DOKLADY EARTH SCIENCES, 2025, Vol. 520, No. 1, pp. 97–105

PALEOGEOGRAPHY

# THE ENVIRONMENT OF THE UPPER KAMA REGION DURING THE LATE GLACIAL AND EARLY HOLOCENE AS REVEALED BY THE STUDY OF BOTTOM SEDIMENTS FROM LAKE NOVOZHILOVO


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Presented by Academician of the Russian Academy of Sciences S. A. Dobrolyubov on July 02, 2024

Received July 02, 2024
Revised August 28, 2024
Accepted September 02, 2024

**Abstract.** For the first time, a high-resolution record of natural events covering the Late Glacial and Early Holocene (14,150–9,730 cal BP) was obtained for the southern part of the Kama-Vychegda watershed based on drilling sediments in lake Novozhilovo (Kama-Keltma lowland, Upper Kama basin). The article presents the results of the study on the reconstruction of sedimentation conditions, based on paleobotanical, sedimentological and radiocarbon dating analyses. The beginning of the lake's formation was apparently preceded by a period of predominantly alluvial morpholithogenesis, which is thought to correspond to the LGM. There were four stages in the evolution of the lake basin, with the first three characterized by lacustrine-alluvial sedimentation that was predominantly mineralogenic in nature, and the fourth stage marked by typical lacustrine organic-rich sedimentation. The first stage covered the Bølling-Allerød interstadial period from 14,150 to 13,500 cal BP, and it was characterized by the accumulation of sand under conditions of high water flow. At the boundary between the Allerød and Younger Dryas periods, bioproductivity increased significantly. During the second stage, which lasted from 13,500 to 12,420 cal BP, water exchange slowed down and organic-mineral lake sediment formed. The third stage, known as the transitional sedimentation period, refers to the Younger Dryas and Early Holocene periods (12,420–10,700 cal BP). During this time, alluvial inputs predominated, with a decrease in organic matter content. Finally, the fourth stage, the eutrophic lake stage (10,700–9,730 cal BP), was characterized by a high organic matter content in sediment, and an increase in the size of silty particles.

**Keywords:** *Late Neopleistocene, Holocene, Late Glacial, alluvial morpholithogenesis, bottom sediments, geochronology, lithostratigraphy, palynological analysis, diatom analysis*

**DOI**: 10.31857/S26867397250111e1

## INTRODUCTION

The relief of the northeastern Russian Plain (the southern part of the Komi Republic and the north of the Perm Territory) (Fig. 1a) is characterized by the presence of a large number of swampy depressions, which in the Neo Pleistocene and Holocene became the arenas of river basin rearrangements [1-4]. One of these depressions is the Kama–Keltma lowland (Fig. 1b), which cuts through the Northern Hills and the Nemskaya Upland. The rivers Kama, Yuzhnaya Keltma, Timsher, Bortom, and Chepets flow within the lowlands. The depression is 60 km long and 25 km wide.

The Kama here is pressed against the high right bank and forms a relatively straight channel with a narrow left-side floodplain and fragments of floodplain terraces. The surface of the lowland in its southern extension is occupied by lakes (Bolshoy and Maly Kumikush, Novozhilovo, Chelvinskoye, etc.) and oligotrophic ridge-hollow raised bogs.

Similar in shape lakes Kadam and Sher-Kadam are located in the valley of the upper Vychegda, in the so-called Kadam expansion (Fig. 1b). The expansion is limited by the Vychegda River itself and its abandoned paleochannel, which now contains

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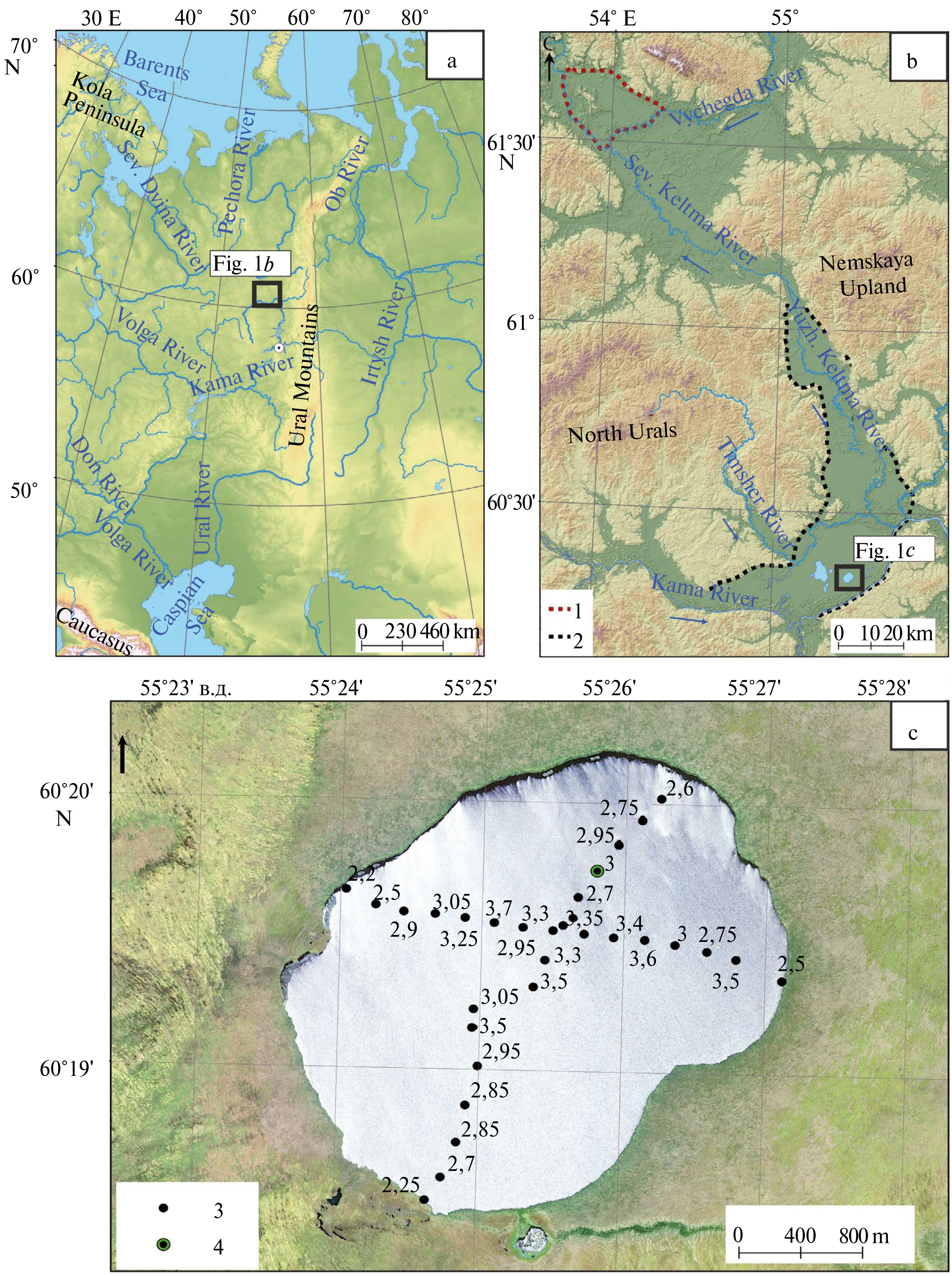


**Fig. 1.** Work area and location of drilled wells
a – location of the study area on the map of the East European Plain; b – Kama-Vychegodsk watershed; c – location of drilled wells on Lake Novozhilovo.
Legend:
1 – boundaries of the Kadam expansion in the Vychegda valley; 2 – contour of the Kama-Keltma lowland; 3 – measured depths of the lake, m; 4 – location of the NZH-1 well.

Lake Don-ty. It has been established that the age of the paleochannel and terrace in the Kadam expansion is Late Glacial, and the terrace itself was formed as a result of the Vychegda River activity in extraglacial environments [5]. Within the adjacent basins of Vychegda and Kama at this time, alluvial and aeolian morpholithogenesis prevailed [6] – a sublatitudinal macrodune with drainage channels cutting through it was formed [2].

All results of paleogeographic studies of previous years in this region, starting from the time of designing the Upper Kama Reservoir, were predominantly based on the study of paleoarchives of river valleys draining the Kama-Keltma lowland (floodplains and terraces of Kama, Timsher, Southern Keltma) [2, 7, 8]. Lakes have not received due attention in the studies. To date, there is no information about the structure, composition, sedimentological characteristics, and age of their bottom sediments. In addition, the landscape and climatic conditions of the Late Glacial in the region are almost unexplored, although there are many potential paleoarchives for this.

The absence of geochronometric and micropaleontological data on bottom sediments of water bodies within the southern part of the Kama-Keltma lowland motivated our research aimed at studying the sediments of Lake Novozhilovo (Fig. 1c).

## MATERIALS AND METHODS

*Field research.* Depth measurements in Lake Novozhilovo were conducted in February 2023 using a lead weight from the ice (Fig. 1c). The recorded maximum depth was 3.7 m. The absolute water level mark in the lake was 131 m, in the Kama River – 117.6 m. Using a hand auger with an Eijkelkamp semi-cylindrical sampler, 18 exploratory wells were drilled along two transverse profiles with lengths of 2940 m and 3435 m, respectively. A core from the reference well NZH-1 was obtained using a Livingstone piston corer (Fig. 1c).

*Determination of sediment age.* Radiocarbon age of six samples of organomineral and mineral sapropel from the lower part of the NZH-1 core (depths 6.5–8.2 m) was determined by liquid scintillation counting (LSC) and accelerator mass spectrometry (AMS) methods on bulk organic carbon, as well as on wood (Table 1). The LSC dating and sample preparation for AMS analysis were performed at the Center for Collective Use "Laboratory of Radiocarbon Dating and Electron Microscopy" of the Institute of Geography RAS, while measurements were conducted at the Center for Applied Isotope Studies, University of Georgia (USA). Calibration of radiocarbon dates was performed using the Calib 8.10 program with the IntCal20 calibration curve [9].

Age models were constructed based on radiocarbon dates using the Bayesian method in the Bacon package of R 4.3.2 environment. In addition to the "depth-age" model, sedimentation rate graphs (cm/thousand years) were plotted as a function of depth and calendar age (Fig. 2).

*Studies of the lithological composition of sediments.* Sample analysis was performed with a step of 5–10 cm in the laboratory of facies-genetic research of geosystems at Perm University (loss on ignition) and in the laboratory of natural environment paleoarchives at the Institute of Geography RAS (granulometric analysis, magnetic susceptibility).

Grain size analysis of deposits was conducted for 18 samples using a Malvern Mastersizer 3000 laser particle analyzer. Sample preparation included dissolution of carbonates with 10% HCl solution and oxidation of organic matter with 30% $H_2O_2$. After washing off the reagents, the samples were mixed with 4% sodium pyrophosphate $Na_4P_2O_7$ solution for additional dispersion and suspension

**Table 1.** Results of radiocarbon dating of samples from core NZH-1

| Lab. number IGAN | Depth, m | Material | Method | $^{14}$C date, yr BP | Calibrated age, yr BP | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1σ | 2σ | Median |
| 10417 | 6.6–6.7 | Sapropel | LSC | 8950±190 | 9730–10250 | 9545–10440 | 10110 |
| 10418 | 6.7–6.8 | | | 9220±130 | 10240–10510 | 10150–10770 | 10320 |
| 10419 | 7.15–7.25 | | | 9580±120 | 11180–11410 | 10640–11210 | 11130 |
| 10420 | 7.25–7.35 | | | 9870±110 | 10750–11110 | 11080–11750 | 11390 |
| 10421 | 7.6–7.7 | | | 10440±130 | 12100–12410 | 11930–12710 | 12420 |
| 10517 | 8.17 | Wood | AMS | 12240±40 | 14080–14190 | 14050–14320 | 14150 |

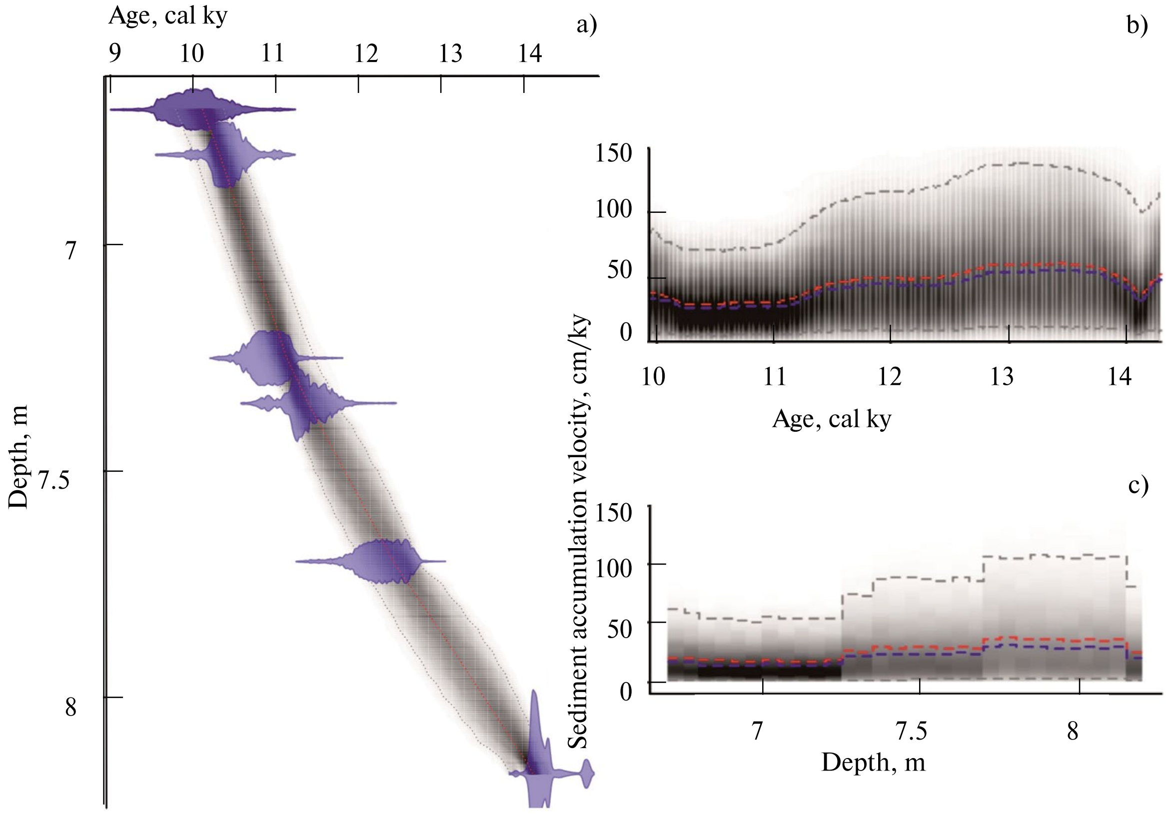


**Fig. 2.** Age-depth model and sediment accumulation rate of core NZH-1. a – age-depth model plot; sedimentation rate dependencies: b – on calendar age; c – on depth

stabilization. Before measurement, the material was dispersed in an ultrasonic bath for 30 minutes. The analyzer performed 7 repeated measurements, which were averaged in the Mastersizer v.3.62 application. Particle size distribution was calculated based on Mie optical theory, with dispersion medium refractive index $n_w = 1.33$, particle refractive index $n_p = 1.55$, and absorption coefficient $k_p = 0.1$.

Loss on ignition (LOI) was determined according to the methodology [10]. Samples of 5 ml volume, placed in porcelain crucibles, were dried at 105°C for 4 hours. Then, sequential ignition at 550°C was performed for 2 hours. After each stage, weighing was performed on electronic scales with 0.01 g precision. The resulting values were calculated using the formula LOI 550 = ((DW105-DW550)/DW105) · 100, where DW is dry weight. According to [10], LOI at 550°C allows estimation of organic matter (OM) content in the sediment.

Specific (mass) magnetic susceptibility (MS) measurement was performed using a ZH Instruments 150L kappameter following the methodology [11]. Samples of 8–12 ml volume were preliminarily dried to air-dry condition in a drying oven for 24 hours at 40°C. Then the mass of samples was determined with 0.01 g precision. MS measurement was performed at field strength 320 A/m and frequency 500 Hz.

*Diatom analysis*. Laboratory preparation of 20 samples was carried out according to the methodology [12] in several stages: removal of carbonates and organic matter, elutriation (removal of clay fraction), centrifugation with the addition of lycopodium. Identification of diatom taxa was performed under an optical microscope at 1000x magnification using the identification guide [13].

*Palynological analysis***.** Sample preparation was carried out according to the standard methodology [14]. Within the depth interval of 6.5–8.2 m, 35 samples were studied. For each sample, at least 300 pollen grains were counted with parallel registration of spores of higher cryptogamous plants and non-pollen palynomorphs (conifer stomata, algae, fungal spores, etc.). The percentage calculation of palynomorph taxa was conducted based on the sum of arboreal and herbaceous pollen. Vegetation types were determined both by the ratio of dominant taxa and groups pollen [14] and using the biomization method [15].

## RESULTS

*Lithological structure of deposits.* In the lower part of the column, the following layers were successively exposed (from top to bottom) (Fig. 3b): 6.5–7 m – brown sapropel, weakly consolidated (layer 1); 7–7.65 m – dense sapropel, greenish-yellowish, mineralized (layer 2); 7.65–8.1 m – gray (brownish-gray) sapropel, mineralized, with isolated plant remains, mineralization and density increase towards the bottom; at a depth of 7.85 m – strongly peaty interlayer (3 cm thick) (layer 3); 8.1–8.2 m – fine-grained sand with peat and sapropel interlayers (up to 2–3 cm), with wood fragments in peat (layer 4).

In the sediment texture of the lower core part at the level of 7.8–8.2 m, rhythmic stratification is observed, manifested in the alternation of dense mineral brownish-gray and dark peaty sapropel, peat, and light sandy layers. Above (6.5–7.8 m), the material gradually becomes enriched with organic matter, becoming increasingly peaty, viscous, and uniform.

*Age of deposits.* The accumulation of deposits exposed in the lower part of core NZH-1 occurred during the Late Glacial and Early Holocene (Fig. 3a). Based on the age model, it can be stated that the highest rates of deposit accumulation are characteristic for depths of 7.7–8.2 m, corresponding to 14150–12420 cal. BP: 120–130 cm/thousand years (Fig. 2).

According to *grain size composition,* three intervals can be distinguished (6.5–7 m, 7.1–7.9 m, 8–8.2 m), characterized by different sedimentation regimes (Fig. 3c). In the interval of 6.5–7 m, fine and medium silt fractions predominate, accounting for 42–45%. Fine sand fraction accounts for about 1% on average, while very fine sand accounts for about 2–3%. In the interval of 7.1–7.9 m, the proportion of clay and very fine silt fractions slightly decreases. The content of very fine (up to 17%) and fine sand (up to 16%) fractions significantly increases. At a depth of 8–8.2 m, the proportion of clay and silt fractions decreases to almost zero. The fine sand fraction at a depth of 8.2 m is 57%, very fine – 15.4%, medium – 26%.

The range of median particle diameter (MD) changes from 5–10 μm at a depth of 6.5–7.9 m to 200 μm at a depth of 8–8.2 m (Fig. 3d). A small jump is noted at a depth of 7.6 m, where MD is 18.2 μm.

*Loss on ignition.* The LOI curve (Fig. 3e) revealed maximum organic matter content at depths of 6.7–6.95 and 7.7–7.85 m. The first interval of LOI increase (6.7–6.95 m) corresponds to the transition from layer 1 to layer 2. The maximum organic matter content was recorded at a depth of 6.7 m – 94.4%. At a depth of 7–7.65 m, a sharp decrease in LOI was noted – the average value is 30%, with a maximum of 42.5% (at a depth of 7.1 m). In the underlying layer (7.7–7.85 m), LOI increases 2.5 times to an average value of 74.8%, with the maximum value characteristic for a depth of 7.7 m – 87.4%.

*Magnetic susceptibility.* Characteristic sections of MS curve variations provide additional grounds for stratigraphic division. Based on the indicator values, two intervals with relatively uniform values are distinguished (Fig. 3f): 6.5–6.85 m; 6.9–8.2 m. In the first interval (6.5–6.85 m), the MS indicator varies from –0.100 to –0.011 with an average of 0.063 $*10^{-6}$ $m^3$/kg. The first interval practically completely corresponds to organic sediment, as MS indicators have stable negative values. At a depth of 6.9–8.2 m, MS varies from 0.012 to 0.0762 with an average of 0.053 $*10^{-6}$ $m^3$/kg. The interval corresponds to mixed sediment with high mineral matter content.

In bottom sediments, 71 taxa of *diatom algae* belonging to 35 genera were identified. The highest number of diatom algae is present in samples from depths of 7–8 m. Overall, representatives of genera *Staurosira, Staurosirella and Pseudostaurosira dominate.* Algae are pioneers colonizing forming water bodies and can be resistant to unstable and changing environmental conditions [13]. At a depth of 6.5–6.6 m, there are isolated findings of diatom algae. Dominant species (>10%) at depths of 6.7–6.8 m are *Pinnularia spp.*, 6.9–7 m – *Crenotia thermalis, Tabellaria flocculosa,* 7.1 m – *Pseudostaurosira brevistriata, Punctastriata lancettula, Staurosira cf. tabellaria,* 7.2–7.6 m, – *Ps. brevistriata, Pseudostaurosira polonica*, *St. cf. tabellaria, Staurosirella cf. ovata*, 7.7 m – *Achnanthidium anastasia, C. thermalis, Ps. brevistriata* , *St. cf. tabellaria,* 7.8 m – *Nitzschia fonticola* , *Staurosirella cf. pinnata, St. cf. tabellaria,* 7.9 m – *St. cf. pinnata,* 8–8.2 m – *P. lancettula* , *St. cf. pinnata, St. cf. tabellaria*, *Staurosira cf. venter, Ps. brevistriata.*

The results of *palynological analysis* are presented in the spore-pollen diagram (Fig. 4), where three groups of palynospectra can be distinguished based on changes in the content of dominant pollen.

The first group in the interval of 7.7–8.2 m is characterized by high content of green algae colonies with maximum species concentration of *Pediastrum* (119–465 thousand specimens/g) and *Botryococcus* (up to 20 thousand specimens/g) in the depth interval of 7.8–8 m. This indicates favorable conditions for phytoplankton development in the formed freshwater reservoir with high organic matter content. At a depth of 7.7 m, pondweed

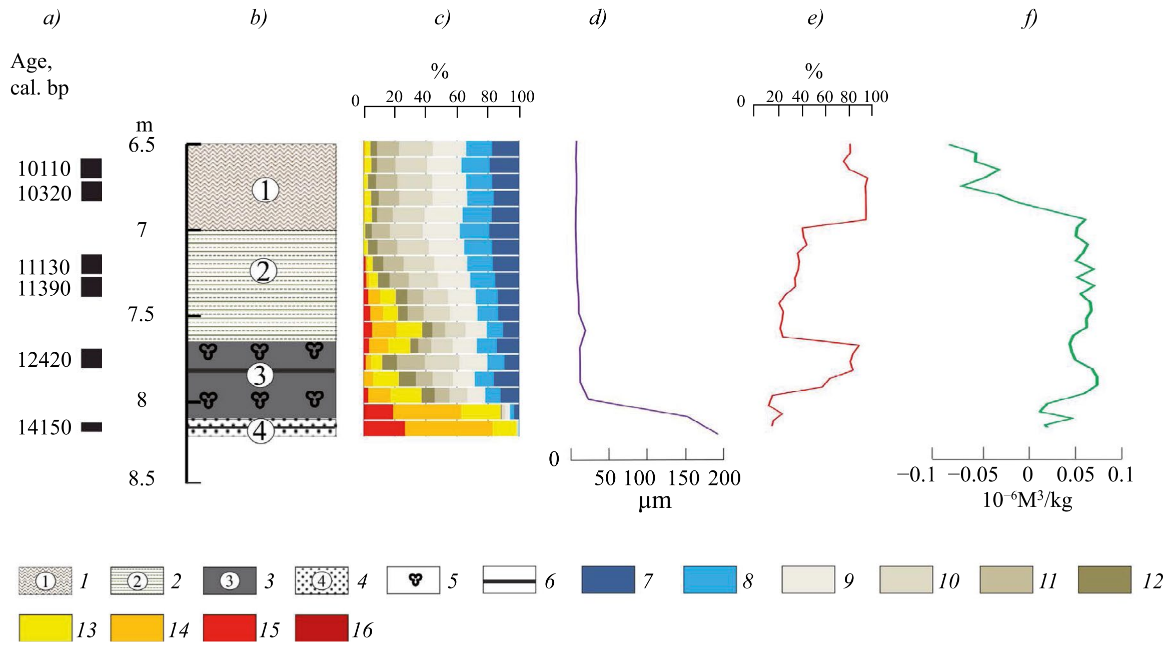


**Fig. 3.** Structure, composition, and age of bottom sediments in Lake Novozhilovo: a – calibrated radiocarbon dates; b – lithological column of NZH-1; c – granulometric composition; d – median particle diameter; e – losses on ignition at 550°C; f – specific magnetic susceptibility measured at low frequency (500 Hz).
Legend: 1 – brown, slightly consolidated sapropel (layer 1); 2 – sapropel dense, greenish-yellowish (layer 2); 3 – gray sapropel (brownish-gray), mineralized (layer 3); 4 – sand (layer 4); 5 – plant remains; 6 – layers of peat. Granulometric fractions (μm): 7 – <2 (clay); 8 – 2–4 (very fine silt); 9 – 4–8 (fine silt); 10 – 8–16 (medium silt); 11 – 16–31 (coarse silt); 12 – 31–63 (very coarse silt); 13 – 63–125 (very fine sand); 14 – 125–250 (fine sand); 15 – 250–500 (medium sand); 16 – 500–1000 (coarse sand).

seeds (*Potamogeton natans* and *P. filiformis*) were found – perennial aquatic plants that grow in shallow waters, characteristic of slow-flowing or standing waters and mark the initial stage of lake development. The overall high pollen concentration (100–500 thousand pollen grains/g) indicates good biological productivity of existing landscapes in the relatively warm climate of the Bölling-Alleröd interstadial. The combination of tundra (*Betula* sect. *Apterocaryon=B. sect. Nanae, Salix*), steppe (*Ephedra*, *Artemisia*, Chenopodiaceae, Poaceae) and forest ( *Betula* sect. *Betula=B.* sect . *Albae*, *Larix*) components in palynological spectra indicates the spread of periglacial landscapes around the water body with shrub thickets of dwarf birch and willow, as well as open woodlands of tree birch and larch.

In the second group of palynological spectra at depths of 7.35–7.7 m, the concentration of pollen and algae sharply decreases, reflecting deteriorating conditions and, consequently, reduced bioproductivity of landscapes and the water body itself. The predominance of wormwood pollen (30–45%), presence of pollen grains of *Ephedra*, Plumbaginaceae, Caryophyllaceae, *Polygonum, Valeriana* and reduction of tree birch proportion to minimum (less than 10%) indicates climate aridization.

The third group of palynospectra in the depth interval of 6.5–7.35 m is characterized by the predominance of tree pollen (70–82%), with the taiga biome (forest vegetation type) becoming most prevalent. The maximum of spruce (*Picea* – up to 55%) and larch, with a slight increase in the abundance of other conifers against the background of decreasing pollen content of shrub birches (less than 15%) and wormwood (5–10%), is recorded in the interval from 7 to 6.7 m, the upper boundary of which dates to 10513–10244 cal. BP. The increase in spruce and larch abundance is accompanied by findings of conifer stomata. In palynospectra from a depth of 6.7 m (10246–9730 cal. BP), against the background of spruce reduction, the abundance of tree birch (*Betula* sect. *Betula* = *B* .sect. *Albae*) increases to 40% and pine (*Pinus*) increases.

## DISCUSSION

Based on the obtained data, the history of Lake Novozhilovo was reconstructed in the context of the Upper Kama valley development during the Late Glacial – Early Holocene.

The lake formation was apparently preceded by *a stage of predominantly alluvial morpholithogenesis*, presumably during the Late Pleniglacial. This is indicated not only by the significant content of sand fraction but also by the median particle diameter of up to 200 μm at a depth of 8.2 m. We assume that the formation of Lake Novozhilovo is the result of erosion-accumulative processes that prevailed within the ancient alluvial plain of the Kama River during the Late Glacial period. The lake morphology and geomorphological position in relation to the modern channel indicate similarity with West Siberian sors – large shallow water bodies that form on the Ob River floodplain during long and high floods [16]. It should be noted that during the drilling of the raised bog by the Kama expedition of the VSEGEI (1938-1939), fine-grained gray sands, exposed by a borehole on the southwestern shore of Lake Novozhilovo at a depth of 8 m, were interpreted by geologists as "ancient alluvial" [7].

*The first stage of lacustrine-alluvial (transitional) sedimentation* occurred in 14150–13500 cal. BP (depths 8–8.2 m) and covered the Bølling-Allerød interstadial. This period was characterized by rhythmic environments: alternation of sapropel, peat, and sand layers in the basal part of the core. The rate of sediment accumulation was most intensive during this time.

The average LOI values were 14%, which corresponds to organomineral sediment and lacustrine-alluvial conditions. The boundary between the first and second stages is erosional, with a sharp increase in OM content values, which corresponds to the end of the period of active sediment erosion.

The alternation in depth of diatom findings *Staurosirella cf. pinnata* and *Pseudostaurosira brevistriata* indirectly confirms the rapid change of conditions from flowing water body to a lake with calm hydrodynamic regime and vice versa. Sedges and grasses with the participation of forbs formed coastal-aquatic and meadow communities. Ephedra and Chenopodiaceae-Artemisia groups occupied unvegetated areas and dry habitats with poor sandy soils. Tree birches grew in small numbers in the vicinity of the water body. Conifers (probably larch) were also present, as indicated by the presence of single pollen grains of *Larix* and the finding of Pinaceae stomata. Although the Bølling-Allerød stage is characterized by the northward advancement of forest ecosystems up to 60°N and the spread of sparse coniferous and small-leaved forests combined with tundra and steppe communities [17], our data do not indicate the predominance of forest vegetation type.

*The second stage of lacustrine-alluvial sedimentation.* The increase in OM content at a depth of 7.7–8 m (13,500–12,420 cal. BP) indicated increased bioproductivity of the formed water body. The content of sand fraction decreased compared to the underlying layers, while the silt fraction, conversely, increased. The conditions of a non-flowing water body with slightly alkaline environment and high productivity are identified by diatom findings of *Staurosirella cf. pinnata* at a depth of 7.8–7.9 m.

MS indicators show the predominance of alluvial (mineragenic) sedimentation conditions. A possible explanation for this could be the increase in high floods on the Kama River [8], during which mineral particles could enter the lake. When compared

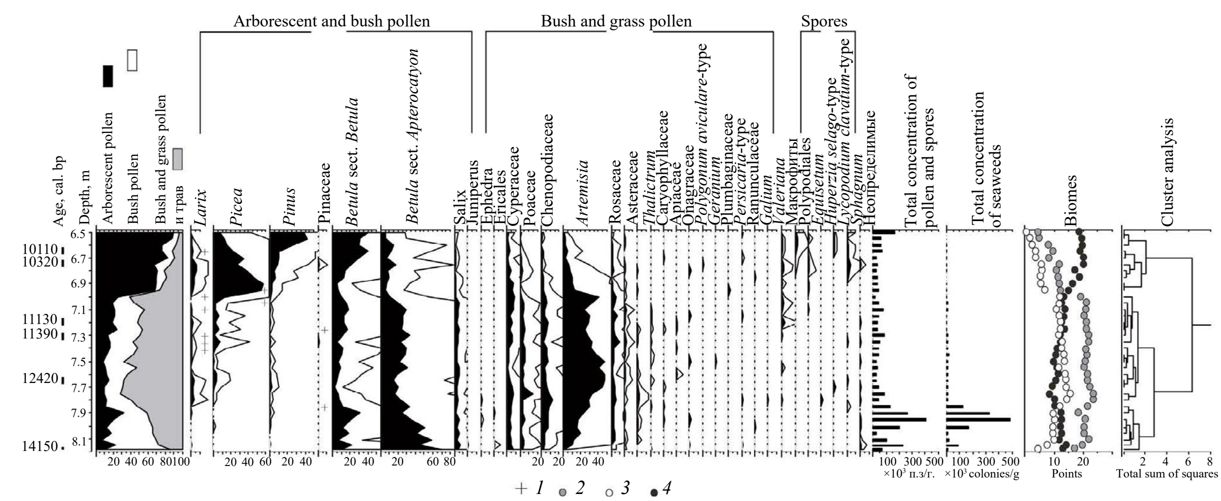


**Fig. 4.** Spore-pollen diagram of sediments from core NZH-1.
Legend: 1 – finds of stomata from coniferous plants; Biomes: 2 – taiga; 3 – steppe; 4 – tundra.

with the curve of fluvial epoch activity [18], this time corresponds to the intensification of erosion-accumulation processes on the East European Plain during 13,700–11,800 cal. BP.

*The third stage of lacustrine-alluvial (transitional) sedimentation* refers to the Late Dryas – Early Holocene (12,420–10,700 cal. BP, depths 7–7.7 m). This period was characterized by a decrease in organic matter content. The granulometric composition shows an increase in clay fraction content, while at depths of 7.3–7.7 m, the proportion of sand increases. MS values, a short-term increase in sand fraction, and a small jump in GS at a depth of 7.6 m generally indicate the predominance of alluvial material input. This is indirectly confirmed by findings of diatom algae *Staurosirella cf. ovata* at depths of 7.5–7.6 m. They typically identify flowing conditions with possible lowering of water level and activation of erosion processes in the catchment [13].

The combination of tundra, steppe, and forest components in the Late Dryas palynological spectra indicates the dominance of open periglacial landscapes with prevailing Chenopodiaceae-Artemisia groups, sedge and grass-forb communities, shrub thickets of willow and dwarf birch, and isolated larches. Colder conditions during the transition from Late Dryas to Holocene are also identified by findings of Arctic-Alpine type diatoms *Tabellaria flocculosa* at a depth of 6.9 m .

*The fourth stage of predominantly lacustrine sedimentation* (10,700–9,730 cal. BP, depths 6.5–7 m) was characterized by the predominance of organic sediment according to MS measurements. Sedimentation rates stabilized at 50 cm/thousand years – the lowest accumulation rate of lake bottom sediments. According to LOI analysis results, organic matter content increased almost 3 times compared to the previous stage (averaging 87%). The granulometric composition of sediments was dominated by silt fraction with minor presence of very fine sand, which may indicate aeolian input or high water levels in the Kama River during floods. For comparison, in the Mologa-Sheksna lowland during this time, there was a sharp and stable transition to organogenic sedimentation regime, with almost complete cessation of minerogenic accumulation [19].

The transition to active waterlogging in the lake catchment area is identified by findings of diatoms of the genus *Pinnularia* at a depth of 6.7–6.8 m. The increase in the proportion of tree pollen in the early Holocene palynological spectra is characteristic of forest vegetation type and reflects the spread of larch-spruce open woodlands with shrub birches during the Preboreal period (10,510–10,240 cal. BP) and birch forests with spruce and pine during the Boreal period (10,250–9,730 cal. BP). From a depth of 6.65 m, the total pollen concentration began to increase in the palynological spectra corresponding to the Boreal period. Such replacement of periglacial plant communities with forest vegetation was characteristic of the East European Plain during the transition from the Late Neopleistocene to the Early Holocene [20].

## CONCLUSION

Based on chrono-, bio- and lithostratigraphic data, it was possible to obtain a high-resolution record of the transition from the Late Glacial to Early Holocene within the southern part of the Kama-Keltma lowland. It can be stated that Lake Novozhilovo sediments are represented by a two-member sequence of lacustrine-alluvial and lacustrine deposits. The age of sediments in the basal core sequence is 14,150–13,500 cal. BP, which chronologically correlates with Bølling and Allerød.

The alternation of organic-mineral lake silt, peat and sand with diatom algae, identifying changes in limnological conditions under periglacial conditions, changes in bioproductivity and sedimentation rates, made it possible to distinguish a stage of predominantly alluvial morpholithogenesis, three stages of lacustrine-alluvial sedimentation, and a stage of lacustrine accumulation. Features of the granulometric composition of deposits revealed periodic connection of the lake with erosion-accumulation processes in the catchment area, mainly with the activity of the Kama River, similar to the formation of sors in Western Siberia.

## FUNDING

The study was carried out with the support of the Russian Science Foundation, grant No. 22-77-00086, https://rscf.ru/project/22-77-00086/

## REFERENCES

1. *Kvasov D.D.* Late Quaternary History of Large Lakes and Inland Seas of Eastern Europe. Leningrad: Nauka, 1975. 280 p.

2. *Nazarov N.N., Kopytov S.V., Zhuykova I.A., Chernov A.V.* Pleistocene drainage channels in the southern part of the Keltma Depression (Kama-Vychegda interfluve) // Geomorphology. 2020. No. 4. Pp. 74–88. https://doi.org/10.31857/S0435428120040070

3. *Panin A.V., Astakhov V.I., Lotsari E., Komatsu G., Lang J., Winsemann J.* Middle and Late Quaternary glacial lake-outburst floods, drainage diversions and reorganization of fluvial systems in northwestern Eurasia // Earth-Science Reviews. 2020. Vol. 201. 103069. https://doi.org/10.1016/j.earscirev.2019.103069

4. *Lysa A., Larsen E., Buylaert J.-P., Fredin O., Jensen M., Kuznetsov D.* Late Pleistocene stratigraphy and sedimentary environments of the Severnaya Dvina-Vychegda region in northwestern Russia // Boreas. 2014. Vol. 43. Pp. 759–779. https://doi.org/10.1111/bor.12080

5. *Zaretskaya N.E., Panin A.V., Golubeva Yu.V., Chernov A.V.* Sedimentation environments and geochronology of the Late Pleistocene to Holocene transition in the Vychegda River valley // ras reports. Earth Sciences. 2014. Vol. 455. No. 1. Pp. 52–57. https://doi.org/10.7868/S0869565214070238

6. *Zaretskaya N.E., Panin A.V., Utkina A.O., Baranov D.V.* Aeolian sedimentation in the Vychegda river valley, north-eastern Europe, during MIS 2-1 // Quaternary International. 2024. Pp. 83–89. https://doi.org/10.1016/j.quaint.2023.05.022

7. *Ziling D.G., Kapitanova K.V., Kulagin S.I., Galushkin Yu.A., Simonov A.N., Korganova L.S.* Report on the results of engineering-geological studies conducted by the Kama Party in the zone of the projected Upper Kama reservoir (in the section from Bondyug village to Gainy village) in 1958-59. Moscow: Ministry of Geology USSR, 1960. 830 p.

8. *Lapteva E.G., Zaretskaya N.E., Lychagina E.L., Trofimova S.S., Demakov D.A., Kopytov S.V., Chernov A.V.* Holocene vegetation dynamics, river valley evolution and human settlement of the upper Kama valley, Ural region, Russia // Vegetation History and Archaeobotany. 2023. Vol. 32. Pp. 361–385. https://doi.org/10.1007/s00334-023-00913-5

9. *Reimer P., Austin W.E.N., Bard E. et al.* The IntCal20 Northern Hemisphere radiocarbon age calibrationcurve (0–55 cal kBP) // Radiocarbon. 2020. Vol. 62. No. 4. Pp. 725–757. https://doi.org/10.1017/RDC.2020.41

10. *Heiri O., Lotter A.F., Lemcke G* . Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results // J. Paleolimnol. 2001. No. 25. Pp. 101–110. https://doi.org/10.1023/A:1008119611481

11. *Maher B.A.* Magnetic properties of modern soils and Quaternary loessic paleosols: paleoclimatic implications // Palaeogeography, Palaeoclimatology, Palaeoecology. 1998. Vol. 137 (1–2). Pp. 25–54. https://doi.org/10.1016/S0031-0182(97)00103-X

12. *Battarbee R.W., Jones V.J., Flower R.J.* Diatoms // Tracking Environmental Change Using Lake Sediments. Terrestrial, Algal and Siliceous Indicators. 2001. Vol. 3. Pp. 155–202.

13. *Kulikovsky M.S., Glushchenko A.M., Genkal S.I., Kuznetsova I.V.* Guide to Diatoms of Russia. Yaroslavl: Filigran, 2016. 804 p.

14. *Chernova G.M.* Spore-pollen analysis of Pleistocene-Holocene deposits. St. Petersburg: SPbSU Publishing House, 2004. 128 p.

15. *Prentice C., Guiot J., Huntley B. et al.* Reconstructing biomes from palaeoecological data: a general method and its application to European pollen data at 0 and 6 ka // Climate Dynamics. 1996. Vol. 12. Pp. 185–194. https://doi.org/10.1007/BF00211617

16. *Beletskaya N.P.* Genetic classification of lake basins of the West Siberian Plain // Geomorphology. 1987. No. 1. Pp. 50-58.

17. *Markova A.K., Kolfschoten T., Simakova A.N., Puzachenko A.Yu., Belonovskaya E.A.* Ecosystems of Europe during the Late Glacial Bølling-Allerød warming (10.9–12.4 thousand years ago) based on palynological and theriological data // Proceedings of the Russian Academy of Sciences. Geographical Series. 2006. No. 1. Pp. 15–25.

18. *Panin A.V., Matlakhova E.Yu.* Fluvial chronology in the East European Plain over the last 20ka and its palaeohydrological implications // Catena. 2015. Vol. 130. Pp. 46–61. https://doi.org/10.1016/j.catena.2014.08.016

19. *Sadokov D.O., Sapelko T.V., Bobrov N.Yu., Melles M., Fedorov G.B.* Late Glacial and Early Holocene History of Lake Sedimentation in the North of Mologa-Sheksna Lowland: Case Study of Lake Beloe (Northwest Russia) // Bulletin of Saint Petersburg University. Earth Sciences. 2022. Vol. 67. Issue 2. P. 266–298. https://doi.org/10.21638/spbu07.2022.204

20. *Paleoclimates* and Paleolandscapes of the Extratropical Northern Hemisphere. Late Pleistocene – Holocene. Atlas-monograph / A.A. Velichko, O.K. Borisova, V.P. Grichuk et al.; ed. A.A. Velichko. Moscow: GEOS, 2009. 119 p.