНОВЕ ПАЛЕОБИОЛОГИЧЕСКИХ МЕТОДОВ

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ИСТОРИЯ ОЗЕРА КАНОЗЕРО В ПОЗДНЕЛЕДНИКОВЬЕ И ГОЛОЦЕНЕ НА ЮГЕ КОЛЬСКОГО ПОЛУОСТРОВА (СЕВЕРО-ЗАПАД РОССИИ)

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Для изучения реакции экосистемы озера на изменения природной среды была изучена колонка донных отложений из озера Канозеро на Кольском полуострове с помощью палинологического, диатомового и литологического методов. Результаты показали, что экосистема озера прошла следующие этапы: позднеледниковую фазу, последующий спуск водоема, поступление речных вод под влиянием расширения близлежащих заболоченных земель, образование мелководного озера в голоцене. Органическое вещество начало накапливаться в озере около 9100–9200 кал. тыс. л. н., что указывает на минимальный возраст дегляциации бассейна. Для этого периода характерны изменения всех реконструируемых показателей. Климат становится теплее и суше. Распространяются сосновые и березовые северотаежные леса. О понижении уровня озера свидетельствуют исчезновение планктонных диатомей Aulacoseira spp. и общее увеличение числа бентосных видов. Очень сильное обмеление произошло в начале этапа формирования современного озера Канозеро. Активные перемещения древних людей были возможны в конце атлантического и начале суббореального периодов.

Ключевые слова: озерные отложения, плейстоцен, голоцен, пыльца, диатомовые водоросли, изменения уровня озера, климат, ландшафты, петроглифы

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1. INTRODUCTION

The sediments of the lakes of the Kola Peninsula are an important source of information on the Late Glacial and Holocene history of the development of the natural environment in Fennoscandia. At the same time, the lakes of the northern part of the Kola Peninsula have been studied much better than the lakes of its southern part (Sapelko, 2017). It is especially important to trace the history of the formation of lakes in the southern part of the peninsula in connection with the dynamics of the White Sea level. Thus, on the southern coast of the Kola Peninsula, near the Umba village, small lakes were studied in the context of their isolation during the movement of the sea level in the Late Pleistocene-Holocene (Kolka et al., 2013; Sapelko et al., 2015).

Investigations on the southern coast of the Kola Peninsula (Evzerov et al., 1976) have shown that a series of sand and silt deposits with some varve-like lamination was accumulating in the ice-dammed basin from the Allerød to the early Preboreal. Thickness of individual layers decreases upward, along with increasing proportion of sand at the expense of silt and clay, which suggests a gradual shallowing of the basin. The apparent thickness of the sediments is more than 14 m.

After the ice dam had been removed from the White Sea mouth, the sea water salinity grew since the second half of the Preboreal and a normal marine regime became established by the Boreal. The sediments dated to the second half of the Preboreal are sandy silts with varve-like lamination changing into fine sands up the sequence. The top of the sands was eroded by the subsequent marine transgression. The apparent thickness of the deposits does not exceed a few meters. In the Early Holocene the climate in the northern and central Kola Peninsula was more continental than in its southern part, with warm and dry summers and cold and dry winters (MacDonald et al., 2000). In the south Kola Peninsula, the climate was wetter, having acquired marine characteristics after the ice sheet recession. In the southeast of the peninsula, birch forests were spread most widely. Since 10 000 cal. yr BP, pine forests have become common (Kremenetski, Patyk-Kara, 1997; Sapelko, 2009), which suggests warm and

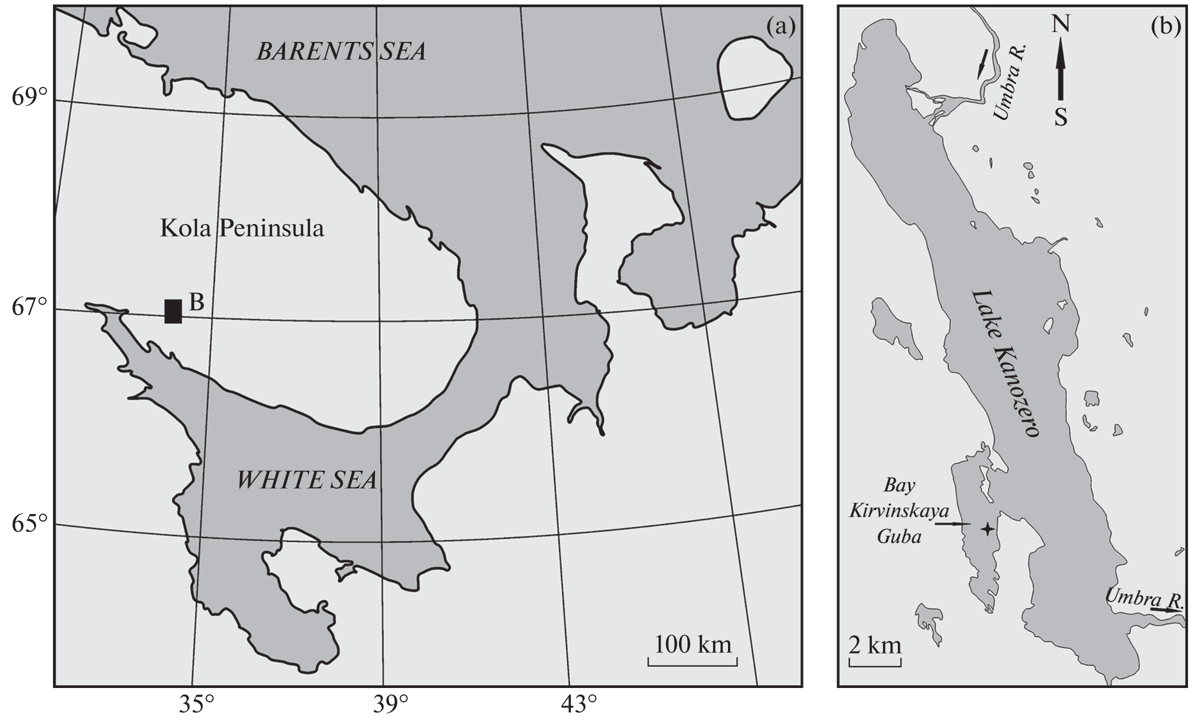

Fig. 1. Location map (a) and study site (star) (b).
Рис. 1. Карта района исследований (a) и место исследования (звёздочка) (b).

humid enough conditions favorable for the afforestation of the region. The growing importance of forest landscapes, both in the north and in the south of the peninsula, is seen in the pollen data recovered from the lakes sediments (fig. 1). In particular, data on the pine and birch distribution have been obtained from sediments of three lakes: Babozero (66°22′30″ N, 37°31′ E), Krugloye (66°22′ N 37°35′ E), and Kanozero (67°03′ N, 34°06′ E), the catchment basin of the latter being most densely forested. In the Preboreal, there were herb and dwarf shrub communities in the lake catchment basin, with occasional groves of birch. Pine was also common here at that time, that is, earlier than in the Lake Krugloye basin (Kremenetski, Patyk-Kara, 1997). As to Lake Babozero, areas of pine forests were also growing in importance at that time, while the birch percentage is reduced. Occasional findings of macrophytes in combination with willow suggest the presence of shallow water locally. Relatively warm and humid conditions favorable for the forest advance northward existed around Lake Berkut (66°20′69″ N, 36°39′77″ E) until 7000 cal. yr BP (MacDonald et al., 2000). Similar climatic conditions are recorded in the northern and central regions of the Kola Peninsula about 8500–7000 cal. yr BP. At the same time, relatively high lake levels and the beginning of the peat accumulation are recorded in the Khibiny Mountains (Davydova, Servant-Vildary, 1996; Kremenetski, Patyk-Kara, 1997). It follows from the preceding that the beginning of the Holocene was an important stage in the environmental evolution on the Kola Peninsula.

Lake Kanozero (67°3′33″ N; 34°6′12″ E) is located in the southern part of the Kola Peninsula. Thanks to the petroglyphs found on the islands of Lake Kanozero (Kolpakov, Shumkin, 2012) interest arose in studying the history of the lake. For the present time there have been discovered over 1400 rock carvings. The petroglyphs are confined to the three Kanozero islands (Gorelyi, Yelovyi, Kamennyi) and a single-standing inland rock (Odinokaya). The dominant theme of the Lake Kanozero rock carvings is whale hunting using harpoons and boats. The dating of rock carvings is always associated with serious difficulties. When available, the data of natural science should be used to overcome them. The first rock carvings on the islands of the Lake Kanozero were discovered in 1997. Typological connections between Kanozero rock carvings can be traced throughout Northern Fennoscandia. The study of the paleoenvironment in this region in addition to solving purely paleogeographic problems, allows a comprehensive approach to correct the age and stages of formation of the Lake Kanozero petroglyphic complex (Sapelko, Kolpakov, 2010).

2. MATERIAL AND METHODS

Lake Kanozero is located 28 kilometres north of the village of Umba in the Tersky district of the Murmansk Region and belongs to the White Sea basin.

The lake represents an overflow of the Umba River. Lake Kanozero has surface areas of 84.3 km^2 and a catchment area of 4920 $км^2$. The lake's altitude is 52.7 m of above the sea level, the maximum depths are about 5–7 m. The lake is located in the northern taiga subzone; pine-spruce forests are common in the catchment area. The lake is surrounded by impassable bogs.

In the course of field work, sediments sequences were retrieved both from Lake Kanozero itself and from Lake Treugolnoye, as well as the Akhmolambina bog, located at different elevations (fig. 1). By now, the reconstruction of the development stages of Lake Kanozero has been carried out based on the study of the sediments sequence from the Kirvinskaya Bay. The sediments sequence was sampled in the shallow part of the Kirvinskaya Bay from a depth of 1.7 m with a Russian corer (chamber length 1 m, inside diameter 5 cm) and was studied using lithological, pollen, diatom and radiocarbon analyses. In addition, a surface samples from the coring place the Lake Kanozero sediments was obtained for the pollen and diatom analyses using Voronkov sampler.

The loss-on-ignition (LOI, %) analysis was performed following the method adopted at the Institute of Limnology of the Russian Academy of Sciences. It included drying of the powdered samples, cooling in a drying oven to room temperature, weighing, and ignition for 6 hours at 500°C. After subsequent cooling to room temperature, weighing of the samples is performed to calculate weight losses after ignition.

The radiocarbon dating was performed by accelerator mass-spectrometry (AMS) at the Laboratory of radiocarbon dating at the University of Helsinki, Finland. The data was calibrated using OxCal 4.3 (Bronk Ramsey, 2009), which employs the IntCal13 atmospheric curve (Reimer et al., 2013).

Technical treatment of samples for pollen analysis followed a standard method (Grichuk, 1940; Berglund, Ralska-Jasiewiczowa, 1986) with separation by potassium-cadmium heavy liquid. When calculating the percent for each of the taxa, the total amount of pollen of the trees (AP), herbs (NAP) and spores was taken as 100%.

The samples for diatom analysis were treated following the standard treatment procedure that includes oxidizing of the organic matter in 30% H_2O_2, and subsequent repeated washing in distilled water (Davydova, 1985). Diatom concentrations in 1 g of dry sediments were calculated following Davydova (1985). The ratio of chrysophyte cysts to diatoms was calculated according to Smol (1985).

3. RESULTS

3.1. Lithology and chronology. The lower part of the sequence is represented by light-gray bluish dense clays with organic matter content 1.9–3.2% (fig. 2), overlain by greenish-brown gyttja with organic matter content 4.5–30% and brown gyttja with organic matter content 39–41% with a gradual boundary between the lithological zones. The transition from gray clay to greenish-brown gyttja was radiocarbon-dated (AMS) to 8215 ± 54 (Hela-3072) corresponding to about 9200 cal. years ago (cal. BP) (fig. 2). Radiocarbon date doesn't correspond in depth to the studied sequence, since it was taken from another core with possibly eroded deposits. Although the radiocarbon age was obtained from another sediment core, the date clearly indicates a transition horizon to organogenic sedimentation.

3.2. Pollen analysis. The analysis of the surface samples showed that tree pollen dominates in the spectra. The leading role belongs to *Pinus* pollen, the content of *Picea* pollen is high. The amount of *Betula* pollen is less significant. The percentage of herbs pollen is low. Among the grass pollen, the pollen of aquatic and coastal aquatic plants was marked. The number of spores in the spectra is small. *Sphagnum,* Polypodiaceae*,* Bryales*, Selaginella*, etc. were noted. In general, pollen spectra reflect the type of the modern vegetation.

According to the results of the pollen analysis of the sediments sequence 6 pollen zones were identified (fig. 3):

Pollen zone 1 (depth 455–480 cm). The upper boundary of the zone almost completely coincides with the lithological boundary of light-gray clays. Zone is characterized by relatively low arboreal pollen content (about 60%) and concentration. Among the tree pollen which the leading role belongs to *Pinus* pollen (up to 50%), the participation of *Betula* pollen is high (20–40%). The content of spores in the spectra sometimes reaches 35%. Spores of Polypodiaceae predominate here. Spores of *Lycopodium clavatum, L. annotinum, Botrychium* and Bryales are present as well. The percentage of herb pollen is not high, but the diversity and species composition are high. The pollen of Poaceae and Cyperaceae is dominant. Pollen of Chenopodiaceae and Artemisia is less abundant. The hypoarctic taxa of *Empetrum, Rubus chamaemorus* are present.

In general, the vegetation of this period can be characterized as rather diverse. There are both the boreal and hypoarctic taxa. Among the boreal genera, there are single grains of *Pinus, Picea* and *Corylus* which are partly transferred. Among the boreal taxa were *Filipendula, Lycopodium clavatum* and *L. annotinum* also recorded. Despite some presence of boreal species, hypoarctic species such as *Betula nana, Selaginella selaginoides, Botrychium boreale, Empetrum,* and *Rubus chamaemorus*, determined the vegetation type of this period. The climate at that time was cold. The vegetation was open periglacial landscapes with cryophilic shrubs became widespread. Shallow water is indicated by the presence of macrophytes pollen.

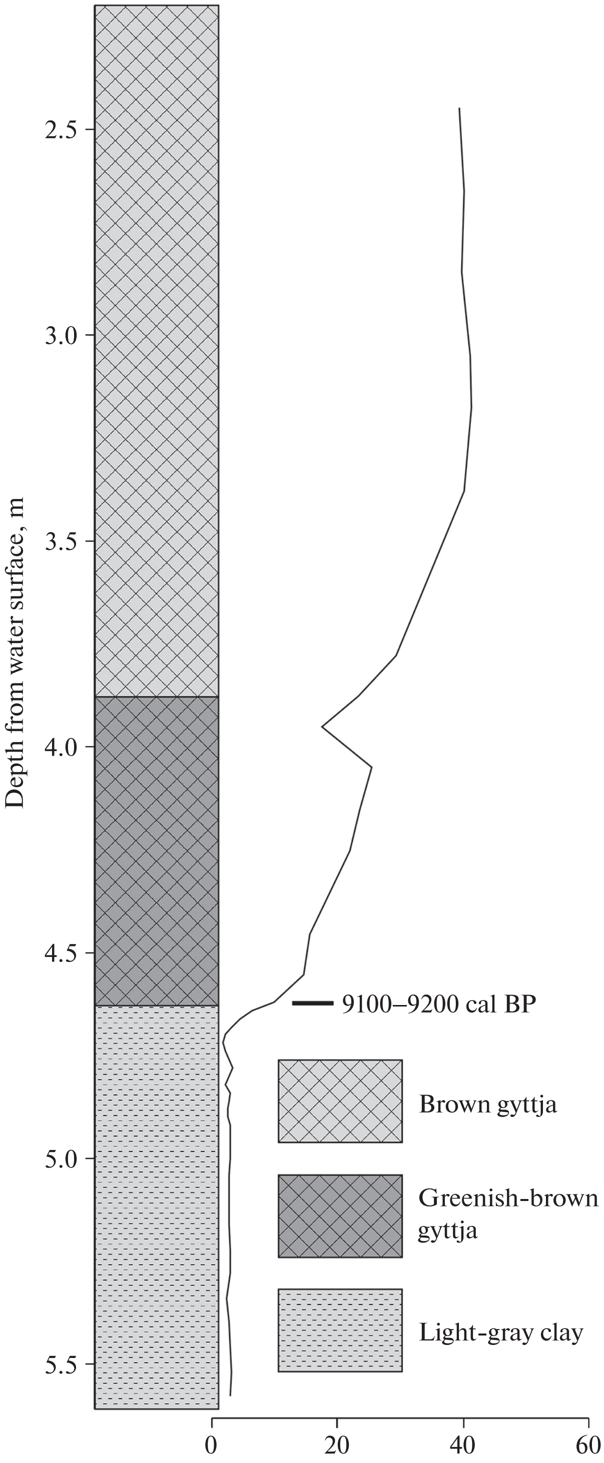

Fig. 2. Lithology with radiocarbon (AMS) date of Lake Kanozero and LOI (%).

Рис. 2. Литологическая колонка донных отложений из озера Канозеро с радиоуглеродной датировкой и потерями при прокаливании (%).

Pollen zone 2 (depth 405–455 cm). Zone is roughly corresponds to most of the uniform greenish-brown gyttja. In the general composition of the spectra, a high percentage of tree pollen is observed. Pollen of *Pinus* and *Betula* dominates. The percentage of them is almost the same which may indicate an increase in the influence of *Betula* in the vegetation cover of this period. The pollen content of shrubs and dwarf shrub increased. Varia dominated among herbaceous plants. Pollen of Poaceae and Cyperaceae does not decrease. Pollen of Chenopodiaceae and *Artemisia* are present. The pollen content of aquatic and coastal aquatic plants increased. *Sphagnum* appears among the spores, Bryales and Polypodiaceae increases. The *Isoëtes lacustris* appears and forms a continuous curve.

During this period, there is some improvement in climatic conditions. The climate is still cool, but more humid. The *Betula* sparse forests spread everywhere. By the increase of macrophytes we can talk about the decrease in the level of the lake. The appearance of *Isoëtes lacustris* indicates clean, clear water.

Pollen zone 3 (387–405 cm). Zone is represented by a transitional horizon from greenish-brown to homogeneous brown gyttja. The percentage of *Betula* pollen increases, *Betula nana* reaches its maximum content in this zone. The species composition is changing. The boreal species increases and the hypoarctic taxa decreases. However, the pollen of thermophilic species is also absent. Pollen of macrophytes disappear. The percentage of spores is decreasing.

The climate of this period is warmer and drier. The vegetation acquires a northern taiga type. *Pinus* and *Betula* forests are spread. The absence of macrophytes with the widespread of Cyperaceae plants imply the decrease of the lake level.

Zone 4 (305–387 cm). This zone coincides to the horizon of homogeneous brown gyttja. Pollen of *Pinus* predominates among tree species. *Picea* pollen appears in significant amounts and forms a continuous curve up to the end of the zone (up to 15%). The pollen of thermophilic species appears periodically. Single pollen grains of broadleaved trees of *Ulmus, Quercus* and *Carpinus* were identified. Pollen of *Corylus* also appears. Varia dominated among herbaceous plants. The pollen of aquatic and coastal aquatic plants again appears. Pollen of *Typha latifolia* appears for the first time. Spores of *Sphagnum, Equisetum*, Polypodiaceae and Lycopodiaceae present. The green algae *Pediastrum* and *Botryococcus* present in high amounts.

The climatic conditions of this zone are the most favorable. The climate becomes warm and humid. The vegetation acquires a medium taiga type. *Pinus* forests are widespread with inclusions of *Betula, Picea* and broadleaved species. The increase of Cyperaceae and *Sphagnum* correlated with waterlogging increased.

Pollen zone 5 (245–305 cm). Zone is also represented by brown gyttja. The percentage of *Pinus* pollen is reduced due to an increase in *Betula* and *Picea* pollen (up to 20%). Pollen of *Quercus, Corylus*, and *Alnus* continues to occur.

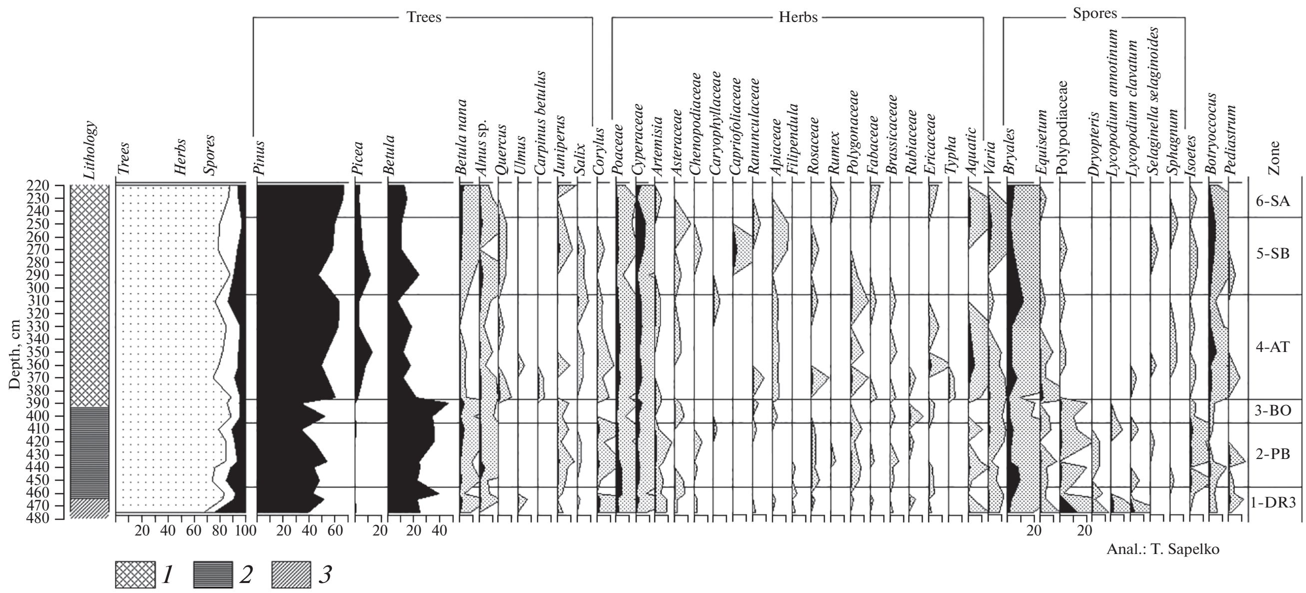

Fig. 3. Pollen diagram of Lake Kanozero. *Lithological units: 1* — brown detrital gyttja; *2* — greenish-brown gyttja; *3* — light-gray clay.

Рис. 3. Спорово-пыльцевая диаграмма донных отложений озера Канозеро. *Литология: 1* — коричневая детритовая гиттия; *2* — зеленовато-бурая гиттия; *3* — светло-серая глина.

Pollen of *Alnus* is identified in this zone of two species *Alnus incana* and *A. glutinosa*.

In the upper part of the pollen zone, herbs pollen curve declines. The content and variety of the non-arboreal pollen (NAP) group is small; the main role belongs to Cyperaceae pollen. In the upper part *Sphagnum* spore curve also increases. The pollen of *Rubus chamaemorus, Betula nana*, and spores of *Selaginella selaginoides*, which belong to hypoarctic species, again appear.

The climate becomes colder. The vegetation again acquires a northern taiga type. By the end of the zone, swamping occurs again. In swampy areas, the importance of *Betula* increases. The lake level also decreases again towards the end of the zone, as evidenced by both the process of swamping and the appearance at this time of pollen from aquatic plants.

Pollen zone 6 (220–245 cm). Zone coincides to the brown detritus gyttja. The percentage of *Pinus* pollen increases again and reaches its maximum (80%) by the end of the zone. The amount of *Picea* pollen decreases, pollen of broadleaved species disappears. The total amount of the non-arboreal pollen (NAP) group is the lowest in the sediment sequence. Pollen grains of *Calluna vulgaris, Artemisia* and *Rumex* have been found. Pollen of aquatic plants are present.

The climate becomes similar to modern. Northern taiga landscapes are spreading. Pine forests are predominating. The pollen spectra of this period are similar to surface samples of lake sediments. The lake level increased and began to correspond to the modern. At the same time, the average depths of the modern lake correspond to about 5 meters.

3.3. Diatom analysis. Four local diatom assemblage zones (DZs) were visually recognized (fig. 4).

KDZ-1 (480–467 cm) is characterized by the predominance of alkaliphilous species, mainly of Fragilariacea family (*Fragilaria exigua, Staurosira construens, S. venter, Staurosirella lapponica, S. pinnata*). These taxa massively grow in alkaline environments and in a wide range of trophic conditions. Benthic species also include oligotrophic northern-alpine *Achnanthes calcar* and *A. oestrupii*, as well as oligo-mesotrophic *A. joursacense* and *Cocconeis neodiminuta*. *Navicula aboensis, N. jaernefeltii* and *N. jentzschii* are also particularly abundant in DZ-1. The diatom assemblage is typical of the shallow-water parts of a large cold-water oligotrophic lake. Diatom concentrations are relatively low and do not exceed 30 mln. valves g-1 of dry sediment. Cysts to diatoms ratio also has its lowest values.

In KDZ-2 (467–432 cm) benthic Fragilariaceae remain abundant while most of the other species typical for KDZ-1 disappear from the diatom record. Planktonic diatoms reach their highest values (25%). Alkaliphilous *A. ambigua* with wide geographic distribution, and cold-water neutrophilous *A. valida* and acidophilous *A. humilis* prevail, while *Cyclotella* spp. are less abundant. Diatom concentrations rapidly increase to >200 mln valves. Cysts to diatoms ratio varies from 8% to 16%.

In KDZ-3 (432–395 cm), benthic Fragilariaceae rapidly decrease. However, benthic diatoms remain abundant as periphytic neutrophilous *Achnanthes* spp.

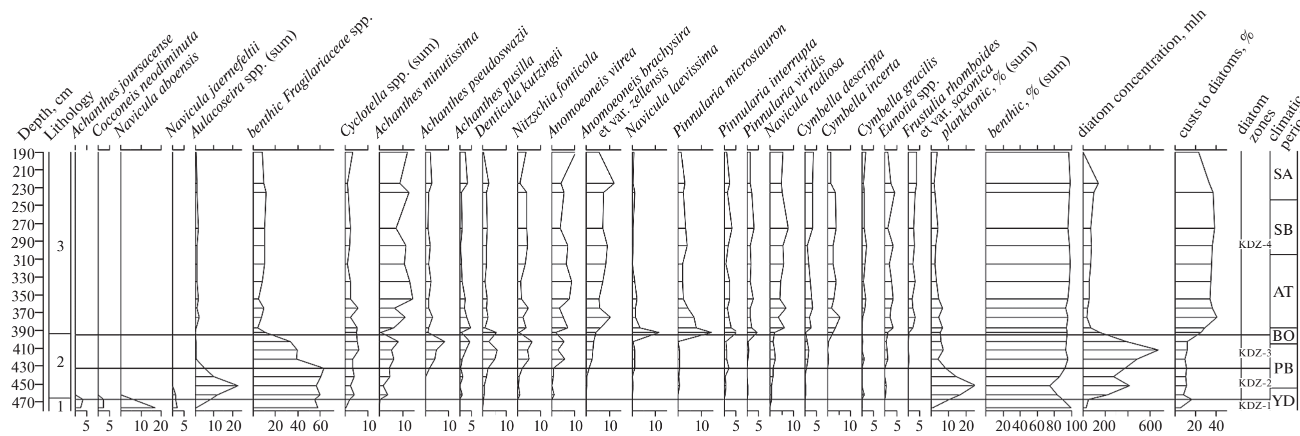

Fig. 4. Main diatom species in the sediments of Lake Kanozero (Lithological units as in fig. 3).

Рис. 4. Основные виды диатомовых водорослей в донных отложениях озера Канозеро (Литологические горизонты как на рис. 3).

(e.g., *A. minutissima, A. pseudoswazii* and *A. pusilla*) increase accordingly. Mesotrophic neutrophilous *Denticula kützingii*, alkaliphilous *Nitzschia fonticola*, and oligotrophic northern-alpine *Anomoeoneis brachysira* et var. *zellensis* and *A. vitrea* appear in the diatom record. Planktonic *Aulacoseira* spp. disappears from the diatom assemblages. Total planktonic does not exceed 9%. Diatom concentrations increase to 670 mln. valves, and rapidly decrease from ca. 412 cm upwards. The values of cysts to diatoms ratio are similar to those in DZ-2.

KDZ-4 (395–190 cm) is characterized with the highest abundances of benthic diatoms (up to 98%). The abundances of alkaliphilous Fragilariaceae drastically decrease, while neutrophilous *Achnanthes minutissima, Cymbella* spp. (e.g., *Cymbella descripta, C. incerta* and *C. subaequalis*) and *Pinnularia spp.* (e.g., *P. interrupta, P. maior, P. microstauron* and *P. viridis*) and *Navicula* spp. (e.g., *Navicula laevissima, N. pupula, N. radiosa*) increase. Acidophilous *Anomoeoneis brachysira* et var. *zellensis*, *Frustulia rhomboids* et var. *saxonica*, *Cymbella gracilis* and *Eunotia* spp. also become abundant. Diatom concentrations are relatively low, varying from 31 mln. to 146 mln. valves. Cysts to diatoms ratio reaches its highest values (to 40%).

4. DISCUSSION

According to the results of the study of the sediments sequence from the Kirvinskaya Bay of Lake Kanozero, several stages of the evolution of paleoenvironments can be distinguished:

The first stage of the lake development is characterized by a cold climate (DR 3). Tundra landscapes with a small participation of tree species have become widespread. Basically, these are birch woodlands. Despite some presence of fairly heat-loving species, hypoarctic species, such as *Betula nana, Selaginella selaginoides, Botrychium boreale, Empetrum* and *Rubus chamaemorus*, determined the vegetation type of this period. The diatom species composition (DZ-1) points to sedimentation in the shallow-water zone of a large cold-water oligotrophic basin with lowering level. The low organic matter content also suggests low productivity and predominantly allochthonous sedimentation.

An increased contribution of the planktonic diatoms at the transition from DZ-1 to DZ-2 indicates more favourable environments for this ecological group. It might have resulted from increased nutrients concentrations as the area of the lake decreased. This shift also coincides with the transition from predominantly mineral to organic sedimentation. Increased productivity of the lake ecosystem is also inferred from drastically increased diatom concentrations.

At the next stage, the climate improves slightly (PB). The climate is still cool, but more humid. The areas occupied by woody vegetation are increasing, where the main species is birch. The level of the lake gradually decreases further, aquatic vegetation spreads in the lake. *Isoëtes lacustris* appears.

The highest abundances of planktonic diatoms in DZ-2 might reflect rather high nutrients concentrations. However, it may also indicate the lake level higher than present. This is supported by the fact that the most abundant planktonic taxa belong to *Aulacoseira* genus. These taxa are characterized with heavily-silicified cell-walls and therefore demand a certain water depth to remain suspended. Presently *Aulacoseira* species are not an important component of the surface-sediment diatom assemblages of the shallow-water Kirvinskaya Bay. However, they are abundant in the 5–7-m – deep main basin. Thus, highest proportions of *Aulacoseira* taxa in DZ-2 also suggest more intensive water exchange between the bay and the main basin during the high-level stage.

The third stage (BO) is distinguished by changes in all in proxies used in reconstruction. The climate is getting warmer and drier. The vegetation acquires a northern taiga type. *Pinus* and *Betula* forests spread. During this period, brown organogenic gyttja begin to form in the lake. The content of organic matter increases sharply up to 30%. This transitional period of shallowing corresponds to the initial stage of the formation of the present Lake Kanozero. A decrease in the area and depth of the lake and an increase in its productivity were recorded in the results of both pollen and diatom analyses. The decrease in aquatic vegetation with a wide distribution of Cyperaceae emphasizes a sharp decrease in the lake level. The diatom record of DZ-3 also suggests environmental changes that apparently related to the water-level lowering, as indicated by disappearance of *Aulacoseira* taxa and general increase in benthic species. As the water exchange between the Kirvinskaya Bay and the main basin weakened, the hydrodynamic, hydrochemical and hydrobiological conditions should have changed accordingly. However, the highest diatom concentrations suggest that ecosystem productivity remained high.

The fourth stage (AT) is characterized by the mildest climate for the entire studied period with the spread of middle taiga landscapes (Sapelko, 2009). Mostly *Pinus* forests are distributed. *Picea* and broad-leaved species such as *Ulmus, Quercus, Carpinus*, and *Corylus* appear. The climate becomes warm and humid. Due to the wetter climate, the lake level might have slightly increased. The aquatic and coastal aquatic plants are widespread, among which *Typha latifolia* appears for the first time. The green algae *Pediastrum, Botryococcus* actively spread in the lake. Brown detrital gyttja is formed with an average organic matter content of about 40%.

Diatom assemblages' composition of DZ-4 points to some dramatic environmental shifts. The rapid decrease in alkaliphilous Fragilariaceae and increase in neutrophilous benthic taxa suggest some pH lowering. Thus starting from the end of the Boreal the conditions similar to present established in the Kirvinskaya Bay. Further weakening of the water exchange with the main basin resulted from water-level lowering. At this time, peat growing apparently started in the northern part of the bay as suggested by increase in acidophilous diatom taxa. Increased values of the cysts to diatoms ratio also suggest a shift towards more acidic and oligotrophic environments. Rapidly decreased diatom concentrations reflect decreased productivity of the lake ecosystem.

At the next stage (SB), the climate becomes cooler. The type of the vegetation changes and again becomes northern taiga. *Pinus* forests predominate, however, *Picea* and *Betula* forests actively spread for a short time due to the reduction in the area of distribution of *Pinus* forests. In the second half of the period, according to pollen analysis, the lake level again decreases, and bogs spread. The content of organic matter in detrital gyttja is still high (39–41%). The composition of the diatom assemblages remained almost unchanged indicating that environmental conditions were rather stable. The predominance of benthic neutrophilous and acidophilous taxa indicate shallow-water neutral – slightly acidic environments.

The final stage of development (SA) is characterized by a small climate cooling. The *Pinus* forests again dominate, while the distribution of *Picea* is reduced and broad-leaved species completely disappear. In general, judging by the results of pollen analysis of surface-sediment samples, the reconstructed landscapes resemble modern ones. The peat growth in the northern part of the Kirvinskaya Bay proceeded as indicated by the constant presence of acidophilic taxa in the diatom record. Bogging of lakes in the Late Holocene is noted everywhere (Kremenetski et al., 1997).

As a result of the study, we can suggest that Lake Kanozero acquired its present features in the Boreal period. During this period, *Pinus* forests become widespread. With 10000 cal. BP in the southern part of the Kola Peninsula, *Pinus* forests are ubiquitous (Kremenetski et al., 1997; Sapelko, 2017), which indicates rather warm and humid conditions favorable for the development of forests. Summer temperatures of the beginning of the Holocene reconstructed from the sediments sequence from Lake Berkut (66°820.69′ N; 36°839.77′ E), were 12.3–12.5°C (Ilyashuk, Ilyashuk, 2005). Similar summer temperatures were reconstructed from the distribution of woody vegetation in Fennoscandia (Giesecke et al., 2008). According to other data (Velichko et al., 2002) during the degradation of the Scandinavian Ice Sheet, at the warmer intervals of the Lateglacial and Early Holocene, the regional differences in temperature deviations from the present-day values in the northwestern part of the East European Plain, near the Scandinavian Ice Sheet became smaller (up to 8°C). About 10100–8400 cal. BP in the southern part of the Kola Peninsula, there is also a decrease in the level of lakes and an increase in their productivity (Ilyashuk, Ilyashuk, 2005; Solovieva, Jones, 2002). Previously, Lake Kanozero was part of a larger water body. The stabilization of the paleoenvironment apparently contributed to the appearance of the first sites of ancient people in the southern part of the Kola Peninsula. It is not earlier than the 7^{th}–6^{th} millennium BC, when people spread to the southwest and southeast, later than in the north of the Peninsula (Shumkin, 2017). It can also be noted that based on the results of pollen analysis, events associated with the presence of people in the catchment area of the lake are indirectly recorded. The identified stages of some open landscapes expansion with grasses of disturbed habitats in rather favorable conditions for the growth of vegetation cover are associated with fluctuations in the level of lakes (Kolka et al., 2013; Olyunina et al., 2008; Sapelko et al., 2013) and, accordingly, with the appearance of man on the islands of the lake in the Subboreal period. The absence of the archeo-

Fig. 5. The rock carvings at the Eloviy 7 group. 2021.
Рис. 5. Наскальные рисунки группы Еловый 7. 2021.

logical sites in the lake area can be explained by the dynamics of the lake level and the flooding of settlements. The rise in the water level in the lakes of the Kola Peninsula during this period was probably widespread and ensured the formation of new waterways from south to north. For example, the lake-level rise at that time was reconstructed for Lake Berkut (Ilyashuk, Ilyashuk, 2005) in the southern part of the Kola Peninsula.

In the XX–XXI centuries the main human impact is exerted by numerous tourists rafting on the Umba River and Lake Kanozero and rafting of timber, which no longer exists now. The degree of impact on the lake landscape is approximately equal to the influence of ancient people during the period of drawing rock carvings. It is possible to draw conclusions about the important and decisive importance of natural processes on the settlement and dynamics of humans on the Kola Peninsula in the past (during the Holocene) and the no less important significance natural impact of the today. In the conditions of hard-to-reach, heavily swamped Lake Kanozero catchment people practically do not live. Thus human impact on the lake ecosystem was insignificant throughout the study period.

The absence of settlement complexes in the coastal areas of Lake Kanozero can probably be explained by the heavily swamped catchment, but it is possible that this territory, inconvenient for living, was a special, uninhabited “delimiting” zone between individual communities on which they converged only at certain times to perform joint sacred actions, the center of which and there were rocky islands with carved rock carvings. The petroglyphs of the Kanozero are included in the range of rock art of hunter-gatherers of Northern Fennoscandia from the Neolithic to the Early Metal Age (IV–II millennia BC). The typology of carvings and artifacts found in the course of our excavations near groups Elovyi-6 9 (fig. 5) and Kamennyi-7 do not contradict to the broad dating of the Kanozero petroglyphs (Kolpakov, Shumkin, 2012).

5. CONCLUSION

As a result of the study, it can be concluded:

Late Glacial – cold climate. Tundra landscapes with little tree species. Basically, these are birch woodlands. Large freshwater basin existed in the lake basin, where light-gray clays with low organic content formed.

Preboreal – the climate is still cool, but wetter. The areas occupied by woody vegetation are increasing, where the main species is *Betula*. The lake level is gradually decreasing; aquatic vegetation is spreading in the lake.

Boreal – the climate becomes warmer and drier. The vegetation acquires a northern taiga type. *Pinus* and *Betula* forests spread. During this period, brown organogenic gyttja begin to form in the lake, where the content of organic matter increases to 30%. The area and depth of the lake are reduced, while its productivity increased.

Atlantic period – warm and humid climate. Distribution of middle taiga landscapes. According to pollen data in the second part of Atlantic period to Early Subboreal period the lake level might have slightly increased, establishing more oligotrophic conditions. However, the diatom assemblages show no significant changes possibly due to a short period of increasing lake level.

Subboreal period – the climate becomes cooler. The vegetation type again becomes northern taiga. The lake level is decreasing; the bogs are spreading. The content of organic matter in detrital gyttja is reaches 41%.

Subatlantic period – slight cooling of the climate. Swamping of the northern part of the Kirvinskaya Bay, which continues to this day. The depth of lake gradually decreases.

The conducted studies have shown that active movements of ancient people were possible at the end of the Atlantic – the beginning of the Subboreal periods.

Late Glacial – Holocene History of the Lake Kanozero in the Southern Kola Peninsula, Northwestern Russia

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The sediment sequence from Lake Kanozero in the Kola Peninsula was studied for pollen, diatoms and lithology in order to investigate responses of the lake ecosystem to environmental changes. Our first results show that development of the Lake Kanozero was complex and included a Late Glacial lake phase and subsequent drainage, a history of fluvial input affected by nearby wetland expansion, and formation of the shallow lake. Organic matter began to accumulate in the lake at about 9100–9200 cal. kyr BP, which provides a minimum age for the deglaciation of the basin. This period is distinguished by the all reconstructed indicators. The climate is getting warmer and drier. The vegetation acquires a northern taiga type with *Pinus* and *Betula* forests spread. The diatom record suggests environmental changes that apparently related to the water-level lowering, as indicated by disappearance of *Aulacoseira* taxa and general increase in benthic species. This transitional horizon of very strong shallowing corresponds to the initial stage of the formation of the modern Lake Kanozero. The active movements of ancient people were possible at about the end of the Atlantic and the beginning of the Subboreal periods.

Keywords: lake sediments, Pleistocene, Holocene, pollen, diatoms, lake – level change, climate, landscapes, petroglyphs

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